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Innovation Study in Engineering Design

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Innovation Study in Engineering Design

by

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Abstract

Innovation Study in Engineering Design

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Well developed innovation processes are becoming an essential component to the continued success of a large number of industries. Such processes build upon the evolutionary steps taken to advance innovation. In light of the need for innovation, companies and engineers must create the most efficient processes for their systems or product development teams. A step toward the creation of such processes, as well as the corresponding teaching of such processes in higher-education, is the development of a baseline of current best practices. This paper considers a contribution to this effort in the form of a study of a specific group of innovation practitioners. The study was created to probe a group of leaders in the engineering design domain using technical, demographic, and short answer questions. Various analysis methods are used to obtain a fundamental view of the answers to the questions but also the demographics of the participant group. Two deductive analysis methods are used, the first a set of hypotheses are explored from

participant responses, and second a qualitative technique to understand links in the short answer portion of the study. An additional inductive approach is used, consisting of a correlating approach to compare responses to questions and understand trends across the participants. Results from the analysis emphasize the current perceptions of innovation by the participants and opportunities to refine our search for better innovation practices.

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Chapter 1: Introduction

The contexts in which innovation is studied are multifarious. There are, in fact, a wide range of approaches to conceptualizing innovation research. Although many different scholarly fields investigate innovative tools and behaviors, there is a fairly consistent theme that identifies or describes innovation as the successful implementation of creative and new ideas. A way to think of innovation is to make a distinction between invention and innovation where “invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice” (Fagerberg, 2004, p.4). The scientific study of innovation and innovation processes is clearly an important field of inquiry apparent when reviewing the shear number of innovation publications across diverse fields. Fagerberg has shown, for example, that “the number of social-science publications focused on innovation has increased faster than the overall number of social-science publications” [1]. In one such publication by Future Think LLC entitled “Ready, Fire! Aim?”[2] however, it is noted “research suggests that innovation activity today has little strategic foundation or direction.” Many publications mirror this theme, creating a basis to support advancement of the field of innovation. In this paper we focus on improving innovation activity by exploring the current state of engineering design innovation, at least from the perspective of a particular knowledge domain.

Figure 1: A cutaway of an Automatic Transmission from a Lexus IS F [4]

Forbes magazine in their 85th anniversary December 23rd, 2002, issue noted examples of innovation such as the telephone, transistor and automatic transmission (Figure 1) [3]. A well known innovation is the improved assembly line (Figure 2) representing a system that has dramatically impacted humankind. Innovations of this type raise a very interesting question, which is the focus of this paper: how do we create a better understanding of innovation processes and methods? To begin, we will focus on the particular domain of engineering design innovation. This leads to the development of a study which contains probing questions to be answered by researchers and professionals in this field. Given the fact that most innovation research has been done in a laboratory setting using participants with broad backgrounds, a domain specific (i.e. engineering design) analysis of engineering innovation is essential to creating a more complete picture of innovation. The study is best summarized as an exploration of a technical innovation field to: (1) probe perceptions in this field and (2) determine the understanding of innovation methods in the context of participant demographics. A mosaic results in this paper, presenting results from the domain-knowledge study, analysis of the results, and insights from this analysis in the context of innovation literature and related experiments.

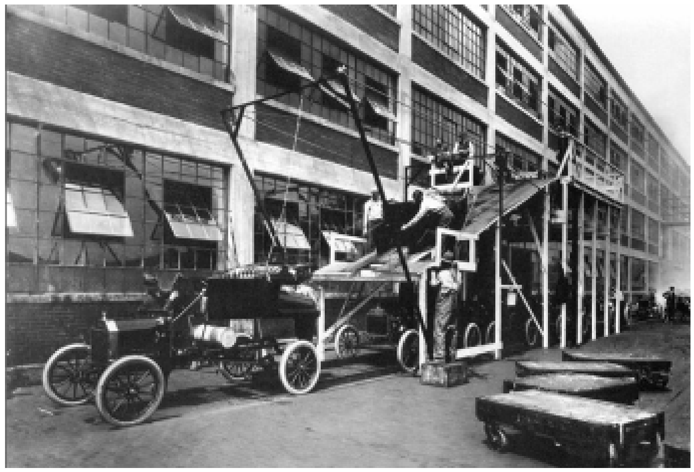

Figure 2: 1913 Ford Model T assembly line.

1.1: MOTIVATION

To strive towards this understanding, we identify the current state of engineering design innovation through the eyes of educational leaders in the field by having those leaders participate in a query-based study. Through analysis of the study's results, this paper serves to create a more complete picture of current beliefs and perceptions in the field of engineering design innovation. The perspectives derived from this research should provide a view of leaders in the field particularly regarding the differences in perception as a function of various demographics.

A complementary goal of this paper is to extract conclusions from this research which can help describe paths forward in the advancement of innovation in practice and education. This will be done in part by evaluating the results of this research study with those from a companion fixation study carried out with the same participant group. Design fixation is a state of obsession which tends to impede additional solutions.

The effect of this research will ultimately be a contribution to innovation processes and the creation of innovative systems and products. Examples are systems to ease tasks for those with disabilities such as an assistive guitar (Figure 3) which can raise the standard of living for those who may need it the most.

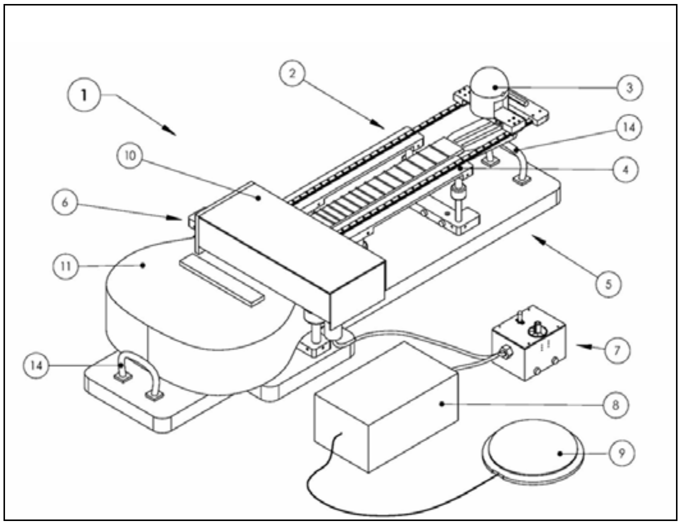

Figure 3: Modular Automated Assistive Guitar

1.2: PRIOR WORK

There are many aspects of the research done here which warrant a prelude. When considering innovation in engineering design, the prior work that exists takes many forms, including engineering tools, cognitive science research, and barriers to innovation just to name a few. In previous research, factor or component level studies evaluate the effectiveness of some innovation methods such as brainstorming. Other studies evaluate managerial innovation, and still more are undertaken to better understand the principles to facilitate an innovation niche in the engineering design space. From this hefty body of work we learn that innovation is a large field of study and that each subcomponent deserves thorough analysis to create a robust understanding of the science of innovation. In the next few sections we will attempt a broad review of the prior work being done in the field to better frame our expectations of the analysis.

1.2.1 Group Idea Generation

Idea generation is fundamental to engineering design and in order to ultimately create innovative solutions must be used. To begin, it is of interest here to discuss the relationship between idea generation and brainstorming. Many utilize the term brainstorming interchangeably with idea generation. Others continue to view “brainstorming” as specifically described by Osborn. Although Osborn’s method includes sound fundamental statements, the method has been studied thoroughly and has shown productivity loss when compared to an equal number of individuals developing ideas in isolation [5]. Other group idea generation techniques show more optimistic results [6, 7] with recent trends focusing on the development of more effective idea generation methods in design engineering and related fields [8, 9]. With regard to the cognitive portion of idea generation it is remarkable to note that the field consists primarily of sentence based methods for idea generation [10].This is very interesting considering the fact that fundamental to design engineering is the use of graphical resources to define designs.

1.2.1.1 Alternatives to Osborn Brainstorming

It is important to note here the alternatives to Osborn’s brainstorming considering, in some regards, that this method has been proven ineffective. There are a number of methods that have varying levels of techniques to provide support for engineering designers in the idea generation phase. One such method is Brainsketching, where participants begin by sketching ideas on a large sheet of paper. These sketches may be expounded upon with short comments. After a set period of time the sketches are passed to the next person to continue development on the previous ideas or generate new ones [11].

The Gallery method is another technique for idea generation which is an adaptation of brainstorming. In this method there are five fundamental steps. First the participants sketch ideas onto a sheet of paper with written descriptions as necessary. Next, the ideas are hung on a wall as if in a gallery and the third step consists of the group discussing those ideas and attempting to come up with new or adapted ideas. This is followed by the individuals again working on the ideas alone to develop them based on the previous steps discussion. Finally, a selection step takes place to identify potential solutions from the generated ideas [11, 12].

The next method has many variants but the fundamental approach is again an evolution of brainstorming. Method 635 [12, 13] requires six participants who quietly describe three solutions to a given problem. These ideas are then passed around the group 5 times to complete the idea generation process with each individual given time to elaborate on everyone's original ideas and adapted ideas. In this method solutions are presented in sentence form. Other variations of 635 have also been proposed [11, 13]. One variation permits annotated sketches. Literature exists which describes the validity and usefulness of these methods [11, 12, 13].

1.2.1.2 Design Methods

Genrich Altshuller was motivated to discover the keys to successful invention. He came up with The Theory of Solving Inventive Problems (TRIZ) or commonly referred to as The Theory of Inventive Problem Solving (TIPS). A portion of his research was based on extracting principles from over 1 million patents [26]. The patent research done by Altshuller was only part of the immense amount of sources reviewed to drive this investigation. Other areas researched included psychological behavior and inventor biographies, technical evolution of systems, analysis of existing methods and tools and analysis of technical and scientific literature. Altsuller's principles or "forty principles" are a set of parameters that can be studied in order to solve multi-variable design problems. Along with the principles, Altshuller's methods for extracting these principles are also of interest along with his methodology that provided guidance for using those principles. Altshullers research led to many profound results that are necessary to understand if we are to advance engineering design activities. Some essential notions that were developed by his research include psychological inertia, product ideality and contradiction. These notions serve to keep the designer focused on innovation. The tools that come from Altshuller's research are of paramount importance considering that many times the designer's sole interaction is with a concise tool developed on immensely complex underlying principles. ARIZ, the algorithm for applying TRIZ, is claimed to provide a series of steps with clear objectives [27].

Other component level design methodologies are continuing to be developed such as the transformational design theory [28]. A transformer is defined as "a system that exhibits a state change in order to facilitate a new functionality or enhance an existing functionality." When compared to TIPS, this is a relatively new approach to innovation. It is a directed or meta-analogy method provided to design multiple state transforming systems. Fundamental to the theory are the principles and facilitators that support the designer in his efforts to create a multiple state system [28]. A Principle is a generalized directive utilized to create transformation, and when embodied, singly creates a transformation. A Transformation Facilitator is a design aid for creating mechanical transformation but their implementation does not create transformation singly. The transformation work has lead to a number of unique ideas such as the transforming ATV-motorcycle as shown in Figure 4. This result utilized the mind map variant of the method for idea generation.

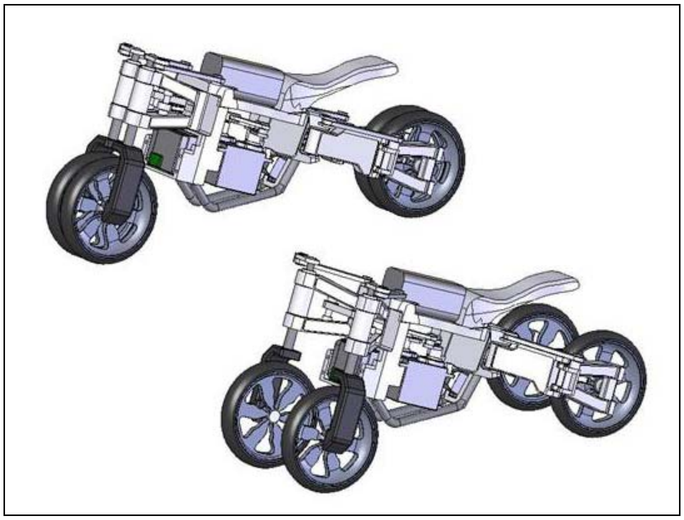

Figure 4: Transforming ATV-Motorcycle Concept

1.2.2 Design Fixation

For this research it is very important to understand not only innovation but barriers to innovation as well. Such barriers exist in many forms but broadly can be encompassed by fixation. For this research on innovation we will refer to fixation as "situations where innovation is blocked" [15]. Previous work has shown that fixation can occur when example solutions are provided to the design engineer [14]. It is more interesting to find that in addition to fixation other detrimental effects occur with the inclusion of preconceived solutions. Results include reduced range of solutions with features which may have violated the original set of goals.

In addition to understanding fixation we must frame the current work that is being done to negate its effects. There are a number of works that have begun to characterize methods for breaking fixation. Chrysikou and Weisberg found that providing de-fixation instructions with the use of analogies could aid in breaking fixation [16]. An analogy in this context is the mapping of knowledge from one domain to another supported by abstract representations (see e.g., [17, 19, 20]). Professional design engineers are quite accustomed to using analogies in idea generation whether knowingly or not [17, 19].

Innovation and the breaking of fixation is benefiting from a variety of research which is of interest to the work in this thesis. For instance some studies have shown that experts use more analogies than novices [18]. In additional research, design teams were shown to use close-domain analogies from past designs [20]. In all, the use of analogies is an attractive method for breaking fixation and thereby advancing innovation science. The benefit is demonstrated by formal methods that have been generated which utilize analogies for idea generation. One such tool was created to automate the idea generation process with analogical inspiration [21].

Chapter 2: Research Approach

This paper seeks to understand ways that current leaders in the engineering design field perceive innovation. The basis of the study is a set of demographic and technical questions. The participants are leaders in the field and conference attendees as part of the periodic NSF CMMI Conference. These participants represent a set of domain knowledge experts in engineering design, and, as such, provide the possibility for key insights into understanding the current state of innovation, at least within this knowledge domain. The technical questions as part of the study include Likert-scale agreement and disagreement queries in addition to a set of short answer questions. These multi-faceted questions provide a basis for analysis, wielding both quantitative and qualitative research methods. These questions were developed through a collaboration which included the authors and participants of a workshop [31] which included experts in the fields of cognitive psychology, social psychology, and engineering design. Through this approach, the intent is to investigate an individual's perception and knowledge of innovation research and methods across demographics. Figures 5 and 6 show a portion of the three part website and questionnaire respectively which were used to conduct the study.

Invitation to Participate... Page 1 of 3

National Science Foundation
WHERE DISCOVERIES BEGIN

Invitation to Participate in an NSF CMMI Sponsored Workshop:

"Discussion on Individual and Team-Based Innovation"

In conjunction with the NSF CMMI Engineering Research and Innovation Conference 2008 to be held in Knoxville, TN, a one day workshop, entitled "Discussion on Individual and Team-Based Innovation," will be offered on Monday, January 7, 2008 to Conference participants. The Discussion will introduce attendees to issues in cognition and social science and relate these to engineering design practice and research. The Discussion will be interactive, including a relevant exercise in the use of cognitive modeling in engineering design. It will provide a forum to begin to generate and explore near, intermediate, and long-term research needs in innovation.

The Discussion will address the following questions:

- What is, generally, the state-of -the-art in innovation processes, tools, and methods?
- What are the roles of multidisciplinary research (engineering, cognitive science, and social psychology) in innovation? and
- What is the relationship of engineering research in innovation to engineering education?

Figure 5: Snapshots of web-based survey for the NSF CMMI Sponsored Workshop

NSF CMMI Workshop: Discussion on Individual and Team-Based Innovation
Participant Innovation Questionnaire

Directions: Please answer all questions in the following questionnaire. The answers to these questions will not be used for workshop selection. Your answers will remain confidential and your name or affiliation will not be connected to your answers. After answering these questions, your application process is complete, and you will be asked to submit the application.

E-mail:

1. Brainstorming is an effective technique for creating innovative ideas.

- Strongly Agree
- Agree
- Somewhat Agree
- Neutral
- Somewhat Disagree
- Disagree
- Strongly Disagree
- Prefer not to answer

2. It is possible to train undergraduate students to be creative.

- Strongly Agree
- Agree
- Somewhat Agree
- Neutral
- Somewhat Disagree
- Disagree
- Strongly Disagree
- Prefer not to answer

Figure 6: Snapshots of web-based survey questions form for the NSF CMMI Sponsored Workshop

Three categories define the study's construction: (1) demographics of the participant group, (2) technical components with quantitative assessment, and (3) short-answer questions. The first section of demographic questions includes characteristic data as well as the participants' professional histories. Following the demographic questions, participants respond to a set of technical questions about innovation, rating responses of agreement to statements using a seven-point Likert scale. The seven points are treated as an interval scale and will be analyzed using a statistical rank-sum and t-test. In this analysis, the Likert scale has the following point allocation: strongly agree = 3, agree = 2, somewhat agree = 1, neutral = 0, somewhat disagree = -1, disagree = -2, and strongly disagree = -3. Averages and standard deviations are calculated for each survey question based on this point allocation. For each calculated average, the results are depicted such that -0.5 – 0.5 is referred to as neutral and 1 – 2 referred to as somewhat agree – agree. Table 1 lists the full range of responses and associated descriptions.

Table 1: Likert Response Averages with Associated Descriptions

From	To	Description
-3	-2	disagree to strongly disagree
-2	-1	somewhat disagree to disagree
-1	-0.5	somewhat disagree
-0.5	0.5	neutral
0.5	1	somewhat agree
1	2	somewhat agree to agree
2	3	agree to strongly agree

The technical questions were developed from various historic and current perspectives in the innovation field, both professional and academic. The survey ends with a short set of multiple choice and short answer questions. These responses, in addition to the participants' applications, are evaluated in an effort to yield an understanding of participants' perceptions but from a qualitative research perspective.

Through this approach, a richer and deeper understanding of the participant responses is possible.

In this paper four primary processes are utilized to evaluate the technical data for extraction of meaningful results. Figure 7 shows the research flow diagram associated with this work. There exist two underlying approaches to the work done in this paper which can be seen in Figure 7 as the inductive and deductive workflows. First seen in this diagram is the deductive work of reporting and analyzing the technical questions which constitutes the aggregate study seen later in section 4.2. This study considers a basic approach of considering aggregate participant data individually. This is done by first organizing the results into graphs and then calculating the average and standard deviation of responses across the participants. Conclusions can then be drawn from a fundamental evaluation of the answers. This aggregate set of data is analyzed further by the three subsequent methods described below. The details of these methods can be seen in section 4.

As shown on the left hand side of Figure 7, the second method, an inductive correlation study, involved a pair wise comparison of all technical and demographic questions across all permutations of technical questions. This analysis led to a large number of correlated results. This set of correlations was then further refined to include only those shown to be statistically significant using a t-test or the rank-sum test. This is accomplished first by dividing the participants into the correlated groups. Then the data is evaluated to determine whether their probability density functions (or mean shifts) are statistically different using the ranked sum and t-test respectively. For this analysis we concluded that a significance level of 0.1 (p-value of 0.1 or a confidence level of 90%) or less was sufficient to interpret the data as meaningful for our research. In all of the following analysis the p-value for each test is shown.

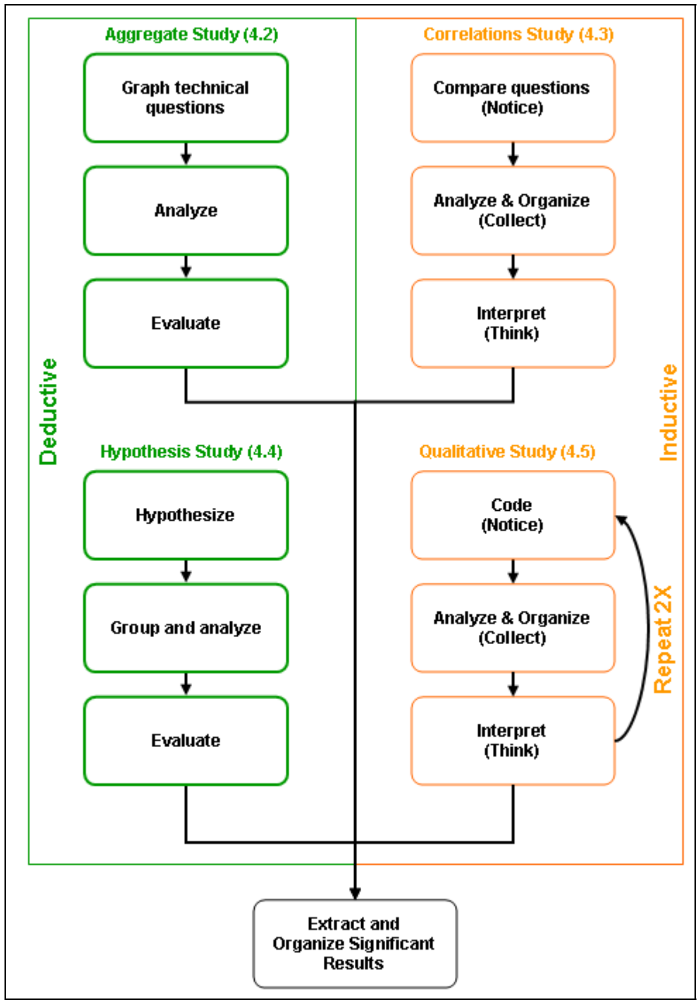

Figure 7: Methods used for evaluating survey data.

The third method, seen on the bottom left of Figure 7, is a deductive process used to analyze the technical questions using hypotheses. To begin, we evaluated all technical questions from the aggregate participant data which lead to the creation of a set of hypotheses highlighting specific comparisons of the participant data. Step two in this approach is where the analysis of the participant data takes place. The basis of this step first organizes the data by the specific characteristic attributes pointed out in the hypothesis. This organization creates sub-groups which were then each evaluated over all technical questions from the participant data. Finally, as with the single correlation study, the list was refined to only those comparisons which proved to be meaningful through a t-test or rank sum test.

The fourth method, seen on the bottom right hand side of Figure 7 focuses on the third type of question provided to the participants. This includes short answer questions about key terms and topics of interest to the participants. An inductive, qualitative analysis is performed for the participants' responses to these questions. The fundamental model for this research was gathered from Seidel [30] which describes a notice, collect, think process of qualitative data analysis, as seen in Figure 7. The qualitative process includes reading the short answer survey results in detail. For the chosen method we first code (or notice) the data given our understanding of the material. This is done by two researchers independently to allow for a well vetted set of results. In this method the two researchers then collect their codes and analyze them by recognizing relationships, links, strength, and quality. The final step is to think about the results. This includes searching for high level classes, processes, patterns, etc with the main goal of reconstructing the data to produce quantitative, graphic, and narrative results. The researchers then combine their individual efforts to continue further analysis which involves iterations of this same set of steps which allows for continued learning and refining the results. This method benefited from the use of Excel and NVivo software [33] to evaluate the data and to collect meaningful results. NVivo software provides the additional capabilities of tracking the users which input user specific codes, relationships, word tress, etc. Finally, after all iterations are complete, we will discuss and provide insights about our survey results in relation to this work and to the larger work of engineering education and engineering design.

2.1: FIXATION STUDY

In a companion study, research was carried out to understand design fixation and strategies for overcoming it. Design fixation is a state of obsession which tends to impede additional solutions. With the understanding that "fixation refers to situations where innovation is blocked" [15], we must consider it in our attempt to better define engineering innovation processes. For example, one may extract from a fixation study that everyone, even those most educated in innovation tools, can become fixated but they can also overcome this fixation through well developed methodologies. The study carried out on fixation asked (1) if engineering educators could become fixated, (2) could their fixation be overcome, and (3) during this process could those surveyed detect that they were in fact fixated.

Based on the number of ideas generated and the number of reused elements for a trial design problem, it was shown that engineering educators developed a tremendously large quantity of concepts, and they develop quality concepts, however they can also become fixated. In addition to these findings, the participants confirmed that they could be guided away from fixation by using innovation techniques such as design by analogy or an understanding of first principles. There is a final key result from this study showing participant's perceptions. Participants thought that they were not becoming fixated but the quantitative data proved that in fact they were.

This final result brings up an interesting question of the effectiveness of a query-based study as personal perception is inherent to the data. In the current survey analysis, we are attempting to obtain participants' perceptions of trends that they have seen from both the designer's perspective as well as the educator/leaders perspective. As a result, the types of perceptions are multifaceted. These perceptions provide for a baseline understanding of innovation within the participants' knowledge domain, and they provide a basis for comparison with research findings in the literature.

Chapter 3: Survey Results

The construction of this study integrates common survey methods including demographic questions, such as the level of experience, and personal characteristics. A second group of questions relates to technical understanding of engineering innovation. The survey also includes a set of short answer questions so that participants can include their opinions in their own words. Through execution of the study with approximately 40 participants, a large quantity of data is created. This data is organized below in five sections: demographic results, individual results of innovation questions, single correlation results, hypothesis study results, and qualitative results.

3.1: DEMOGRAPHIC/EXPERIENCE RESULTS

The first section of the query-based study elicited demographic information from the participants. Figures 8-18 illustrate the demographic results. It is clear from these results that the backgrounds of participants are broad, where the vast majority is well-founded in innovation education. Approximately 90% of the participants are engineering professors, as shown in Figure 8. Relatively large percentages, 34.2% (Figure 9), of the participants are women, where 84.6% (Figure 11) are professors. When compared to the percentage of women faculty in the United States 11.8% [7], it is critical to realize that not only did a good proportion of women attend, but that there may exist a more fundamental connection between women and there passion for innovation or design. There exists a good distribution of participant's age ranges (Figure 10). The largest group 42.1% by far lies in the range from 30-40 years old. This should not distract from the fact that a large number of participants aged 40-60 plus years of age were represented as well as 18.4% of those surveyed being 20-30 years old.

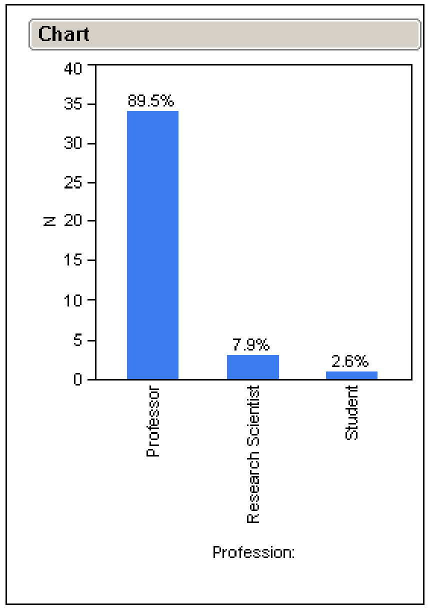

Figure 8: Demographic Results for Profession

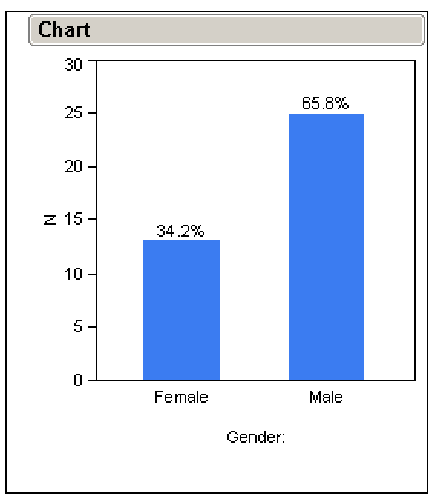

Figure 9: Demographic Results for Gender

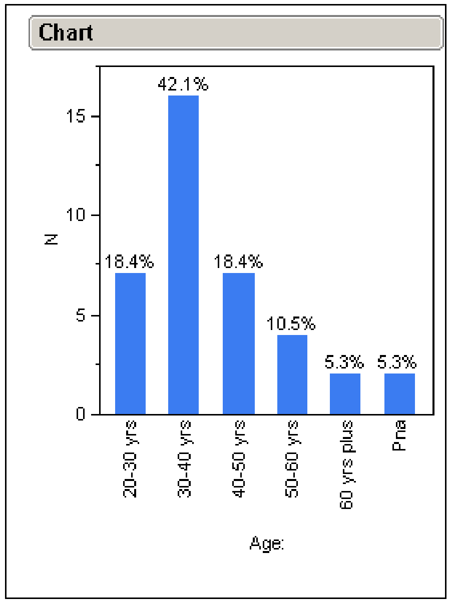

Figure 10: Demographic Results for Age

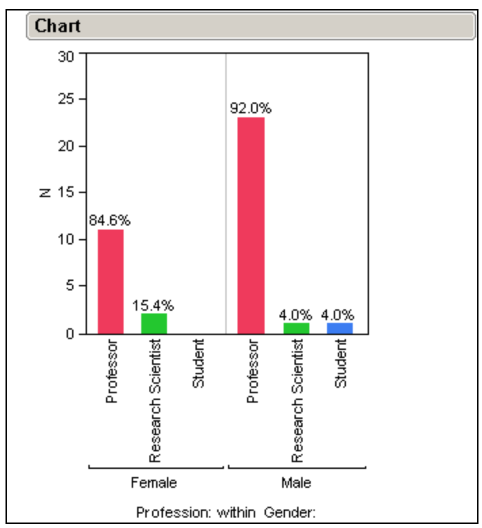

Figure 11: Demographic Results for Profession within Gender

The experience based questions attempt to further understand the resume of those participating in the survey. Some qualities of interest here are those that are postulated as being coupled to innovation. As shown in Figures 12 thru 16, the experience-based questions included: patents granted, design work experience, classes taught, consulting experience, and innovation tools designed. The remaining up-front questions queried the participants with respect to NSF grants and industrial design experience, Figures 17 and 18.

There are a few interesting items to note given the experiences based questions. 50% of those surveyed are named inventors on patents (Figure 12). This number is high compared to the percentage of named inventors across engineering faculty in general, and becomes useful later in more deeply evaluating the technical questions. There are a large number of participants with consulting and/or industrial experience as shown in Figures 15 and 18. 71.1% of those surveyed have taught a product design course (Figure 14). Maybe one of the most telling statistics of the experience of those surveyed, with respect to the purpose of this paper, is shown in Figure 16. Here we see that 63.1% of those who were surveyed have designed tools for innovative design. This, in addition to the teaching experience, highlights the fact that the participants should be well versed in engineering design innovation.

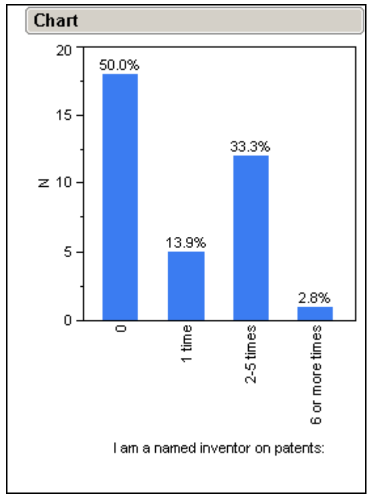

Figure 12: Patents

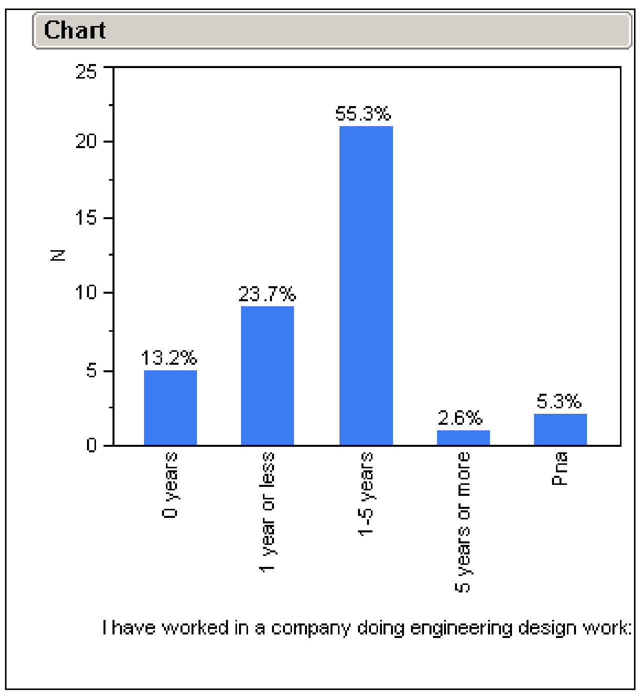

Figure 13: Design Work Experience

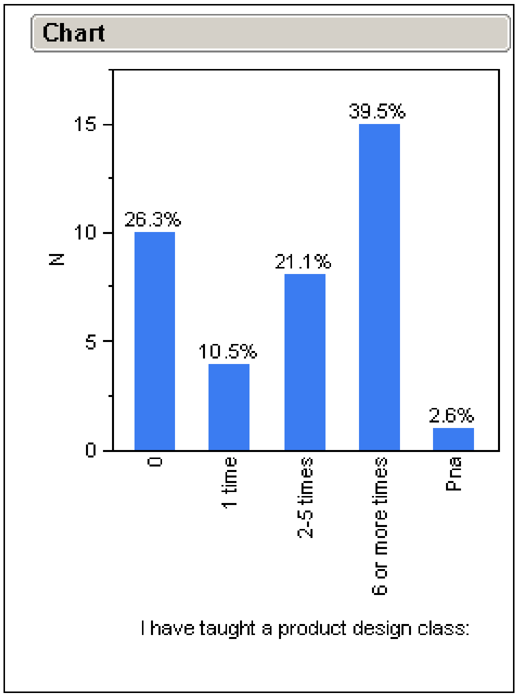

Figure 14: Teaching Experience

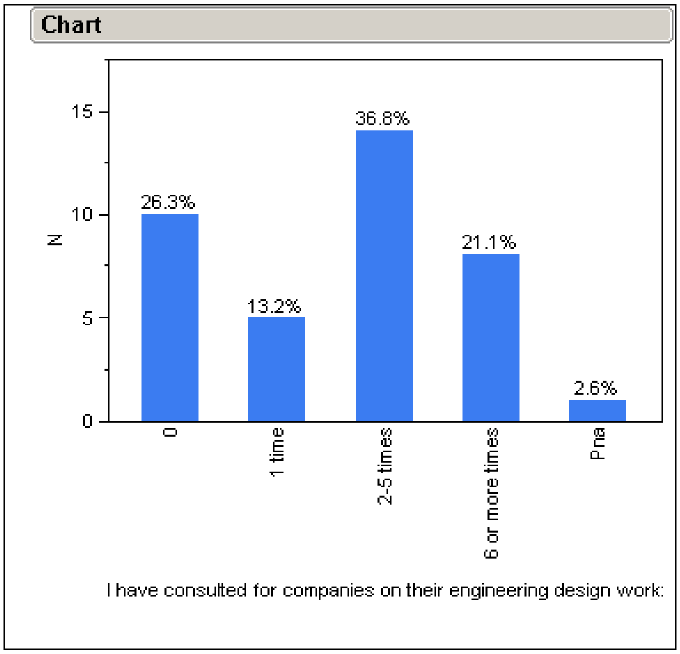

Figure 15: Consulting Experience

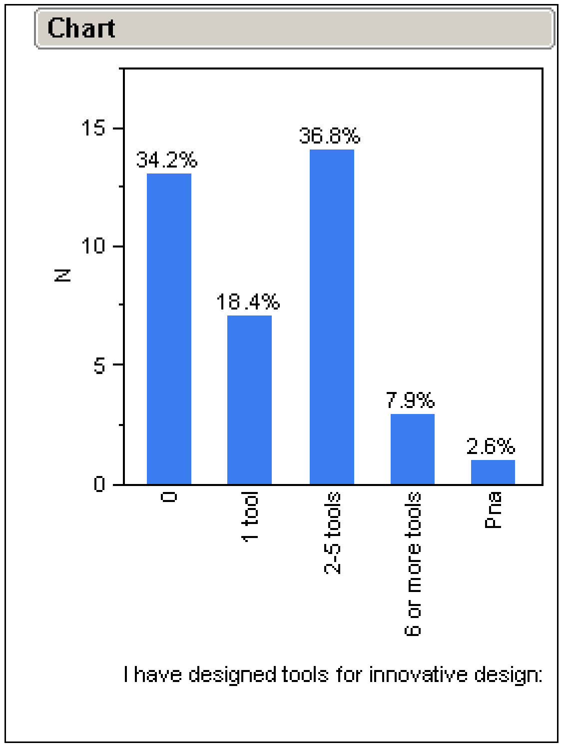

Figure 16: Innovation Tools Designed

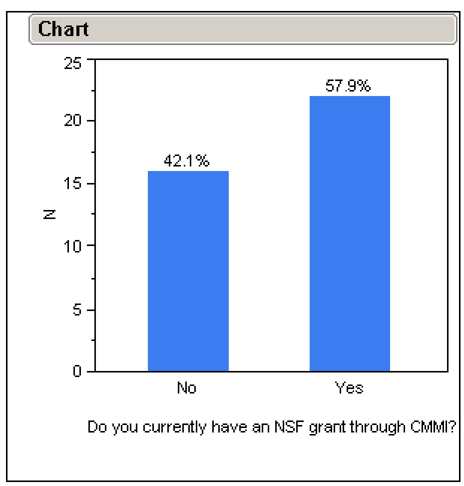

Figure 17: Current NSF Grants

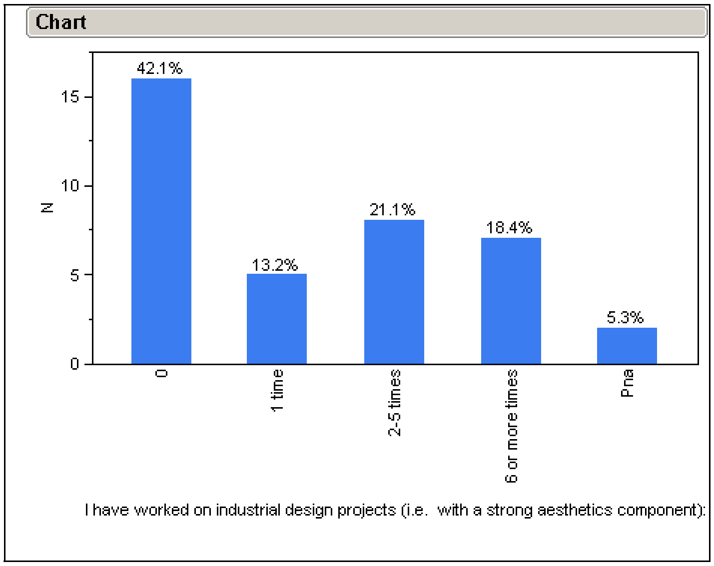

Figure 18: Industrial Design Experience.

3.2: INDIVIDUAL RESULTS OF INNOVATION QUESTIONS

The development of the technical questions in this survey is based on common topics in engineering design. These questions consist of many components that are familiar to most engineering students and even more so to engineering educators. Some include but are not limited to brainstorming, ideation, fixation, creativity, and analogies. In addition to these questions a multiple choice set of questions was used.

The technical questions are grouped into four categories:

- Process or Method
- Designer Characteristics/Qualities
- Education
- Design Teams and In Situ Environment

As shown in Table 2, there are 23 technical questions designed into the survey. This table includes the questions as they were presented in the data acquisition process. Although the sequencing is not completely random, note that the questions from each of the four categories are scattered throughout the form. The creation of these groups allows for systematic analysis of the raw data. The grouped questions are color coded for analysis and are shown in Appendix A. One may notice that questions 22 and 23 are very similar and represent a double barrel question. The addition of one word to differentiate the questions was in hindsight not the best use of the line but in an effort to provide a complete analysis we have left it in and interesting results are noted.

Table 2: Technical Questions from the NSF CMMI Sponsored Workshop Survey

1	Brainstorming is an effective technique for creating innovative ideas.
2	It is possible to train undergraduate students to be creative.
3	The use of analogies is a necessary part of the innovation process.
4	Creativity is positively correlated with grade point average.
5	Undergraduate engineering programs inhibit creativity and innovation as the students proceed in the program.
6	Modeling of a design problem i.e. generalizing or clarifying it is a critical part of the early innovation process.
7	Designers / people become blocked (fixated) on particular solutions depending on how a problem is stated.
8	The presence of people from outside disciplines during ideation can hinder the ideation process.
9	It is possible to create an innovation process that overcomes impasses or fixations that may arise.
10	The physical design environment is critical to assist and empower innovation.
11	During idea generation all constraints should be suspended.
12	During idea generation all negatives or criticisms should be avoided.
13	The use of analogies can cause fixation during the innovation process.
14	The use of physical manipulables can impede innovation during idea generation.
15	The use of pictures of objects can impede innovation during idea generation.
16	The early stages of design should be considered as art not something that can be formalized or lends itself to formalization.
17	K-12 students exhibit a higher degree of creativity than higher education students.
18	Personality types or preferences have an impact on one's ability to be creative.
19	An essential characteristic of a good designer is the ability to decompose a problem into simpler and more manageable sub-problems.
20	Design teams can be more effective than individuals at creating innovation.
21	Every design problem requires a different solution method as applied by a designer or design team.
22	Innovative design outcomes depend upon the input of very creative individuals.
23	Innovative design outcomes depend upon the input of very open/creative individuals.

3.2.1: Process or Method

The first and largest of the categories of technical questions is the Process or Method questions. This group includes questions 1, 3, 6, 7, 11, 12, 13, 14, 15, 19 and 21. As with all groups of questions there is a mix of results providing sub-groups, some with different polarizations, positive or negative. For the Process or Method group, sub-groups are created for ease of visualization due to the large number of associated questions. In order to calculate the average and standard deviation the data is organized in interval form as shown in Table 1.

The first group was organized together based on its strong positive tendency and question commonalities as shown in Figure 19 and includes questions 1, 3, 6, 7, 13 and 19. Figure 20 shows the averages and standard deviation error bars of the results for each question from Figure 19 in the Process or Method sub group. Results indicate that the average is high, typically in the agree to strongly-agree range, with standard deviations that reinforce the likelihood of agreement.

For question 1 on brainstorming, the responses are indicative of the historical popularity and familiarity with brainstorming as a technique. Generally, the participants believe that brainstorming is effective. The spectrums of responses and large standard deviation, however, suggests that a percentage of the participants are either familiar or have experienced the limitations of brainstorming, especially regarding the originally coined method of Osborn [5], or, alternatively, have experience with more recent ideation techniques that are likely to be more effective approaches to group idea generation such as 6-3-5, C-Sketch, Mindmapping or Gallery Method [6, 7, 11, 12, 13, 22, 23].

Responses to question 3 regarding the analogy process show a familiarity with analogy and may even explicitly or intuitively accept the cognitive model of innovation processes where concepts are developed based on similarity relationships with previous known concepts, artifacts, or methods. There was only one participant response indicating disagreement with this statement, showing the need for advancement of analogical reasoning and ideation techniques, and, perhaps, the necessity of teaching analogical reasoning techniques in the classroom.

Question 6, regarding results on modeling of a design problem, show a strong trend to agreement, where the average equates to an “Agree” to “Strongly Agree.” The participants clearly place stock in the need to model design problems in the early stages of design. Recent experimental results from the literature supports this view, especially for domains such as engineering where domain knowledge is critical and intensive. This result is, however, somewhat surprising when considering typical innovation processes in industry and even many innovation processes taught in academia. The “fuzzy front-end of design,” as it is often called, is not given nearly as much attention as other phases of design, both from a research emphasis and time investment for design applications. The participants’ response shows importance and may indicate a need for additional advancement and evolution.

Responses to the question 7 show a trend to agreement with this statement, where the average is “Somewhat Agree” to “Agree.” Given the response for the preceding question, this result is consistent and expected. How problems are stated fall in the realm of modeling a design problem. The participant responses show self-consistency based on this response, but also show the need for innovation methods and processes which provide appropriate problem statements, problem restatements, or ways in which problems may be stated in a variety of forms.

Statement 13 “The use of analogies can cause fixation during the innovation process” has results which show a “Neutral” response. With this question there exists a variety of beliefs regarding the statements. While the responses to question 3 above show a strong agreement that analogies are a necessity in innovation processes, there may exist a potential for analogies to lead to fixation in a section of the design space represented by that particular analogy. This potential pitfall may exist with any idea generated to solve a problem, but it also may call for specialized or focused techniques to either avoid or break fixations caused by analogies.

Question 19 results show agreement with the average between "Somewhat Agree" to "Agree." Many techniques have been developed for assisting designers in decomposing problems, for example by function, sub-systems, or objective/mission. These techniques are seeing wider use and favor in design in the last decade [12, 13, and 26]. The participants' responses suggest that this finding is true and may indicate the need for further research in this area.

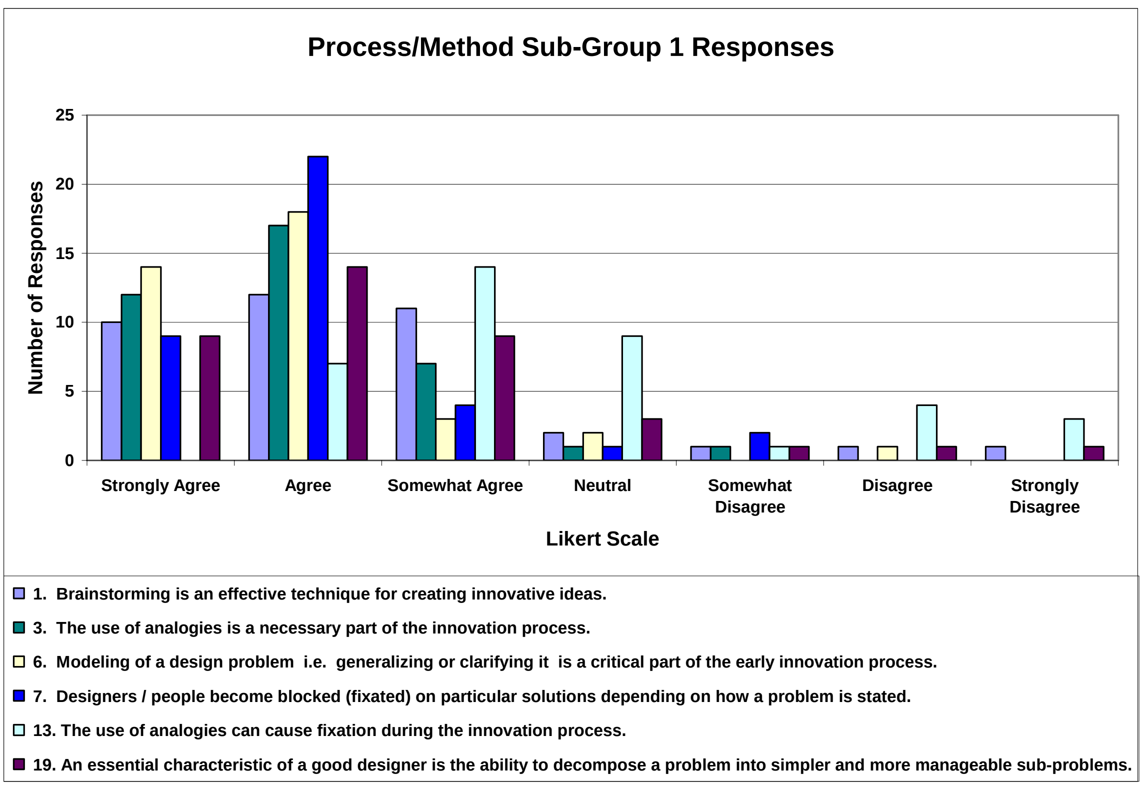

Figure 19: Process or Method Sub-Group 1 Responses.

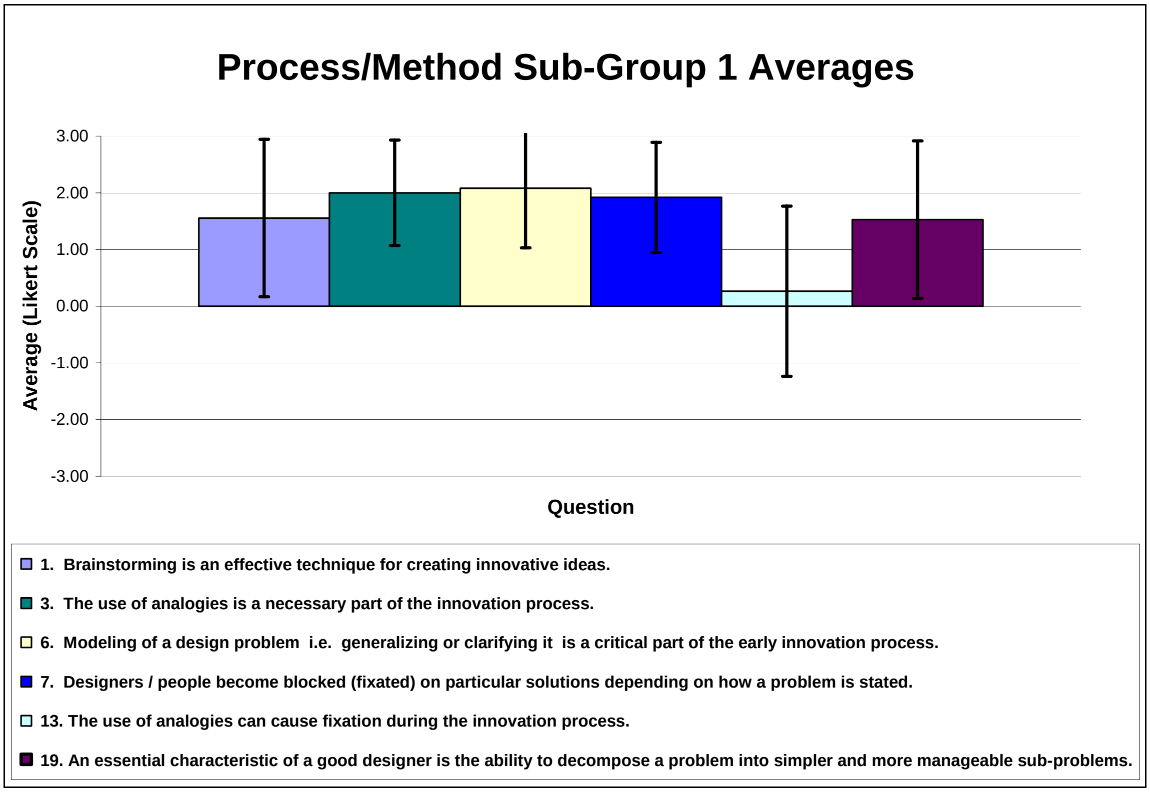

Figure 20: Process or Method Sub-Group 1 Average with Standard Deviation Error Bars.

The second group has a much more broad set of answers as shown in Figure 21 and includes questions 11, 12, 13, 14, 15, and 21. Figure 22 shows the averages and standard deviation error bars of the results for each question from Figure 21 in this Process or Method sub group.

The average of question 11 “During idea generation, all constraints should be suspended” shows a “Neutral” response with this statement. The participants’ responses show a very large distribution of answers, spanning all possible Likert ratings. This statement concerning idea generation is a well known mantra. Clearly, the participants disagree on the extent to which this statement applies or is useful. This disagreement puts one on notice regarding the clichés that are used as part of innovation processes. It also indicates the need for in-depth cognitive, social, and engineering-domain studies that are needed to resolve the degree to which this statement applies, and how to use this understanding to advance innovation processes.

Responses to question 12 again show a neutral average. The participants' responses to this statement show very similar trends to the preceding statement. Similar conclusions may be reached; however, the participants' responses are somewhat surprising. The root of the statement may be attributed, for the most part, to Osborn's brainstorming. Literature exists regarding the need to suspend criticism, yet the participants have a mixed view [24]. Again, research is needed to understand where, why and when this statement applies and how this understanding may be implemented.

Question 14 results show an average of "Somewhat Disagree." Again, there exists a large variation and distribution to the participants' responses. Recently, literature shows that physical manipulables can lead to fixation and other effects [34]. We have all had instances, however, where physical artifacts lead to ideas or discoveries that would not have been developed without the use of tactile or other senses. This may be the reason why those surveyed tended very slightly to disagree. Consistent with survey, a controlled experimental design study with a simple design problem demonstrates that physical models do not cause design fixation and tend to lead to higher quality ideas [35]. However, the role of physical manipulables needs to be understood further, identifying the factors and timing for their use.

For "The use of pictures of objects can impede innovation during idea generation" Question 15, the results again show an average of "Somewhat Disagree." The participant results for this statement mirror the results for the preceding question which, with the close tie between the questions, shows the consistency of those surveyed. The conclusions are similar here as with physical artifacts; however, recent literature shows that pictures of objects can provide useful analogies to spur ideas compared to a control group without such pictures [31, 32].

In evaluating Question 21, a wide variance in responses exists. The average is "Neutral." The participants' responses clearly indicate mixed beliefs regarding the need for innovation processes for different types of design problems. There is perhaps a belief that a general or generic design process exists that can be tailored to handle all types of design problems. Alternatively, some designers believe every design problem, especially those requiring innovation (not routine design), call for solution approaches with a different basis beyond just tailoring a given process.

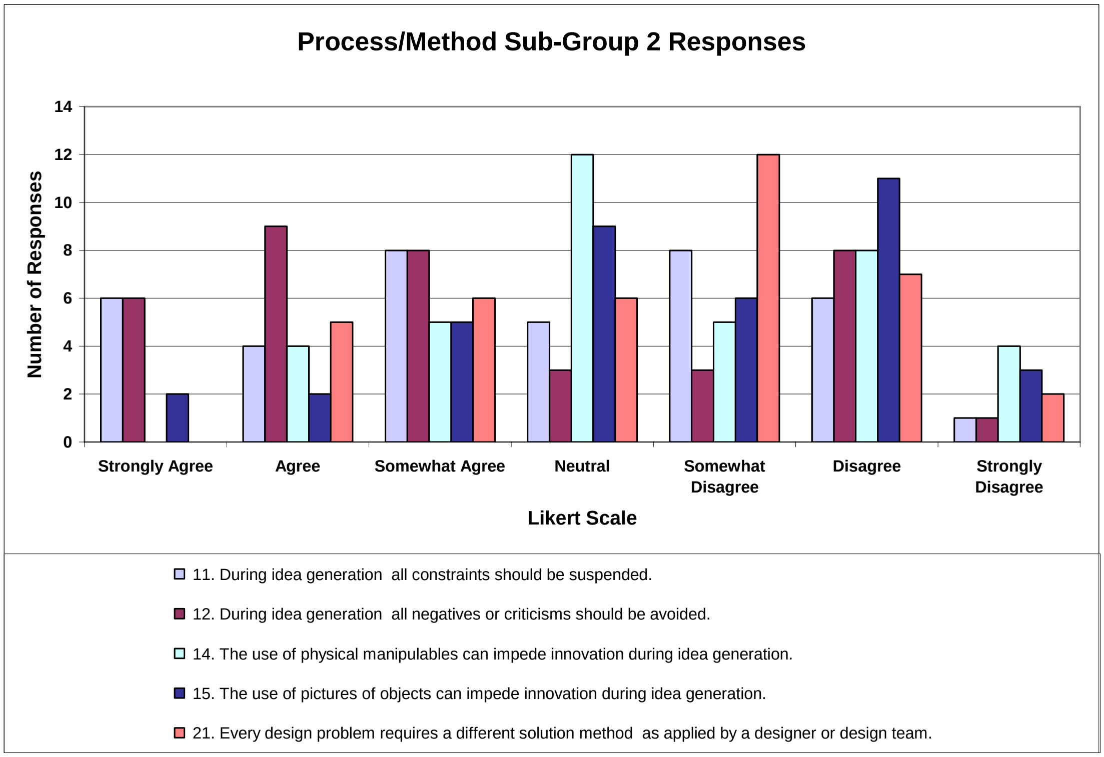

Figure 21: Process or Method Sub-Group 2 Responses.

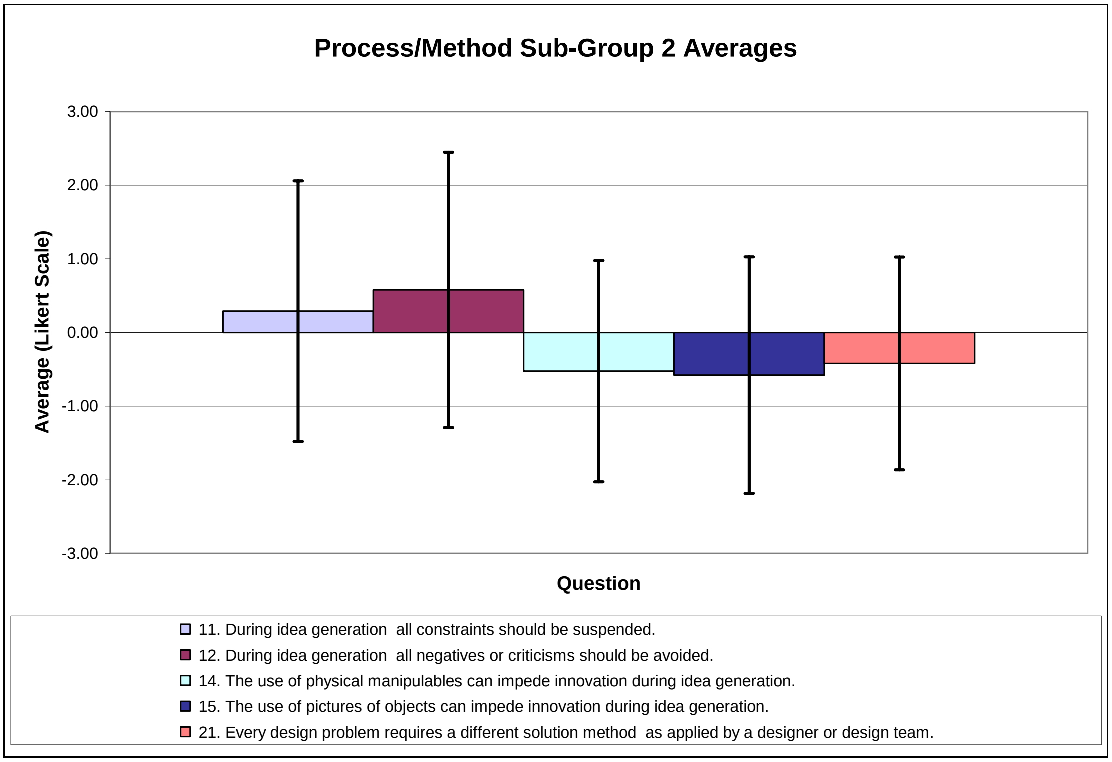

Figure 22: Process or Method Sub-Group 2 Average with Standard Deviation Error Bars.

3.2.2: Designer Characteristics/Qualities

The second category of technical question refers to the characteristics and qualities commonly associated with engineering designers. This group is another with a broad set of answers as shown in Figure 23 and includes questions 18, 19, 22, and 23. Figure 24 shows the averages and standard deviation error bars of the results for each question from Figure 23 in this sub group.

Responses to Question 18 show general agreement, where the average is “Somewhat agree” to “Agree.” The participants’ responses, while in the affirmative, show a fairly broad variance. This is partially characterized by the bimodal distribution. A segment of the participant group either disagreed or strongly disagreed. Recent literature suggests that an appropriate combination of personality types leads to more creative teams [36].

Also shown in the process method sub-group above, the responses to the Question 19 again show general agreement, where the average is between “Somewhat agree” and “Agree.” This result is key for designer characteristics/qualities in that it directly defines a trait which is thought of as necessary by leaders in the field.

Question 22 results show an average of “Neutral.” The participants’ responses show a wide variance again covering the full Likert scale. Research into the key factors for success of an innovative design problem is needed to clarify this issue. If the trend of the participants’ responses is correct, the strategic formation of a team can be very important. However, based on previous responses, there is hope since there is agreement from the participants that creativity can be enhanced through learning.

Responses to the Question 23 show an average between “Somewhat Agree” and “Agree.” It is interesting to note the shift in this response by almost a full Likert unit compared to the preceding statement. Only one word changed, i.e., “open” is added to the characteristics of the individuals working on an innovative design problem. Clearly, the participants, as a general group, believe this characteristic is a key for success.

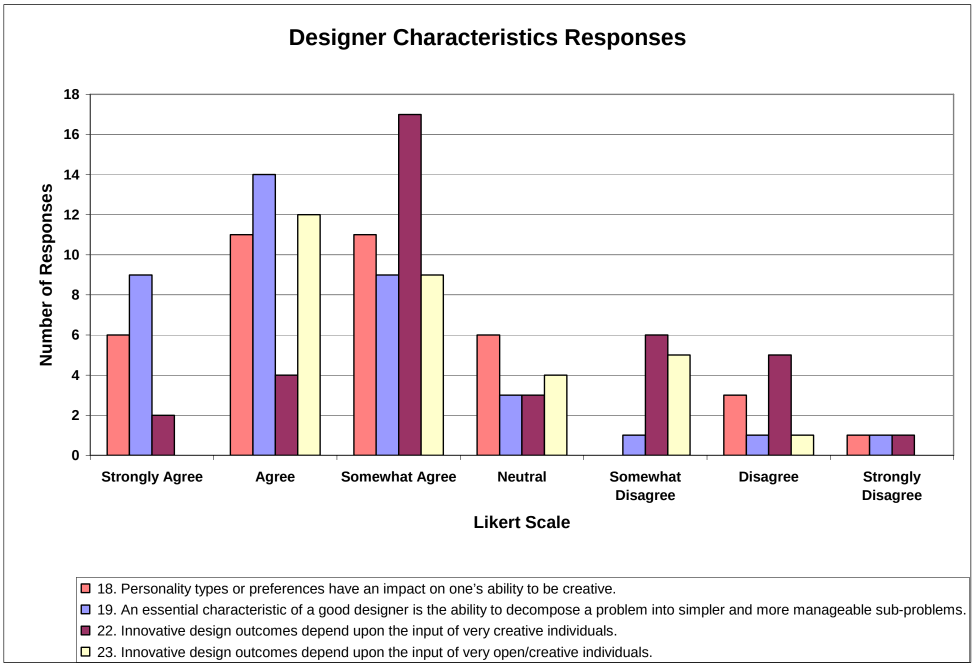

Figure 23: Designer Characteristics/Qualities Questions Responses.

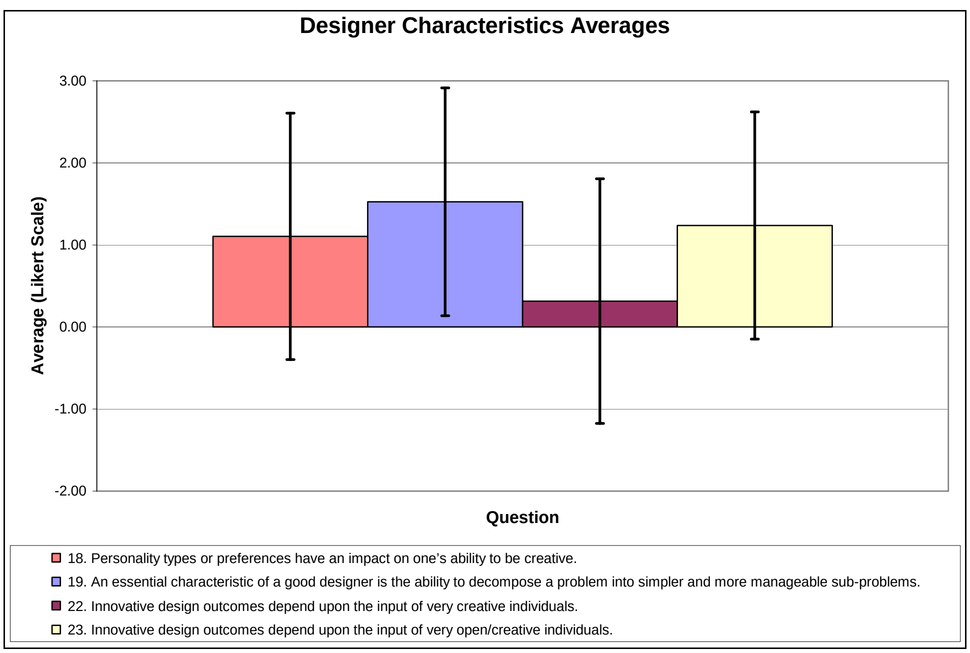

Figure 24: Designer Characteristics/Qualities Average with Standard Deviation Error Bars.

3.2.3: Education

The third category of technical questions includes a common thread to education as it correlates to engineering design. This group includes questions 18, 19, 22, and 23. As seen in Figure 25 the answers to these questions are broadly distributed across the Likert scale. Figure 24 shows the averages and standard deviation error bars of the results for each question from Figure 25 in this sub group.

Responses to the statement “It is possible to train undergraduate students to be creative” Question 2, show a clear trend to agreement, where the average is “Agree” to “Strongly Agree.” The low standard deviation shows a generally uniform agreement amongst the participants, where no participant disagreed with this statement. The participants, being from academia, are likely optimistic about their role in the education process, where a goal is to assist all students in being creative. It is suggested that students do not necessarily improve their creativity between their freshman year and graduation and that students’ creativity may be stifled by the intensive applied science, applied mathematics, and analysis-based engineering curricula. The response from the participants suggests an optimistic view that creativity can be enhanced, perhaps in part due to new trends in engineering accreditation where design throughout a student’s tenure is emphasized. This positive outlook bodes well for innovation research and its potential impact.

In Question 4, “Creativity is positively correlated with grade point average”, results show a trend to disagreement, where the average is “Somewhat Disagree.” Participant responses show a wide range of beliefs about this statement. The large standard deviation supports this conclusion. There exist a variety of views based on the experience of the participants. Research may be called for regarding this statement and the factors that affect creativity.

Responses to Question 5 show an average of "Somewhat Agree" (with a greater majority on the positive side of the scale). The participants' responses are dependent on the range of undergraduate programs known by a given participant. The variance in responses indicates, however, that engineering programs must continue to evolve when creating curricula to teach, encourage, enhance, and promote creativity and innovation.

In the 9th Question of the study "It is possible to create an innovation process that overcomes impasses or fixations that may arise," a strong trend to agreement is shown. This statement has an average of "Somewhat Agree" to "Agree." This result shows optimism on the part of the participants for overcoming fixation, and, perhaps, awareness of research findings where techniques are espoused for "block busting." It is clear from the literature, however, that understanding impasse and fixation as part of teams or cognitively is in its infancy [14, 15, 25]. Much research is needed in this area to ultimately meet the optimism of the participants.

Question 16 shows a general, though not strong, disagreement with this statement, where the average is right at "Somewhat Disagree." The high standard deviation shows that the participant responses are widely distributed and they are not in general agreement. This wide variance is expected due to the historical debate of design as an art or a science. It is interesting that the distribution of responses is skewed toward disagreement where perhaps two decades ago the opposite would have probably been true given the demographics of the participants.

The 17th Question of the survey is "K-12 students exhibit a higher degree of creativity than higher education students." In looking at the results of this question, the first thing noticed is the average of "Neutral." The statement considered here is similar to a preceding statement that addressed undergraduate programs stifling creativity. A similar outcome is found as with this statement except that the response is not weakly affirmative but neutral. It is interesting that the participants did not agree with the mantra represented by this statement even though the statement is used quite often to encourage more creative tasks for engineering programs.

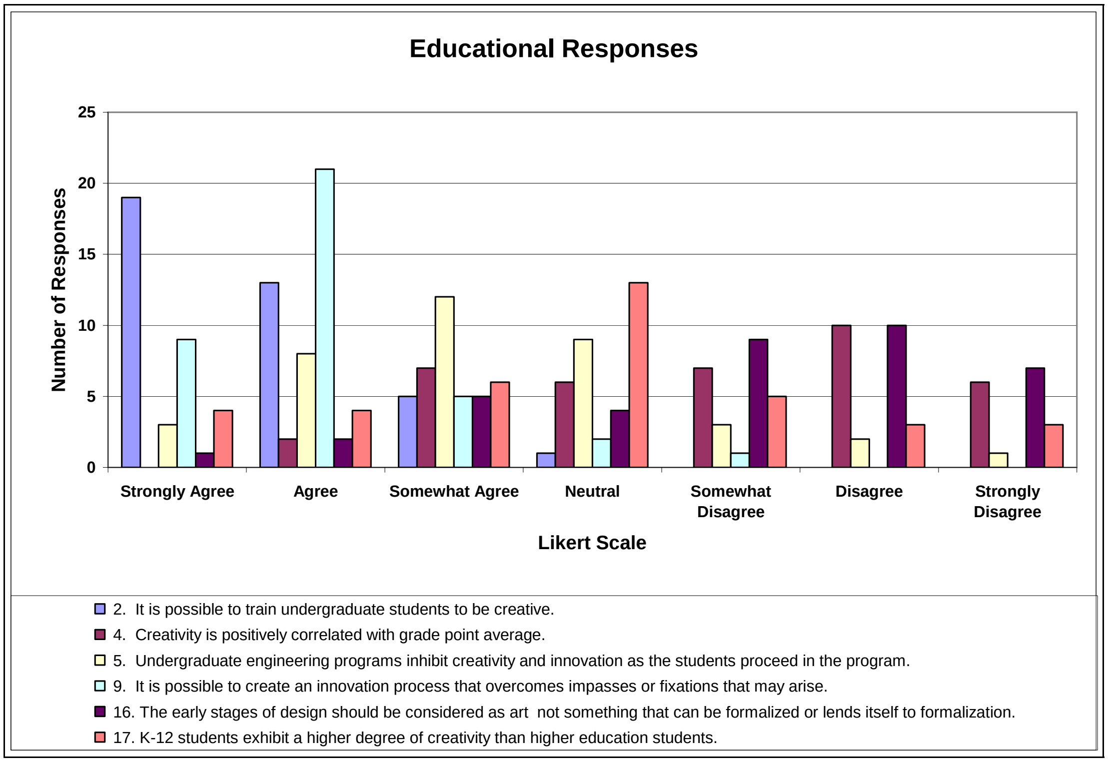

Figure 25: Educational Questions Responses

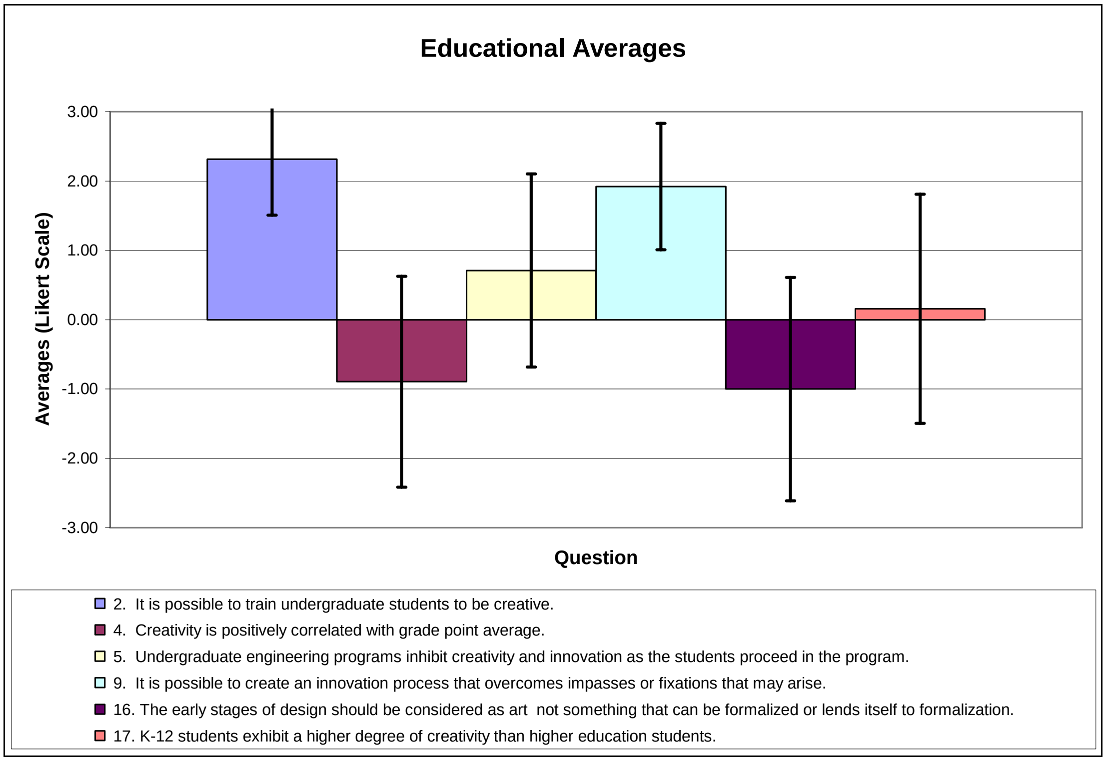

Figure 26: Education Averages with Standard Deviation Error Bars

3.2.4: Design Teams and In-Situ Environment

The next category of technical questions focuses on the team and environmental aspects of engineering design. As seen in Figure 27 this group includes questions 8, 10, and 20, and has a very interesting set of results. This can be more fully appreciated in Figure 28 which shows the averages and standard deviation error bars of the results for each question.

Responses to the Question 8 “The presence of people from outside disciplines during ideation can hinder the ideation process” show a strong average of “Somewhat Disagree” to “Disagree.” Participants clearly believe that bringing “outsiders” into the ideation process is healthy and should be encouraged. More research is called for to determine how, when, why, and where persons outside an innovation problem’s discipline should be included. A basic question is how to choose the make up of ideation teams to produce the greatest quantity, variety, novelty, and quality of ideas. Likewise, what process and iteration approach is warranted to take advantage of the team composition?

In Question 10 the average is “Somewhat Agree” to “Agree.” The participants clearly believe in creating an environment that is conducive to innovation and innovation processes. Again, the jury is out regarding the actual impact on environment, i.e., positively, neutral, or negative depending on the conditions. Significant research is needed in this area beyond the beliefs of individuals or corporate entities that believe in this statement. What is interesting, however, is the intuitive belief by the participants as to the importance of environment. The foundation of this intuition needs to be investigated.

Question 20 “Design teams can be more effective than individuals at creating innovation” show general agreement to this statement, where the average is between “Somewhat agree” and “Agree.” This intuitive response by the participants is supported by the literature, but significant questions surround how methods and techniques can enable the effective characteristics of teams while avoiding dysfunctional pitfalls.

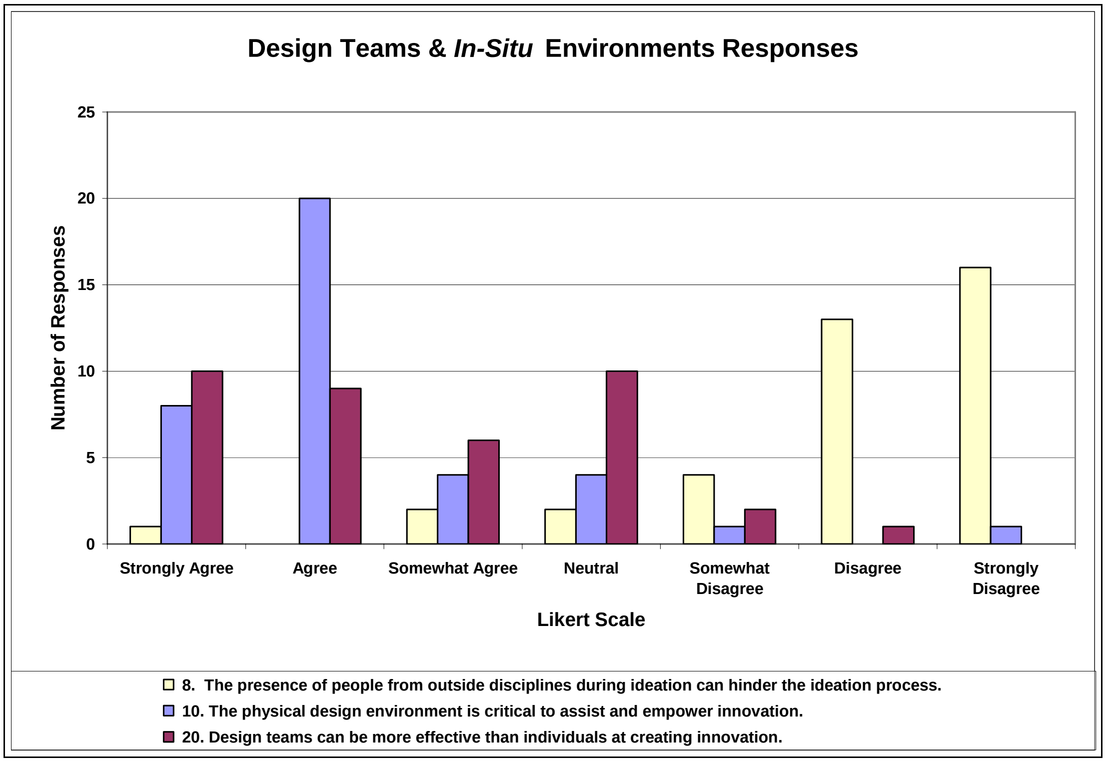

Figure 27: Design Teams & In Situ Environments Responses

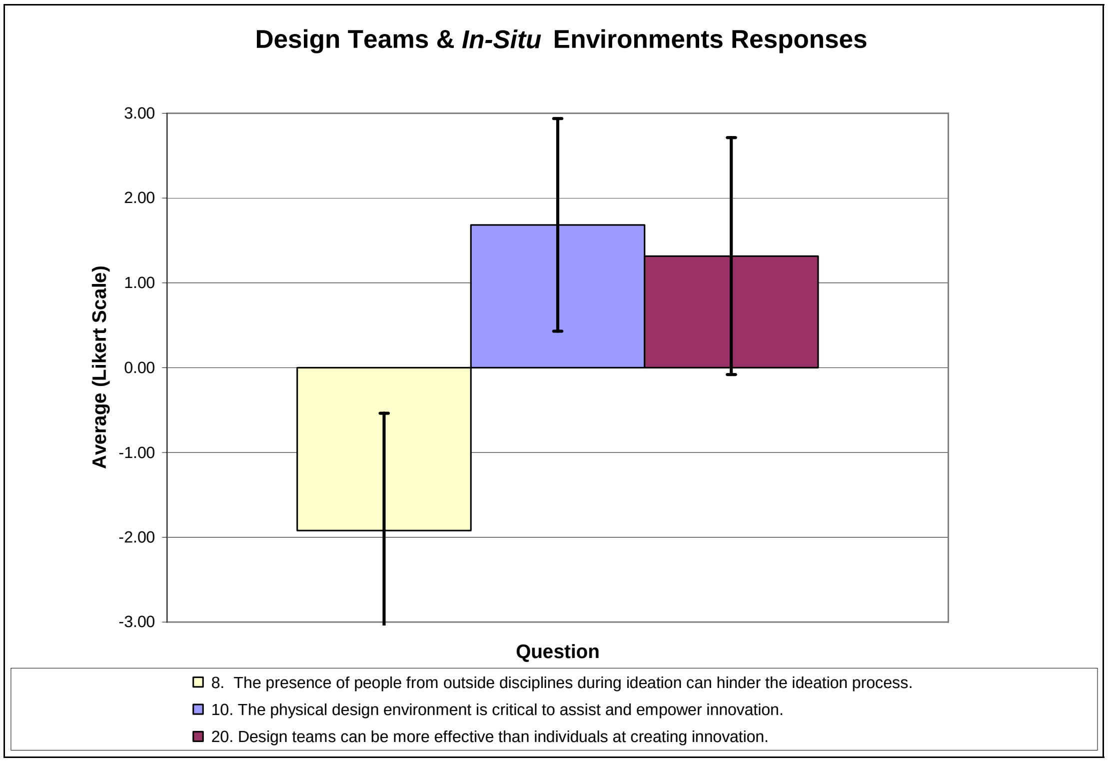

Figure 28: Design Teams & In Situ Environments Averages with Standard Deviation Error Bars

3.2.5: Multiple Choice

The last two questions in the technical question section include two parts and are multiple choice. The two questions asked for the most and second most difficult thing to overcome when attempting to come up with innovative design solutions for students and for the participants. There are six possible answers including: (1) getting stuck with a bad first solution, (2) team conflict, (3) lack of creative team members, (4) Insufficient analysis skills, (5) insufficient time to complete the task, (6) prefer not to answer.

The first of these questions is Question 24 “The hardest part of coming up with innovative design solutions (in my experience) is…” All of the choices provided in the multiple choice question received a fairly high number of responses with the exception of “Insufficient time to complete the task.” This result implies that all of these problems are potential pitfalls in terms of difficulty, and they are all worthy of study. The problem with the highest rating of difficulty, however, is "Getting stuck with a bad first solution." This result shows the need to study ideation techniques, factors affecting psychological inertia, and methods for overcoming fixation and impasse. The experiment carried out during the workshop addressed this general, combined area.

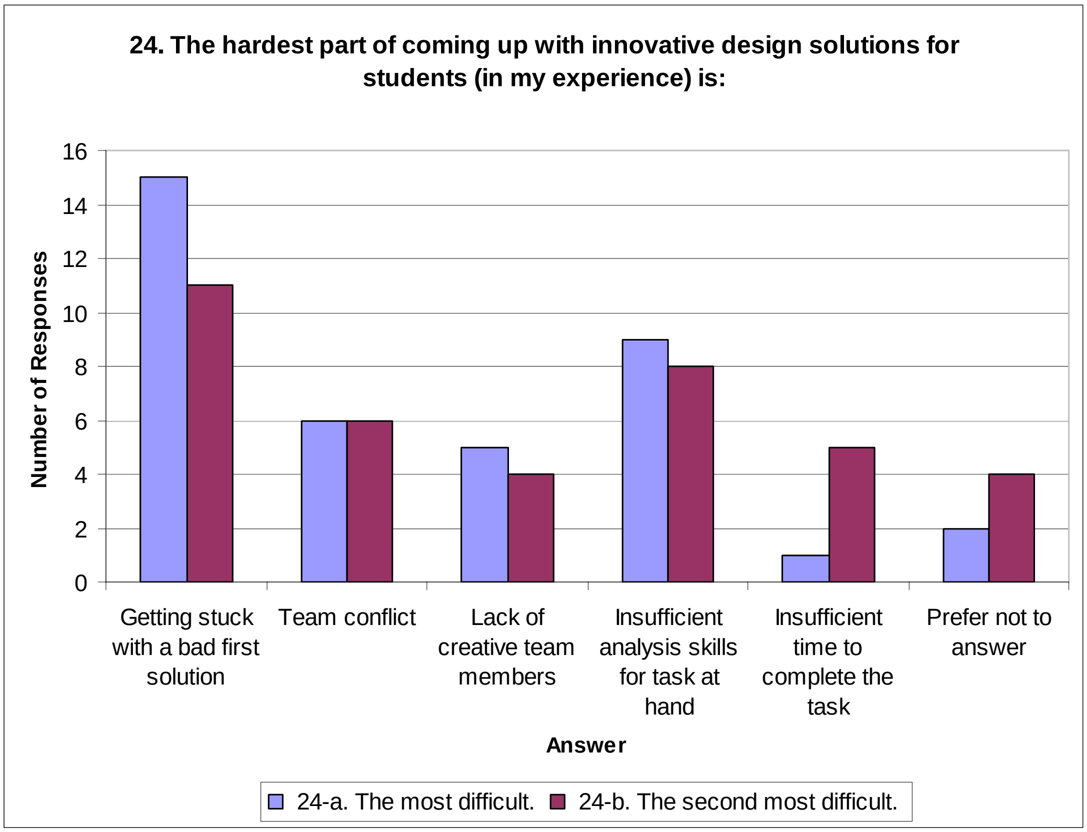

Figure 29: Question 24 Responses

The second of these questions is "The hardest part for me with coming up with innovative solutions to design problems I have worked on was…" This question was a variant of the first multiple choice question, where the focus is on the participant, not a general question about difficulty. Very similar results occur for this question as with the first, except that the distribution became even more uniform compared to the preceding question. Again, the problem with the highest rating of difficulty is “Getting stuck with a bad first solution.”

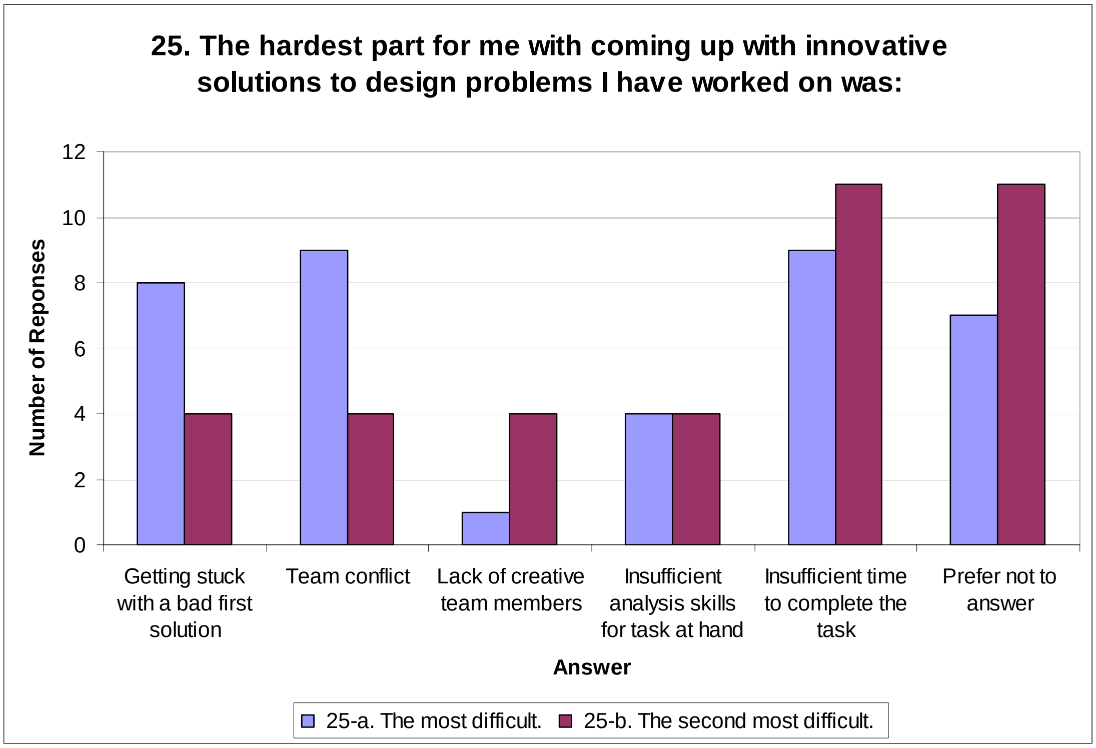

Figure 30: Question 25 Responses

3.3: SINGLE CORRELATION STUDY

In the single correlation study, hundreds of comparisons based on the common combinatorics of question correlations are analyzed to find noteworthy relationships. These correlations are refined by evaluating only those with a p-value of less than 0.1 when analyzed using a statistical t-test or rank sum test. The first step in this analysis requires that two sub-groups be created. This is accomplished by evaluating all correlations and extracting interesting groups whose answers seem polarized from one question to another. The next step is to determine if these sub-groups meet our requirement for significance. We extract the answers provided by the sub-groups and compare them against each other using a t-test and rank sum test to determine there p-value. All associated p-values are provided with the figures below. Only those correlations whose p-value fell below 0.1 for either the t-test or rank-sum test are utilized in this analysis.

Figure 31 shows an interesting observation from this method of extracting unique correlations. The calculated p-value based on the t-test of 0.0014 is lower than our significance level of 0.1. This difference, in the t-test, is based on the mean of those who have taught 6 or more classes in the right hand portion of the figure as compared to the mean for those who have taught 5 or less shown on the left. The low p-value shows a statistically significant difference at our level between these two sets of data. The result shows that those surveyed who have taught 6 or more classes agree completely with Question 6 “Modeling of a design problem i.e. generalizing or clarifying it is a critical part of the early innovation process.” In addition, 66.7% of those who have taught 6 or more product design classes answered “Strongly Agree.” To compare, only 18.2% of those who have taught 5 or less classes strongly agreed with this statement. This result may point to the need for those put in a position to teach product design courses to have a better mentorship into innovation processes. It seems here that maybe over time the trend moves towards more agreement as individuals teach more classes.

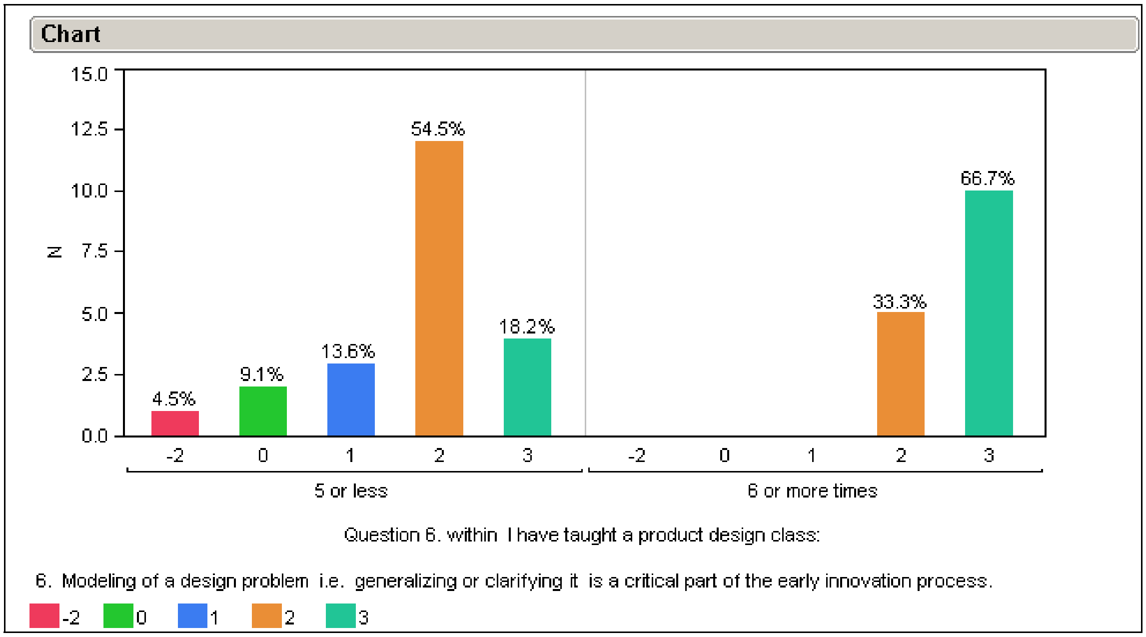

Figure 31: Question 6 results separated by number of classes taught. MatLab Results: pvalue_r = 0.0015, pvalue_t = 0.0014

In Figure 32 we see the second correlation which was created through the methods mentioned above. For this comparison two questions are shown to have an interesting combined result. Those who were in disagreement to Question 22 “Innovative design outcomes depend upon the input of very creative individuals” were more agreeable than the remainder of the group with regard to Question 9 “It is possible to create an innovation process that overcomes impasses or fixations that may arise.” This result is very interesting in that this subgroup of participants believes high levels of individual creativity is not necessary and it is possible to overcome fixation. This result perhaps portrays the belief that anyone can be innovative with the correct process.

Figure 33 continues the analysis of correlations with Question 22. All of those who were in agreement with Question 22, or positive, were in agreement with Question 23 “Innovative design outcomes depend upon the input of very open/creative individuals.” This result was entirely expected as the questions (22 and 23) were very similar with the exception of a single word “open.” In this correlation the interesting point to note is that 38.5% of those who answered either neutrally or in disagreement with Question 22 were in agreement with Question 23. This is remarkable considering the nature of this question and should be more thoroughly analyzed in subsequent studies possibly separating the question into its constituent parts. When the word “open” was attached to a description in a previous question a large portion of the participants changed the polarization of their answer.

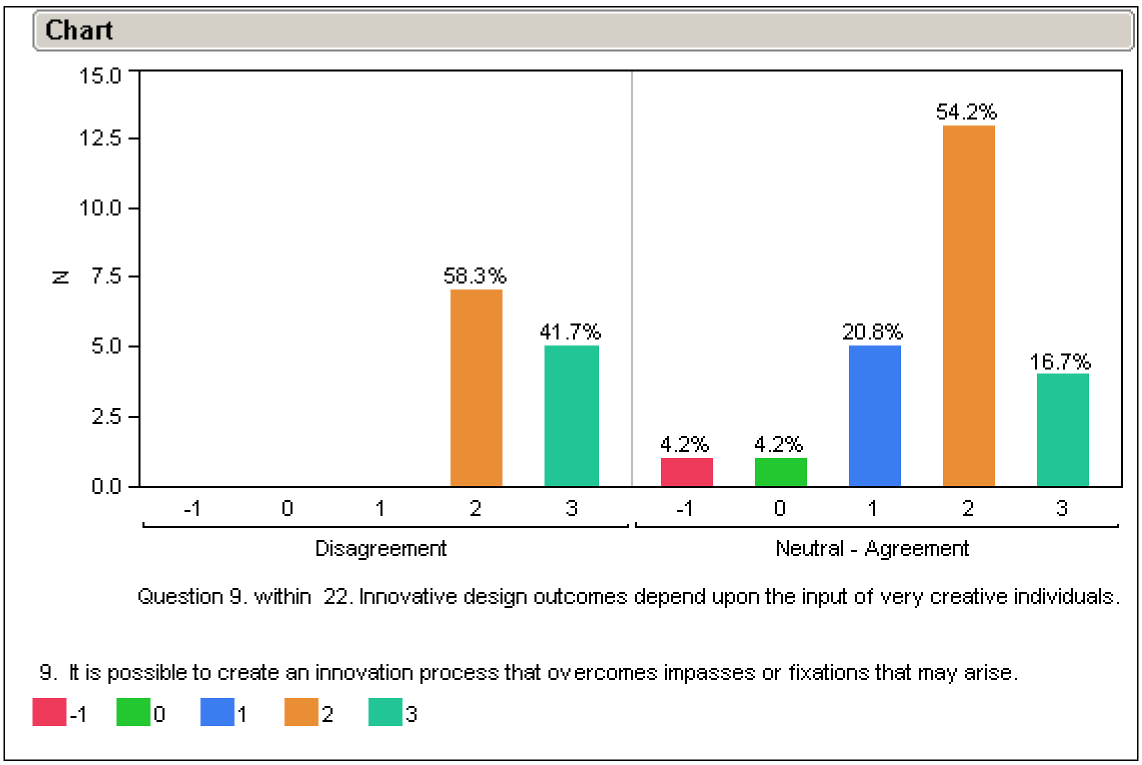

Figure 32: Question 9 results separated by answers to question 22. MatLab Results: pvalue_r = 0.0173, pvalue_t = 0.0049

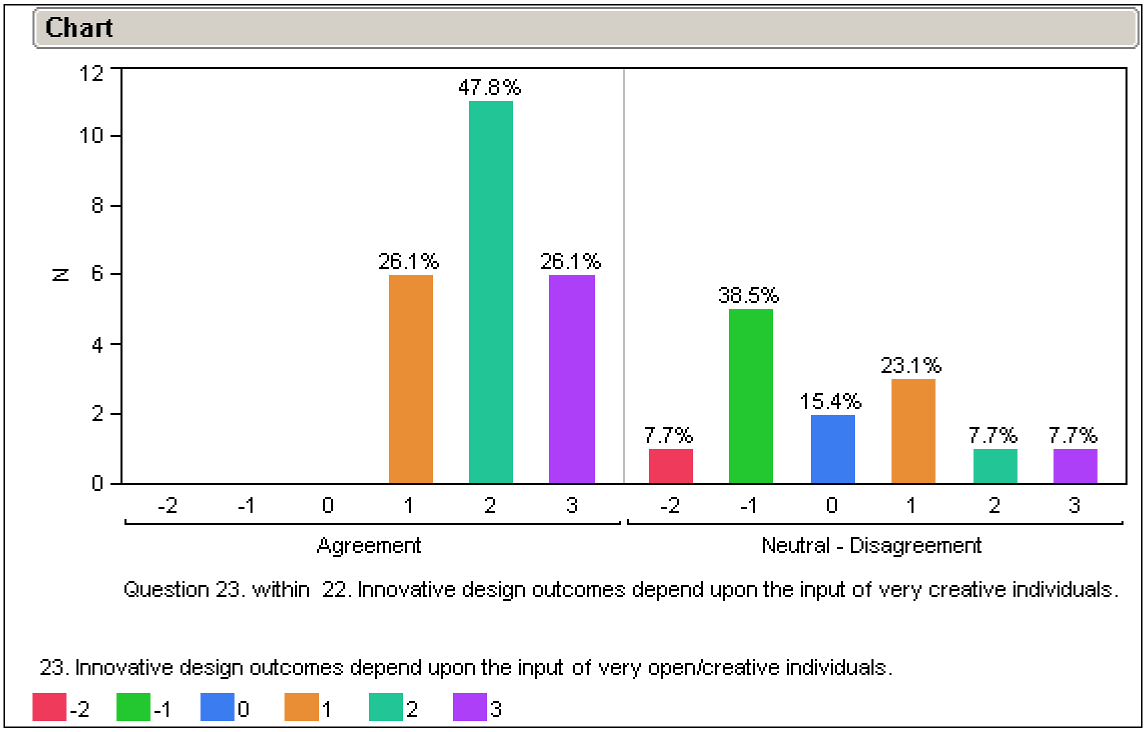

Figure 33: Question 23 results separated by answers to question 22. MatLab Results: pvalue_r = 5.407e-5, pvalue_t = 5.469e-5

The next group of questions to be analyzed using the correlation study method have a common link to Question 13 "The use of analogies can cause fixation during the innovation process." The following comparisons (Figures 34, 35, and 36) illustrate those who were in disagreement with Question 13 were more agreeable than their counterparts within Questions 3, 9, and 19. This group can be seen to believe that analogies are necessary in an innovation process and will not ultimately cause fixation. This result together with the research described in the discussion of fixation above show a trend towards a fundamental link between analogies and better innovation processes. Another interesting point to note from these figures is the group of people who were either neutral or thought that analogies could cause fixation. This group, to a lesser degree, also has a tendency to agree with Questions 3, and 9. This group would be summarized as believing that analogies are necessary but, possibly, should be used with caution as they may also cause fixation when utilized in an innovation process.

Figure 36 shows those participants who answered in disagreement with Question 13 are in agreement with Question 19 “An essential characteristic of a good designer is the ability to decompose a problem into simpler and more manageable sub-problems.” This collection of data depicts an interesting trend. The group who is in disagreement with Question 13 has very strong feelings in other areas of innovation when compared to their counterparts.

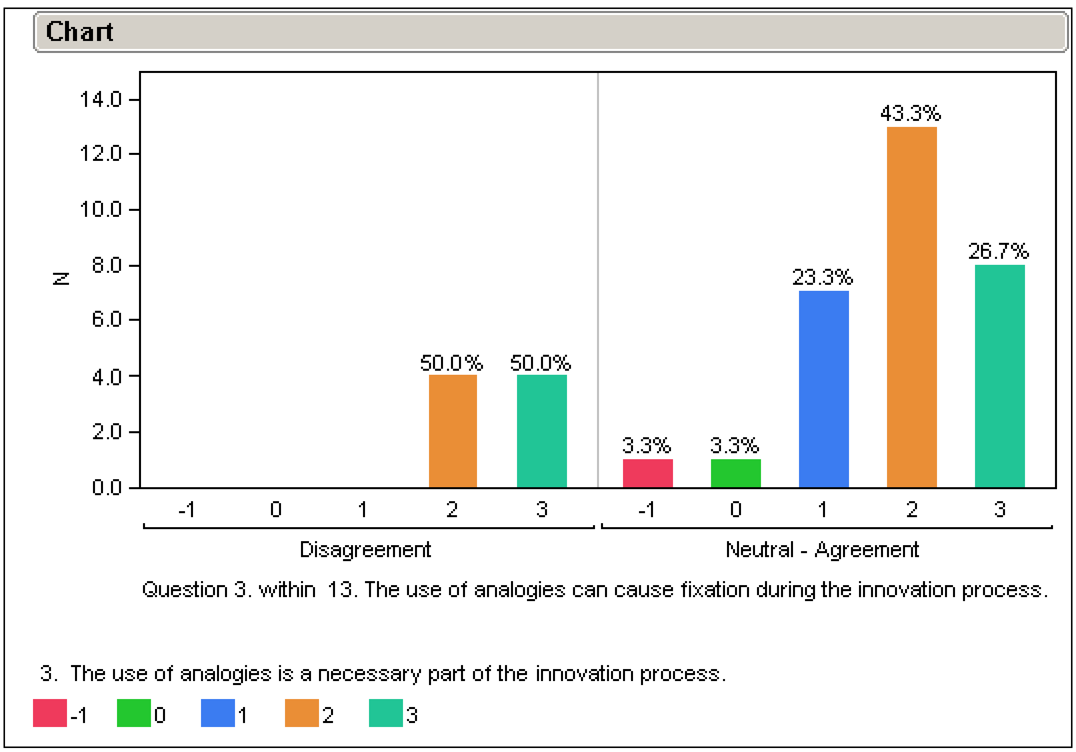

Figure 34: Question 3 results separated by answers to question 13. MatLab Results: pvalue_r = 0.0813, pvalue_t = 0.0236

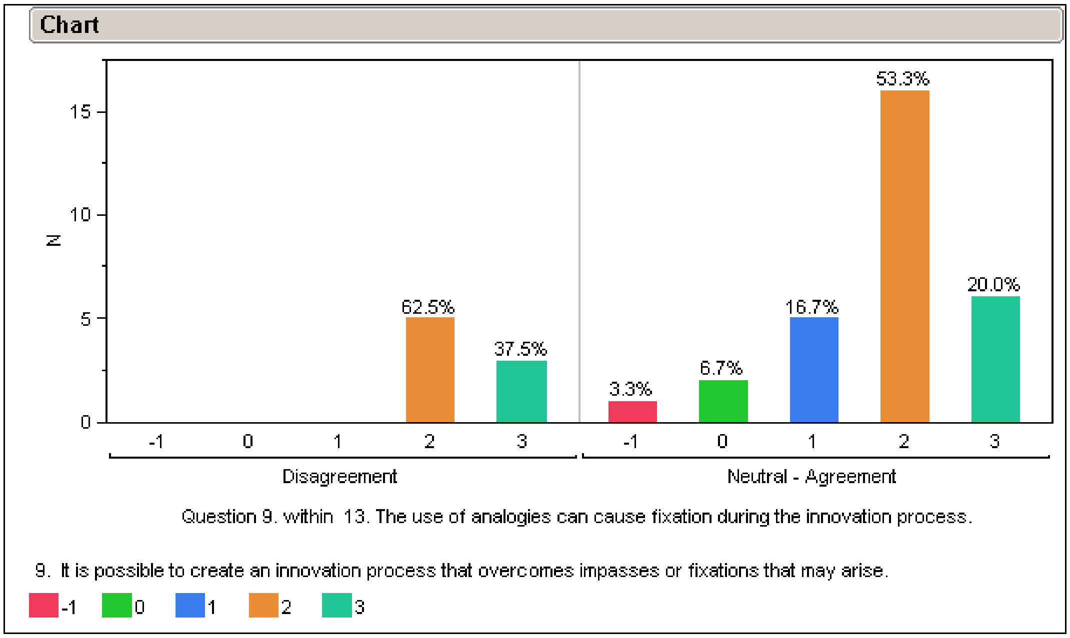

Figure 35: Question 9 results separated by answers to question 13. MatLab Results: pvalue_r = 0.1084, pvalue_t = 0.0338

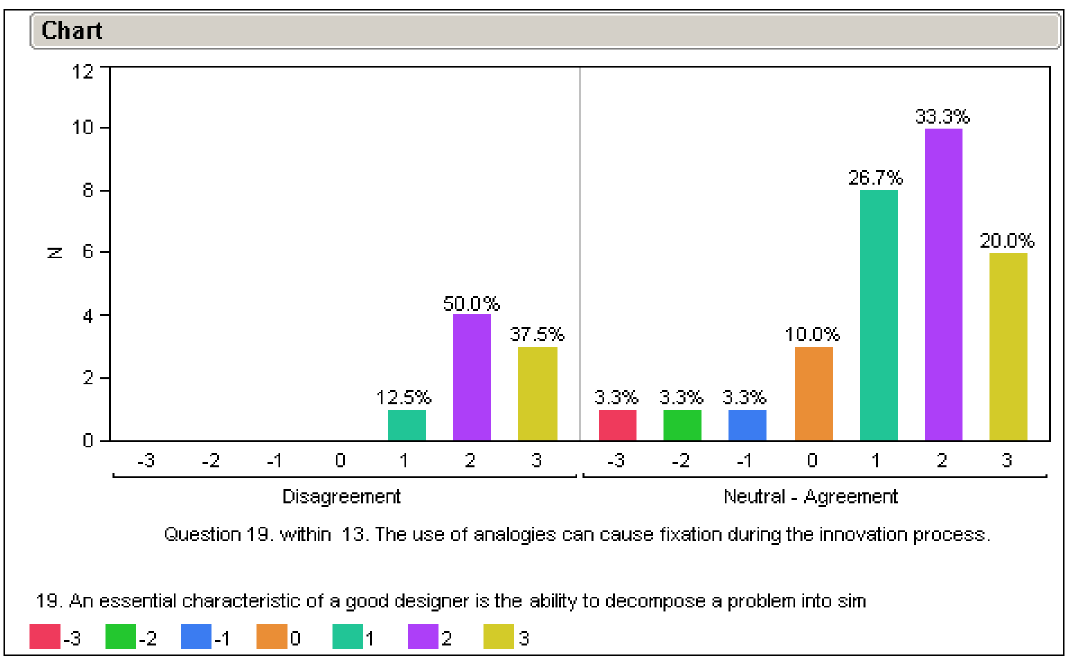

Figure 36: Question 19 results separated by answers to question 13. MatLab Results: pvalue_r = 0.0832, pvalue_t = 0.0195

The last correlation study extracted using the above method considers a group who are in agreement with Question 16 “The early stages of design should be considered as art not something that can be formalized or lends itself to formalization” compared to those who were not (Figures 37 and 38). This group is interesting in that they believe that early design efforts are not meant to be formalized. At the same time they believe that brainstorming and the use of analogies are necessary more so than the corresponding group who do not consider early stages of design as art. These two tools are either common place or becoming more so in design methodologies. This group of participants in agreement with question 16 are saying that processes should be used but not in the early stages of design. An interesting question here would be when do the early stages end and the idea generation steps (with brainstorming and analogies) begin.

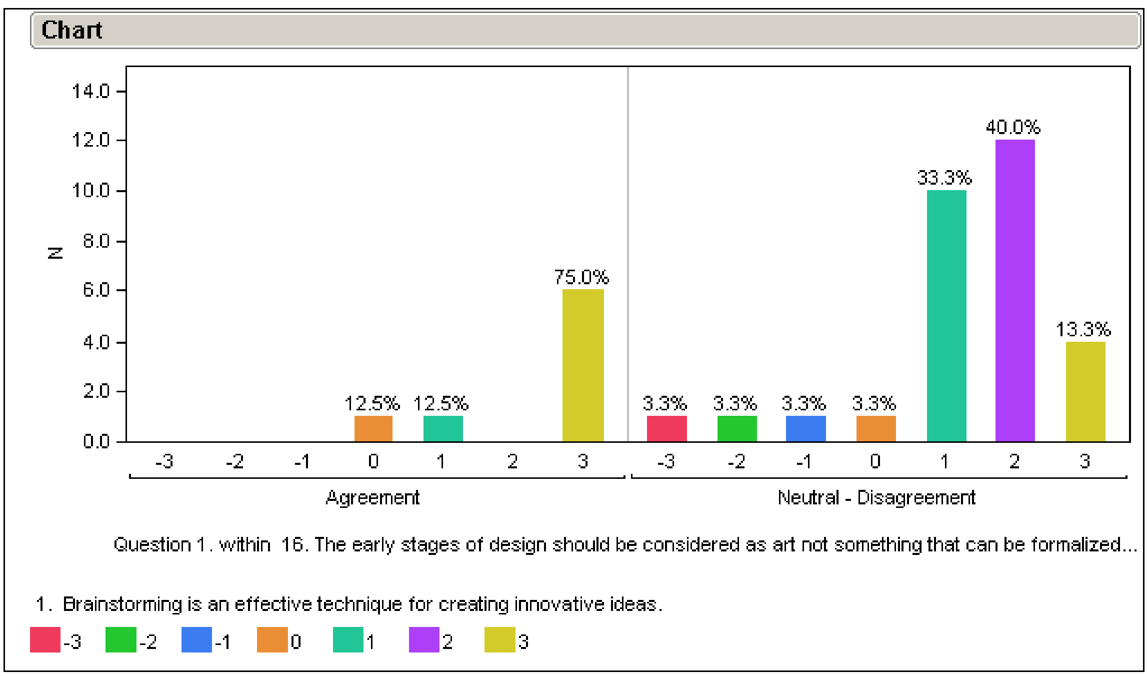

Figure 37: Question 1 results separated by answers to question 16. MatLab Results: pvalue_r = 0.0256, pvalue_t = 0.0537

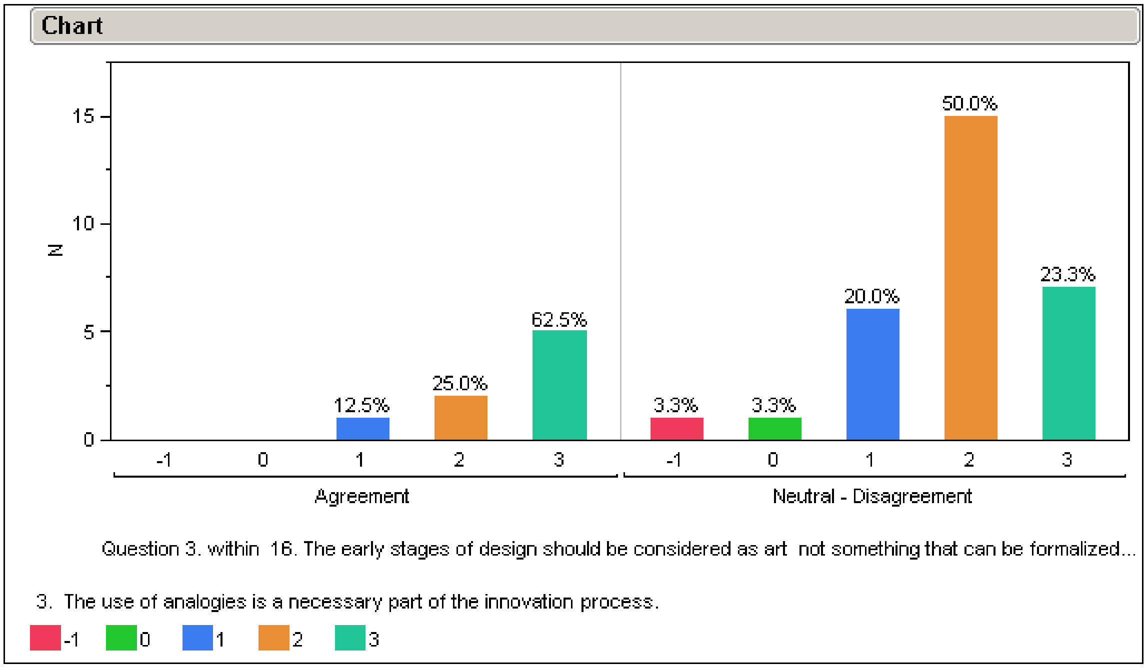

Figure 38: Question 3 results separated by answers to question 16. MatLab Results: pvalue_r = 0.0659, pvalue_t = 0.0667.

3.4: Hypothesis Study

The relationships between demographic groups and their responses to the technical questions are thoroughly analyzed through a number of derived hypotheses. The hypothesis study consists of 4 hypotheses based on expected or possible trends of the study. This approach provides a framework for analyzing the technical questions. The following is the list of hypotheses studied:

- Hypothesis 1: Inventors with patents will have a more polarized (strongly agree or strongly disagree) set of responses to the questions essential to innovation.
- Hypothesis 2: Groups of people who consult or have consulted on engineering projects have a more polarized understanding of innovation in engineering.
- Hypothesis 3: Men and women have fundamentally different views of aspects of innovation in engineering.

- Hypothesis 4: Those surveyed who are less than 40 years old will be more optimistic of innovation methods in general.

Groups of participants are segregated with each hypothesis based on the attributes of the participants. This approach allows for each group to be analyzed with respect to the technical questions. These results are compared again using the ranked sum and t-test statistical significance tests. Of these two tests the p-values were calculated and if either test showed significance at the p-value = 0.1 level we continued the analysis of that question.

3.4.1: Hypothesis 1

Hypothesis 1 proposes that there will be a quantifiably more polarized set of responses provided by participants who have been named inventors on patents. This hypothesis stems from the generalization that innovation is fundamental to patentable ideas. Therefore those who have developed patentable ideas should have a better understanding of what it takes to be innovative. Figure 39 shows the distribution of participants according to number of patents. The group of participants with patents was equal to those without so the comparable sub groups were equal.

Figure 40 shows the results from those participants with patents are agreeable to question 2 “It is possible to teach undergraduate students to be creative” when compared to those without. For Question 4, the participants’ responses of those with patents showed to be agreeable to “Creativity is positively correlated with grade point average” than those without patents. The group as a whole for Question 4 tends to disagree with the statement but 33.3% of those with patents believed that creativity is positively correlated with grade point average as compared to only 16.7% of those without patents. In addition to this result, those with patents had only 5.6% strongly disagree with the statement compared to 27.8% of those without. These two questions combined are interesting when summarized as: those with patents agree more often that creativity is positively correlated with GPA' and students can be trained to be more creative. These results suggest a need for a better training method for instilling creativity in students with a wonderful motivation being that the students GPA may also benefit.

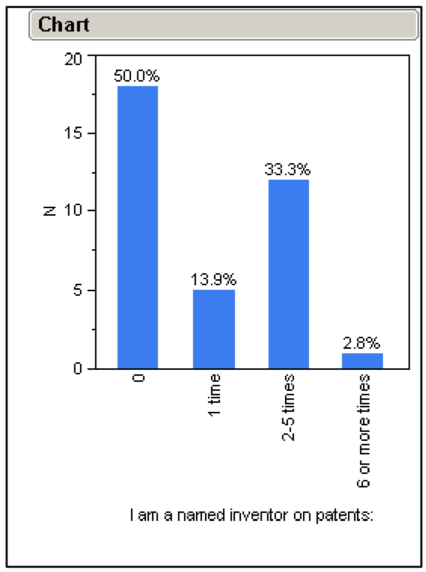

Figure 39: Participants with patents

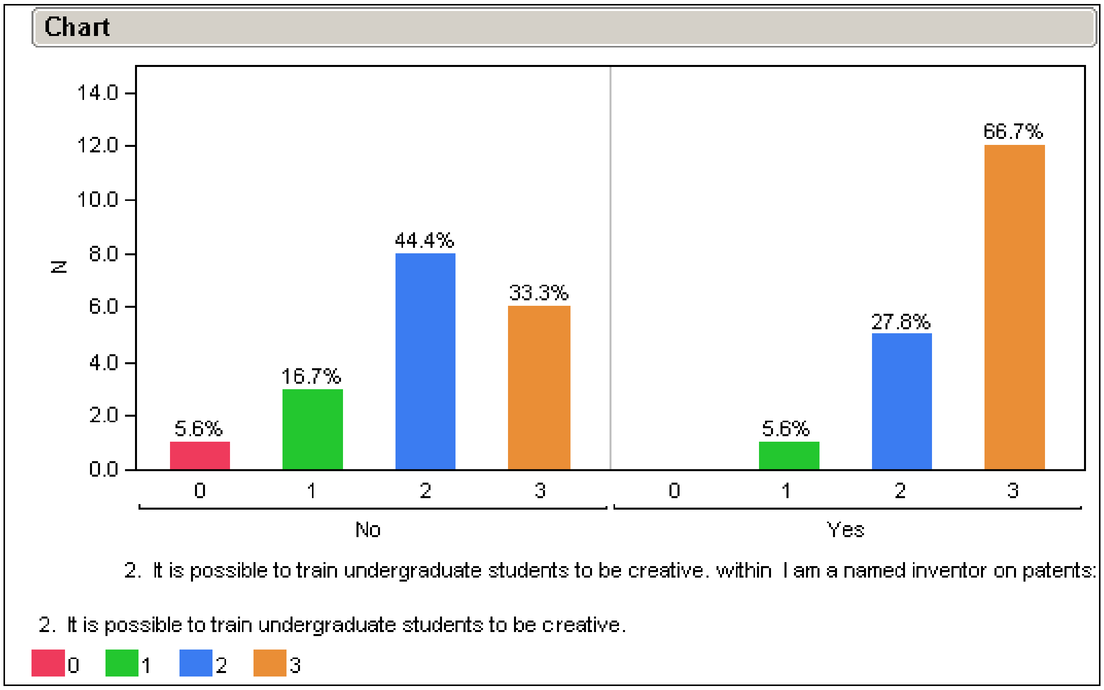

Figure 40: Question 2 results separated by those with and without patents: pvalue_r = 0.0369, pvalue_t = 0.0343

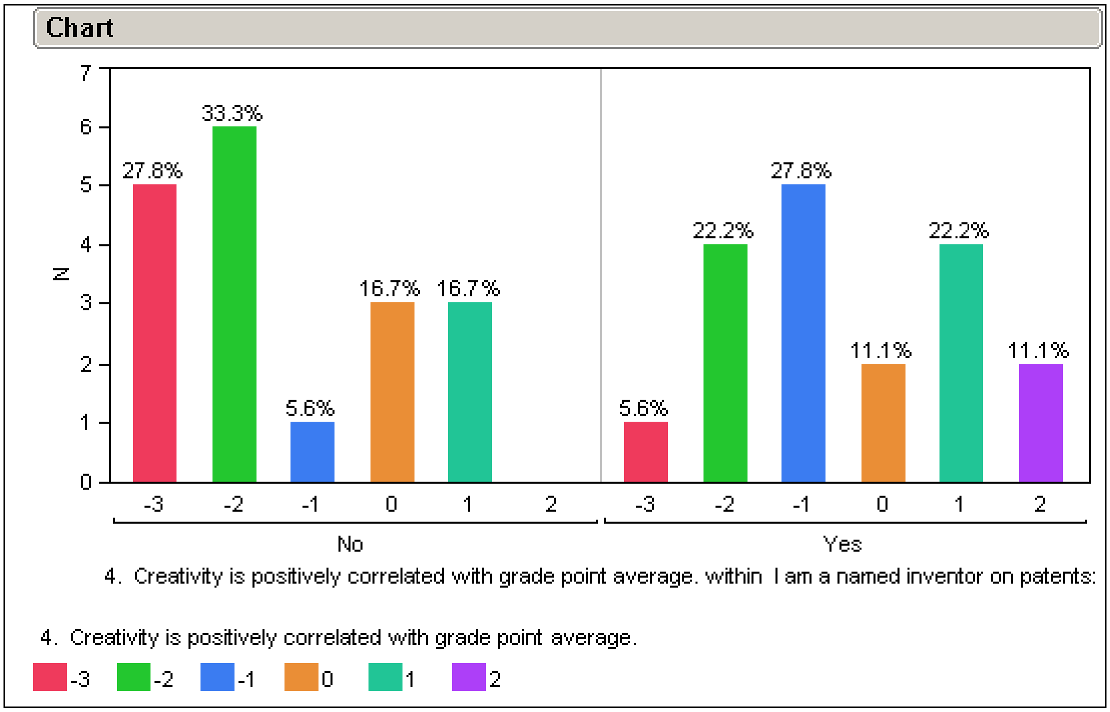

Figure 41: Question 4 results separated by those with and without patents: pvalue_r = 0.0589, pvalue_t = 0.0678

Continuing with Hypothesis 1, we move next to the last two questions based on results from the ranked sum and t-test methods. Those surveyed who had patents were more agreeable to Questions 6 and 19. These two questions share a position in the process/method category above with question 19 also contributing to the designer characteristics category. From this set of data, we see that those with patents are indeed more polarized in their responses to the questions that were deemed relevant through the statistical evaluation method above. Summarizing the findings here it is suggested that those with patents believe in these two processes more so than those without. This is an interesting result when attempting to motivate and encourage future innovation processes.

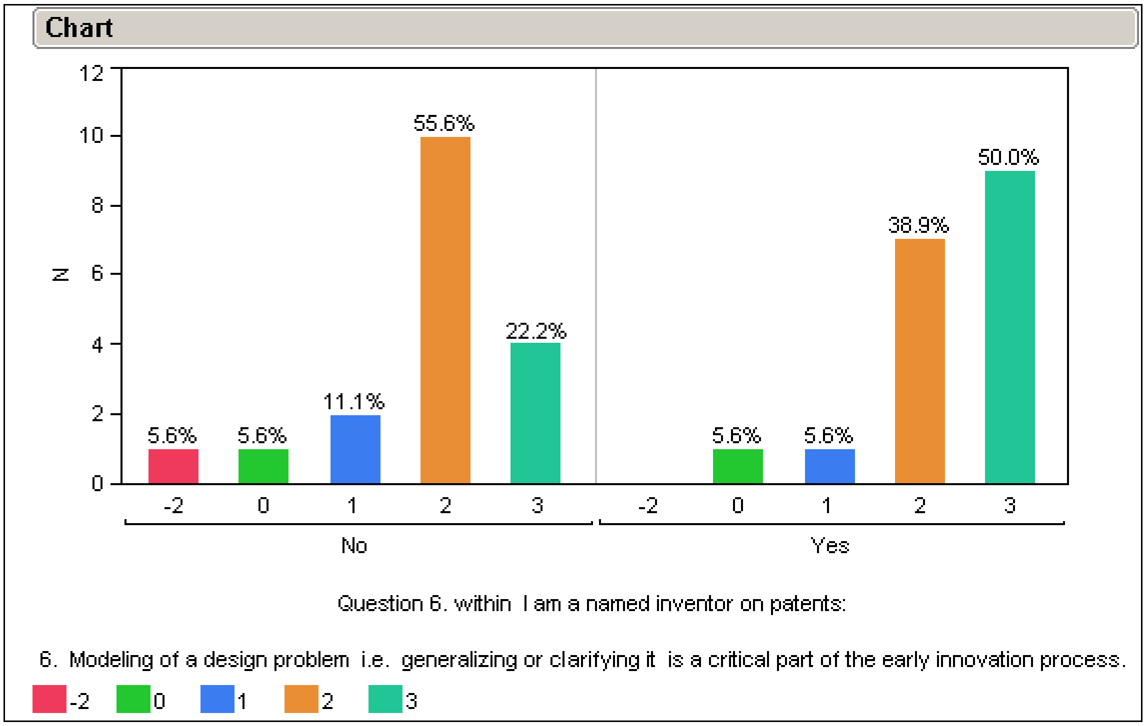

Figure 42: Question 6 results separated by those with and without patents: pvalue_r = 0.0922, pvalue_t = 0.1211

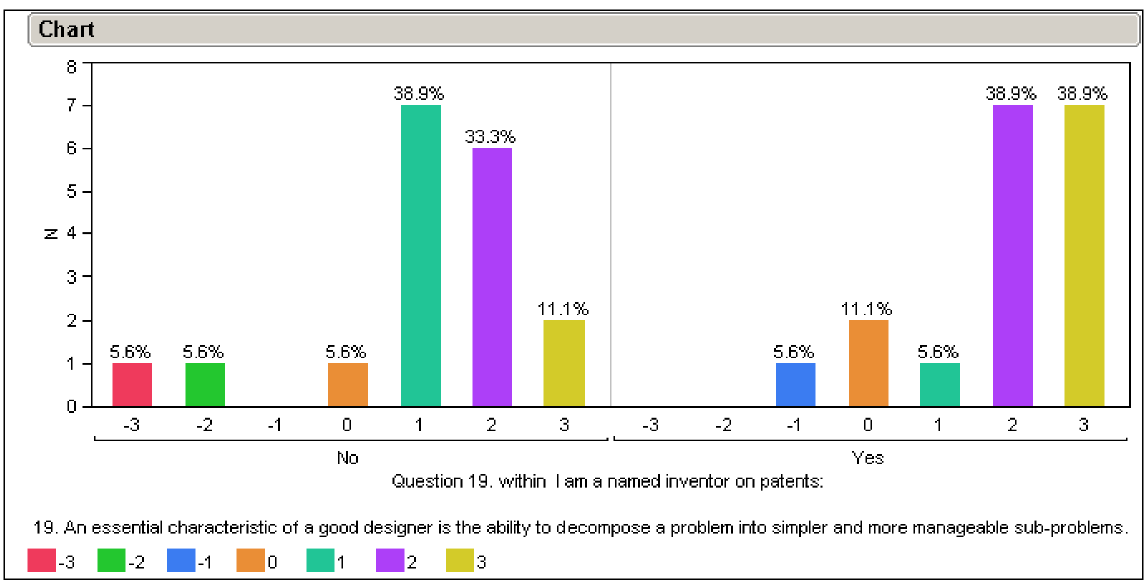

Figure 43: Question 19 results separated by those with and without patents: pvalue_r = 0.0449, pvalue_t = 0.0793

3.4.2: Hypothesis 2

Considering Hypothesis 2, we will evaluate whether those with experience consulting have a more polarized view of the technical questions. This hypothesis is again built upon a speculation that a deeper understanding of innovation processes is based on experience, as with Hypothesis 1. The basic idea is that for people to be able to consult on engineering design work, a level of innovative aptitude would be required. Consulting is often requested when fundamental innovation is required, as described in the introduction as the first attempt to carry out a new idea in practice.

Following the same guidelines discussed for Hypothesis 1, we find two questions that meet our statistical criteria, Questions 4 and 18. Question 4 results are very similar to the data found in the previous section when considering participants with patents. Those with consulting experience are much more agreeable with Question 4 “creativity is positively correlated with grade point average” than those without patents. The comparison (Figure 45) shows very similar data between the two participant groups until one looks at those that chose to agree with the statement. 36.4% of participants with consulting experience agreed with question 4 as compared to only 6.7% of those without. In conjunction with the data collected above on patents, this trend points to the need for creativity cultivation in the educational process.

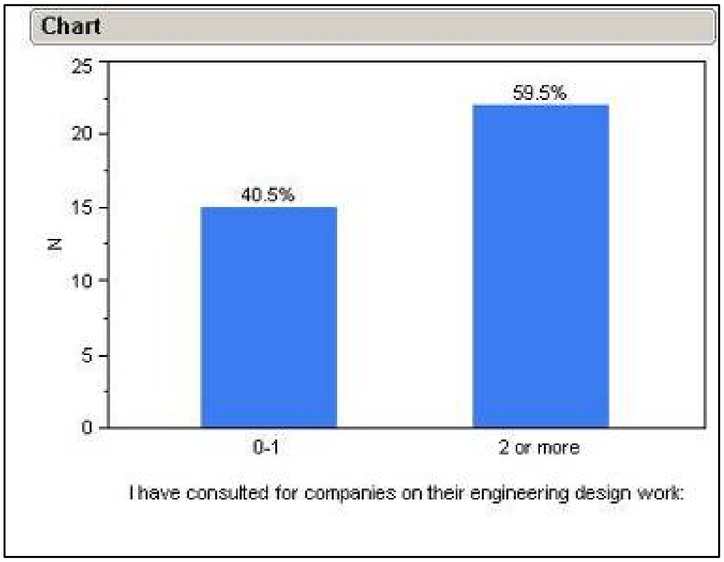

Figure 44: Subgroups created from demographic data on consulting experience.

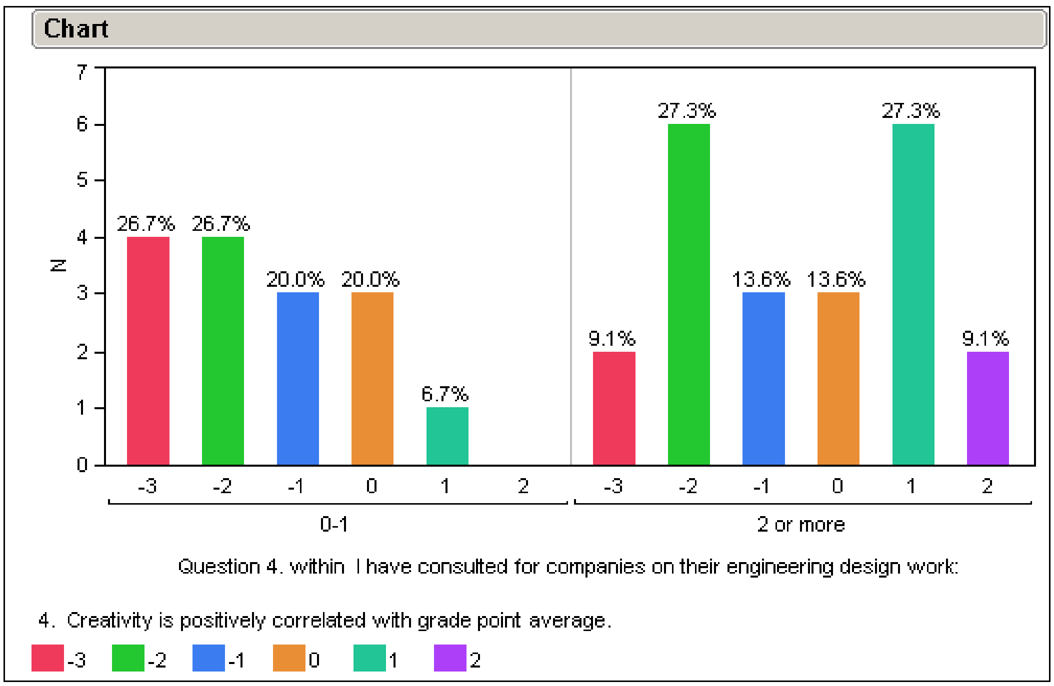

Figure 45: Question 4 results separated by consulting experience: pvalue_r = 0.0696, pvalue_t = 0.0513

The next set of results from this analysis focuses on Question 18 “Personality types or preferences have an impact on one’s ability to be creative.” Those with 2 or more experiences consulting are much more agreeable with this statement than those without this level of experience. In fact 86.3% of those with this experience had a level of agreement as compared to only 53.3% of those without. This is a good example of a more polarized result from the experience based sub-group of participants. Here we see that those with consulting experience show no disagreement with this statement and are entirely more agreeable than those without consulting experience. This shows that, to those with this experience, a critical component of creativity in engineering design is personality types. This may have profound insights into developing ever more advanced methodologies in engineering design as now personalities must be addressed.

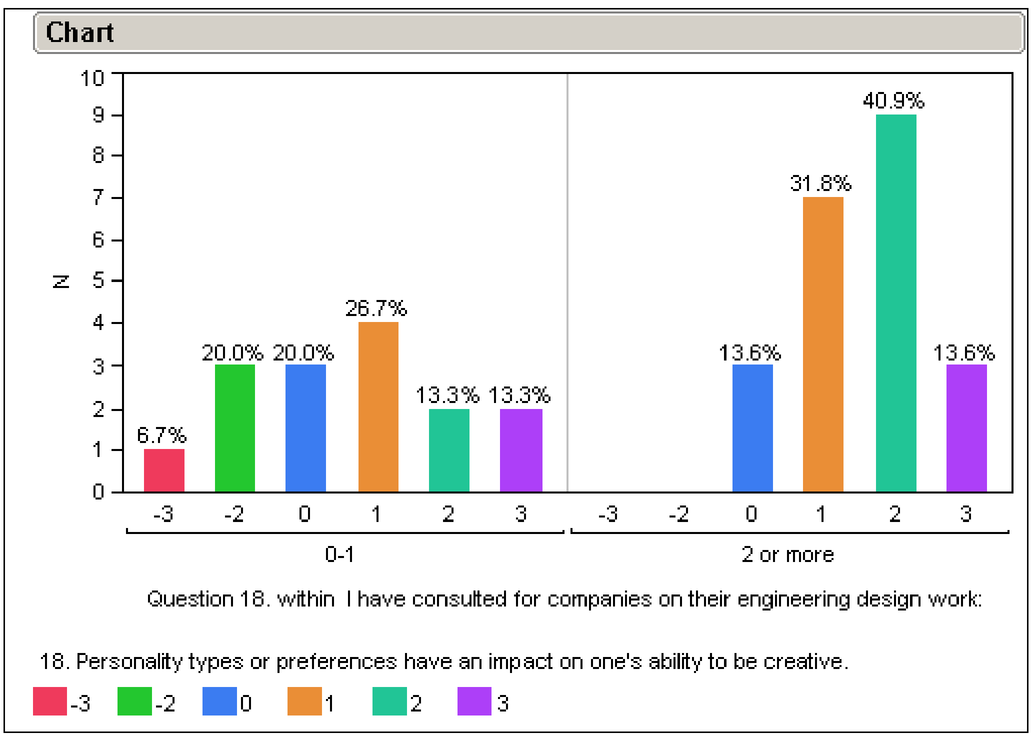

Figure 46: Question 18 results separated by consulting experience: pvalue_r = 0.0412, pvalue_t = 0.0318.

3.4.3: Hypothesis 3

In the third hypothesis the question is asked: is there a fundamental difference between how men and women view innovation? This hypothesis yielded the greatest number of technical questions which met our method requirements. As mentioned in the demographic section there was a good proportion of women participants in this study. From Figure 47, it is clear that a sufficient group exists for both genders.

The first key result derived from this hypothesis is shown from the analysis of educational questions 2, 9, and 16. Questions 2 and 9 results, illustrated in Figures 48 and 50, show a tendency of men to be more optimistic than women towards educational opportunities described in this survey. These figures show evidence that men had a more agreeable attitude towards creating an innovation process to overcome fixation and training undergraduate students to be more creative. The women's responses for these questions averaged between agree and somewhat agree while men averaged agree to strongly agree. Question 16 "The early stages of design should be considered as art not something that can be formalized or lends itself to formalization" shows another very interesting difference between men and women from the educational perspective. Shown in Figure 52, 56% of men are in disagreement while 91.6% of women's responses were in disagreement. This is interesting when considering that men had 28% of their responses in agreement. This seems to lead to an idea that with the male responses to the educational questions 2, and 9, a number of participants think that there exists useful methods but the early stages of design cannot use them and should be left un-formalized. When considering the "design as art" portion of this question, this subset of men may think that innate ability is required in the early stages of design. Women on the other hand with their very strong response show that early stages of design should not be considered as art and should lend itself to formalization. This coupled with their somewhat agreeable responses to educational questions 2, and 9, shows that women would like to see alternatives in the engineering design methods that they use.

Men showed to be more agreeable to an innovation process/method in Question 3 “The use of analogies is a necessary part of the innovation process” as shown in Figure 49. 48% of the men “Strongly Agreed” with this statement and none of the women did. This can be thought of first, in the same vein as the educational questions 2 and 9 when considering the need for processes/methods in any educational structure. Men as a whole seem more optimistic of the educational opportunities outlined in this research than women. If we next simply view this as a process/method the result points to the idea that women just do not find this tool as useful as men.

Question 14 next highlights what seems to be a significant difference between the genders perceptions. In Figure 51 it is shown that 40% of women agreed with the statement “The use of physical manipulables can impede innovation during idea generation” while 58% of men disagreed. These are large percentages especially when considering that 24% and 30% of men and women respectively were neutral for this question. This result may point to a key difference between the genders in the utility of physical manipulables.

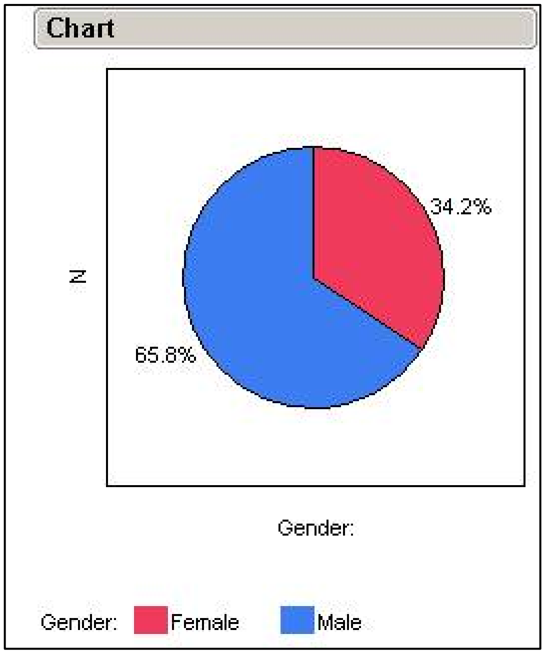

Figure 47: Pie chart of participant’s gender.

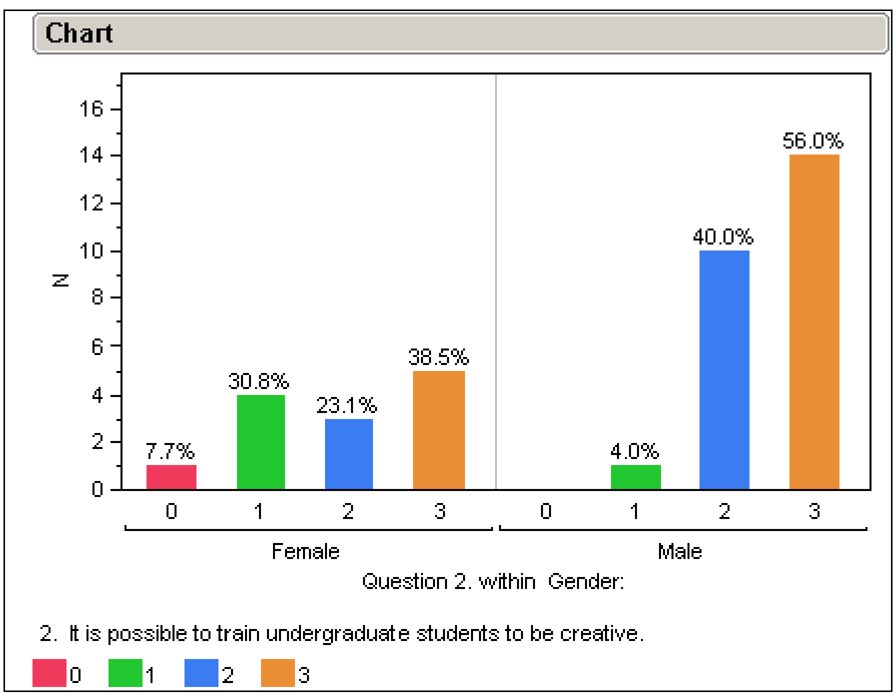

Figure 48: Question 2 results separated by gender: pvalue_r = 0.0796, pvalue_t = 0.0727

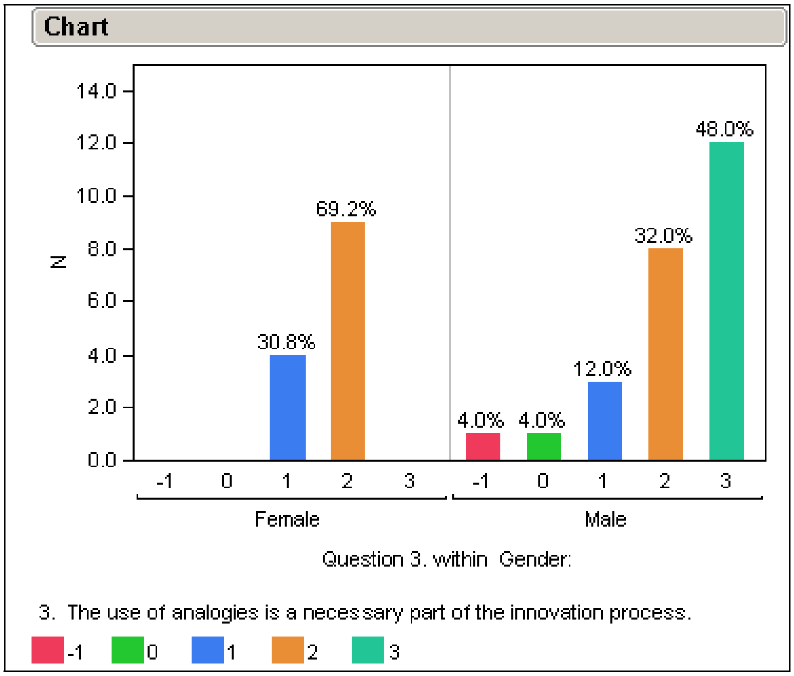

Figure 49: Question 3 results separated by gender: pvalue_r = 0.0274, pvalue_t = 0.0714

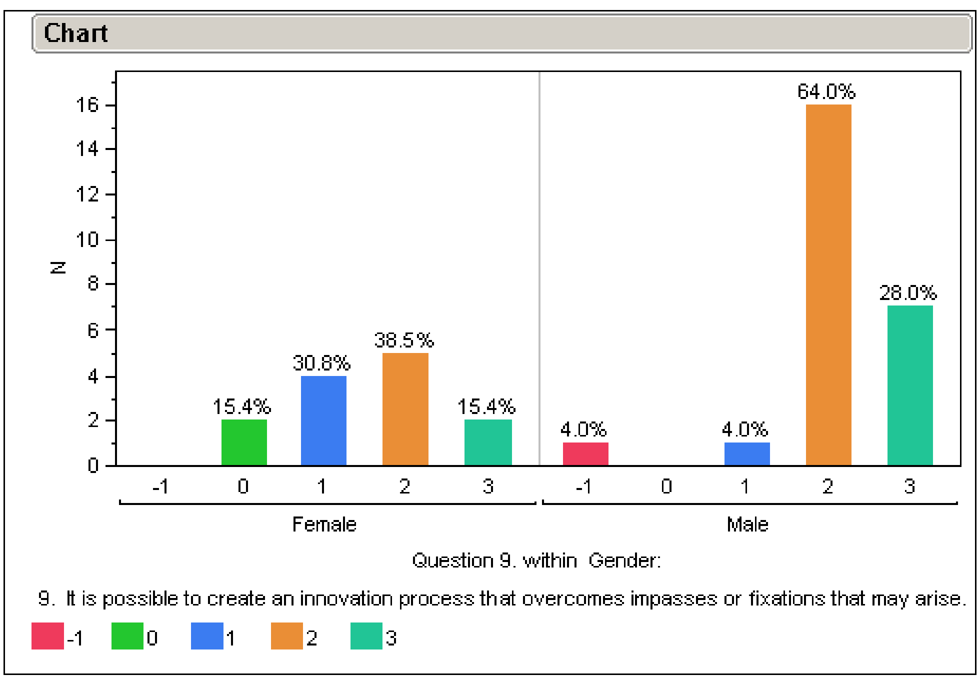

Figure 50: Question 9 results separated by gender: pvalue_r = 0.0377, pvalue_t = 0.0794

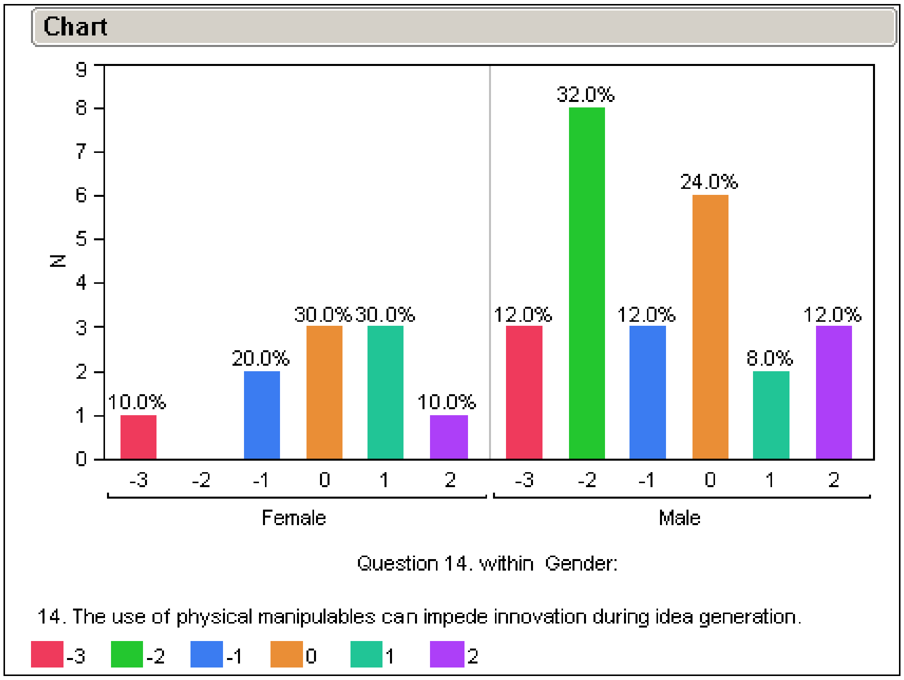

Figure 51: Question 14 results separated by gender: pvalue_r = 0.1012, pvalue_t = 0.0949

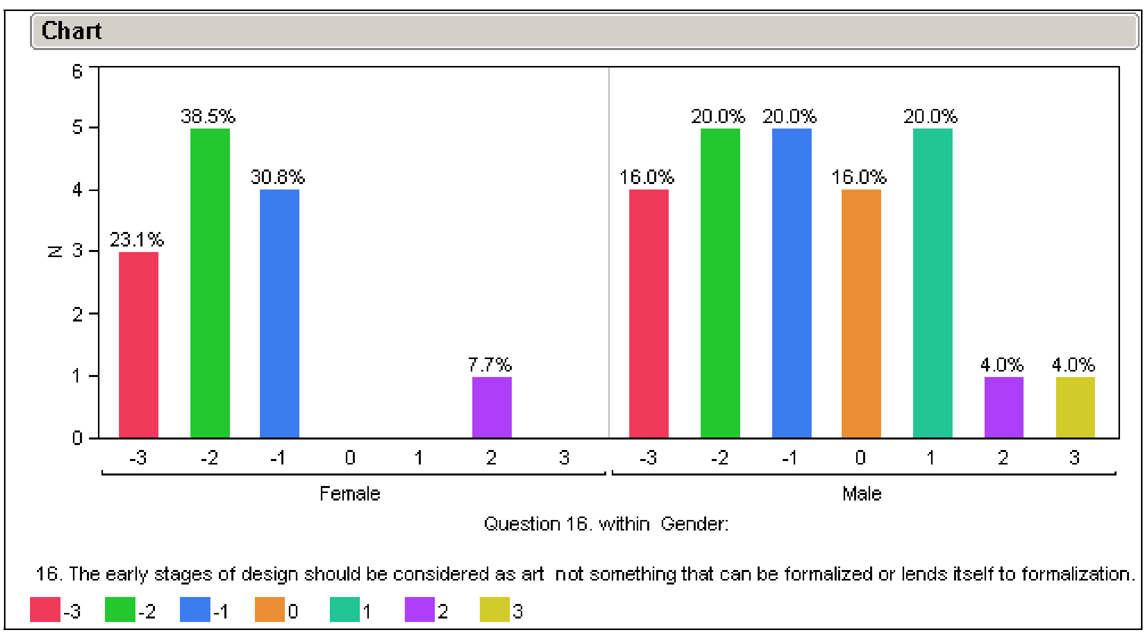

Figure 52: Question 16 results separated by gender: pvalue_r = 0.0898, pvalue_t = 0.0699.

3.4.4 Hypothesis 4

The last hypothesis is concerned with the age of the participants. It proposes that younger individuals will be more optimistic of innovation processes as a whole. Considering the demographic data provided in Figure 53, creating a separation at forty years of age gives a good set of groups to compare.

Four questions are found using our technical approach but with regards to the hypothesis there are two questions that tie in very directly. These include Questions 3 "The use of analogies is a necessary part of the innovation process" and Question 9 "It is possible to create an innovation process that overcomes impasses or fixations that may arise." Considering Figures 54 and 55, those over the age of 40 are more agreeable than the participants under the age of 40. This can be seen by the fact that 46.2% of participants over the age of 40 "strongly agreed" with question 3 while only 21.7% of those under the age of 40 did. This point shows those over the age of 40 being more optimistic about analogies and their use in engineering design. This must come from experience as the literature for these two groups should be the same. Again, in question 9 a key insight exists in the optimism of the responses. 38.4% of participants over the age of 40 "strongly agreed" as compared to 17.4% of those under 40. The experience gained by those over the age of 40 seems to be providing a level of optimism for overcoming impasses or fixation that was not seen in the previous experience based hypothesis. These results are also in direct opposition to the stated hypothesis. There may be interesting opportunities in determining what exactly is making those over the age of 40 more optimistic.

The last two questions that were found showed results that did not directly relate to the hypothesis but are interesting to look at. For question 16 (Figure 56) on the early stages of design as art, those over the age of 40 were very evenly distributed from “strongly disagree” to “strongly agree” with a very slight tendency towards “agree.” Those under the age of 40 are much more disagreeable to this statement. Seen in Figure 57, question 19 “An essential characteristic of a good designer is the ability to decompose a problem into simpler and more manageable sub-problems” showed those over 40 were much more agreeable than those under. This is in agreement with the other experience based analysis above providing again a proof that those with experience of various sorts agree that this is an essential characteristic.

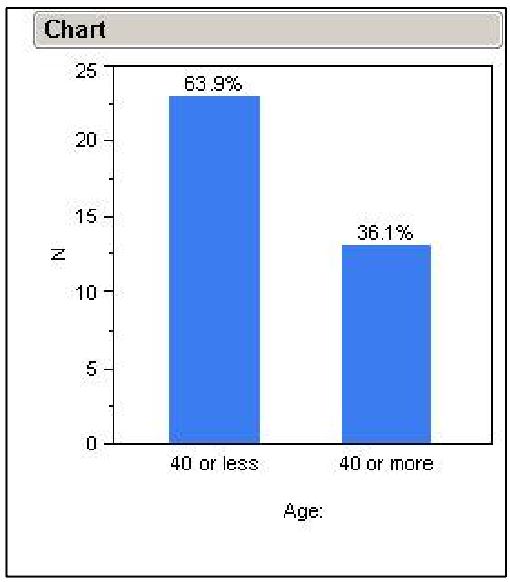

Figure 53: Participants separated into those above and below the age of 40.

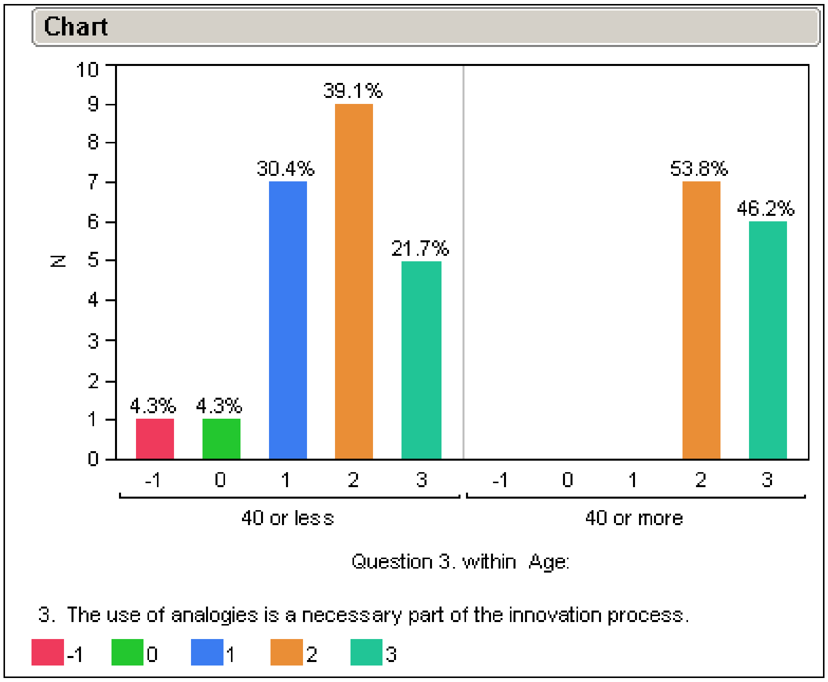

Figure 54: Question 3 results separated by age. pvalue_r = 0.0176, pvalue_t = 0.0053

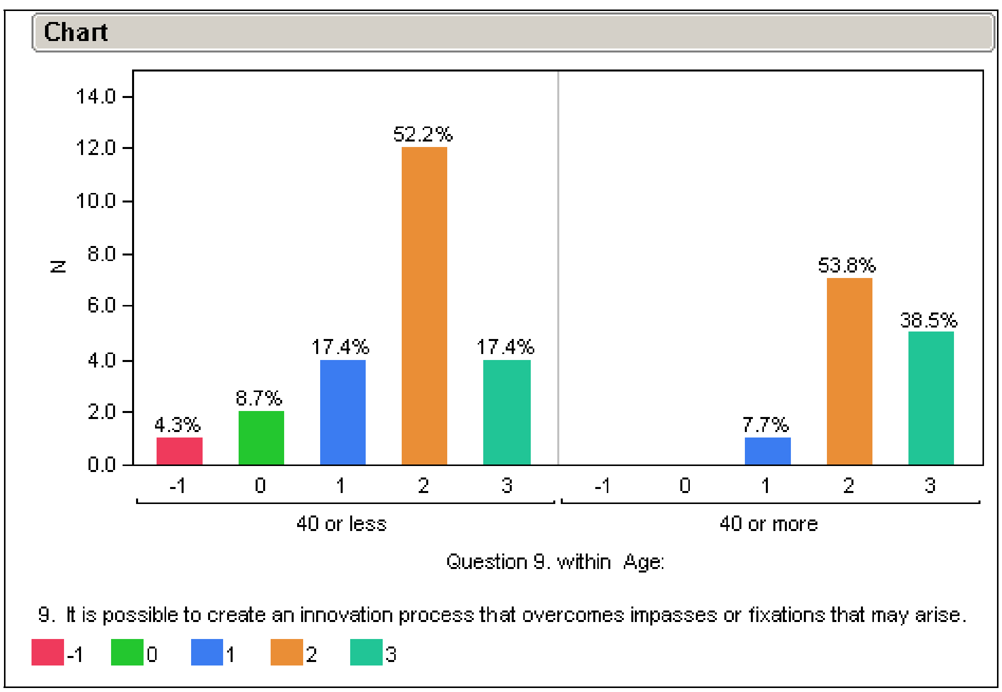

Figure 55: Question 9 results separated by age. pvalue_r = 0.0661, pvalue_t = 0.0330

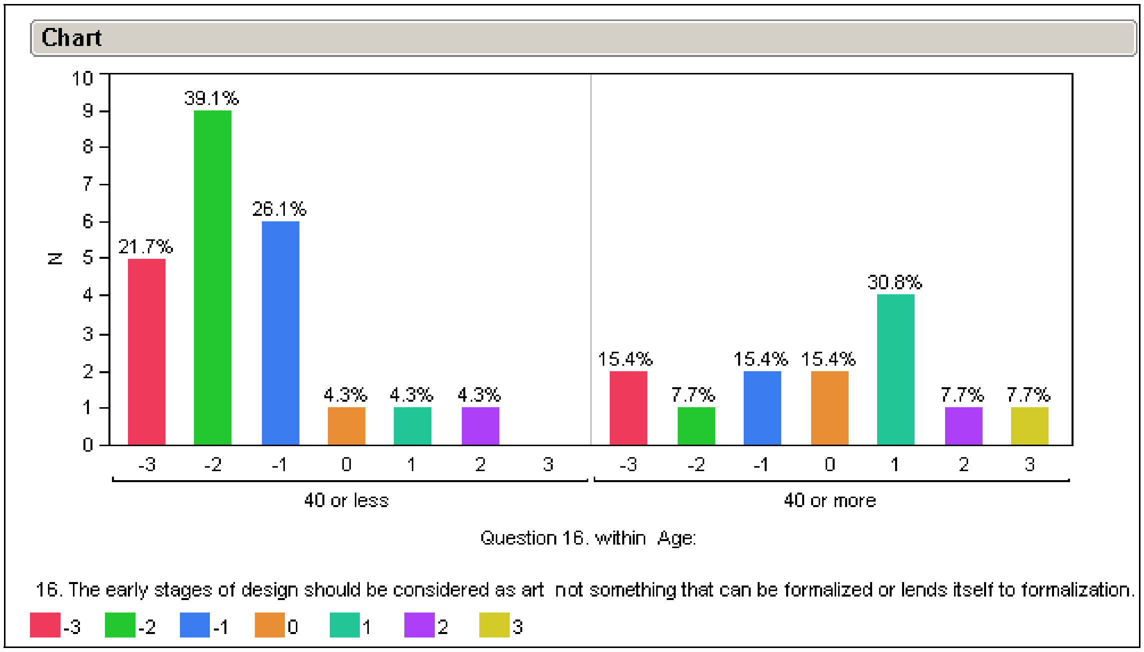

Figure 56: Question 16 results separated by age. pvalue_r = 0.0169, pvalue_t = 0.0186

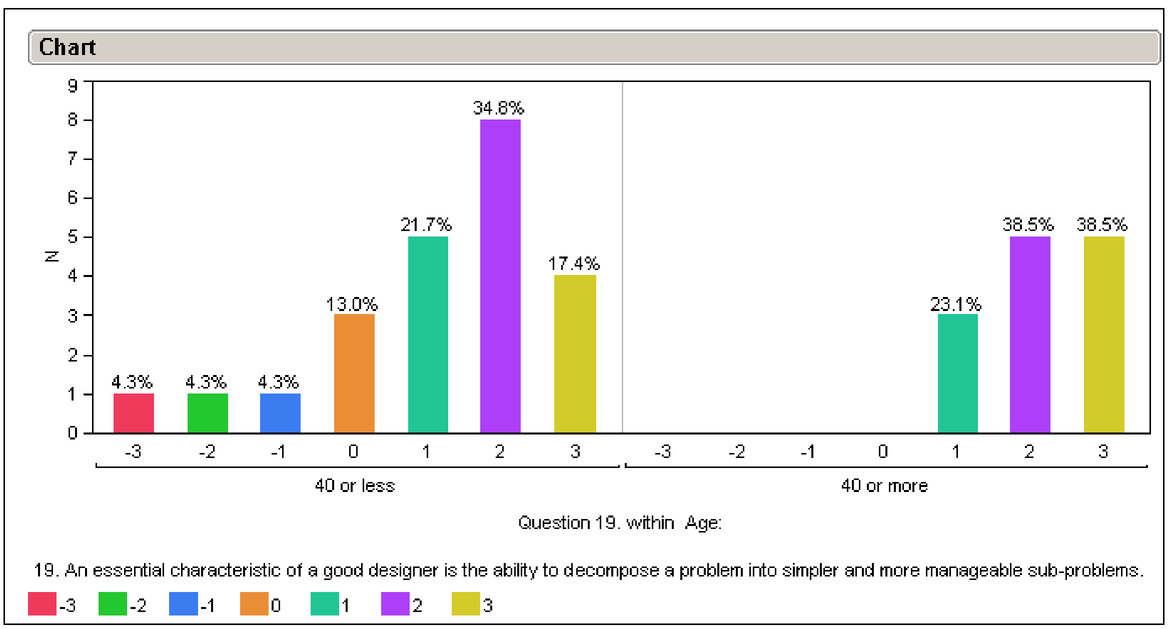

Figure 57: Question 19 results separated by age. pvalue_r = 0.0575, pvalue_t = 0.0192.

3.5: SHORT ANSWER QUALITATIVE STUDY

Building on the above survey analysis' we now look into the set of short answer questions that were posed in addition to the application each person submitted. With these statements, the applications and the analysis above, attempts may be made to better understand the cognitive landscape in engineering design. In the analysis of this data there is a need for a qualitative method which can be used to extract meaningful results. The final question in the survey section asked the participants to define a number of terms used in innovation research. The results [Appendix B] indicate that although there are commonalities in the language of innovation there are no universal definitions. The language around innovation is intriguing in that there is a notion of (in)ability about creativity or impasse in idea generation in engineering design to which most people adhere. Overall, the wide range of definitions provided by the participants shows the lack of common definitions in the innovation research field. Perhaps because of the dynamic and perplexing nature of innovation itself, this should be expected. Also, given the relative infancy and multidisciplinary character of the field, the evolution of the heuristics and definitions are at the foundation level that we expect this research to inform.

3.5.1: Innovative Terms

The first term that was given to the participants was "Creativity." From the method described above a number of interesting results were found for this term including 33% of the participants noting that creativity represented new, original or novel ideas. There are two aspects of this result that could be seen as interesting in developing a common language for engineering innovation. The first would be that the term "ideas" is coupled to creativity and the second being that those ideas are necessarily new, original or novel. A minimum of 13% of the participants additionally described creativity as a cognitive or mental process. A final component determined from the qualitative analysis was that a connection existed between the word “ability” and “creativity.” 60% of the participants used the word “ability” in their description of creativity.

The next term in the survey was “Impasse.” 25% of responses described this term as having to do with process/method. This is interesting considering that a fundamental definition of “Impasses” is not necessarily tied to a process. From the participants results it may be viewed as a failure of a process that the users are not guided past an impasse. The next result showed that 14% of the statements described a cognitive or mental process. Another key result includes 21% of the participant responses being associated with design teams. The final interesting outcome of this research on “Impasse” shows 35% of those surveyed used the word “inability” to describe impasse. This is in stark contrast to the responses to the term “Creativity” above.

The third term in the survey was “Fixation”. This term had roughly 27% of its responses using cognitive or mental processes to describe fixation. 24% of the participants used the word “inability” to define this term as well.

The final term provided to the participants was “Analogy.” A minimum of 26% of responses described this term as having “domain” specific characteristics. 43% of participants use the term “similarity” to describe “analogy.” This term also had 10% of the participants using cognitive or mental processes to describe “Analogy.”

3.5.2: Participants Topics of Interest

The participants were given the opportunity to provide short answers to describe the “The top three topics that interest me in the area of innovation or innovation processes are…” A number of interesting findings were gathered from the same method described above for extracting qualitative results.

Considering the first topic for each participant, we see interesting observations including 39% of the participants stating first, that they are interested in process/methods. This reinforces that fact that the participants are in fact scientists and are motivated to find ever more advanced means to engineering design. The second interesting observation from the first item from each participant was that 14% of the participants were interested in education, or teaching of innovation. This ties together well with the initial finding in that these scientists are largely educators as well with a real interest in advancing the tools used to educate students on how to innovate.

After looking at the first topics of interest for the participants it is next of interest to look at some of the global interests of the participants. When combining all of the participants three topics of interest we find that 14% of the statements show interest in design teams and how they can better innovate. It is interesting to note that so many participants specifically stated that helping design teams to better innovate was an interest. This may point out the importance of working in a team when participants show a high level of motivation to figure out how to better create and guide teams to be innovative. A few non-obvious results showed up when roughly 5% of participant's responses showed interest in metrics for innovation. In addition, another 5% of participants showed interest in computer aided innovation.

Chapter 4: Results and Interesting Findings

Through this research a number of interesting results have been obtained but many more opportunities lie in the groups that have been produced as well as the insights they provided. One prospect for further examination may include going back and interviewing the participants of this survey to learn more based on our initial insights. This may entail additional survey questions to explore deeper into the psyche of the participants. In addition, not all correlations produced significant results but did show interesting trends. These correlations would benefit from this more focused set of survey questions.

4.1: Results Table

In order to wrap up the results, a table has been created to encapsulate trends and raw data results. This table allows for the quick referencing of interesting information gathered through the analysis done in this paper. This table should allow for a quick reference for readers and may allow for determining areas of interest for future innovation research from the design engineering perspective. In addition to this table there were a number of interesting findings that would be worthy of summarizing for a more concise view of the work. Table 4 depicts three of the analysis methods provided in this work including the aggregate data, correlation, and hypothesis trends. Table 3 shows the legend of symbols used for describing the results in the table.

The aggregate column in Table 4 shows the average response for each of the technical questions. For the correlation and hypothesis columns, trends have been included based on the analysis above. The first interesting trends involved the correlations study which was done and is here consolidated into three main headings with one having to do with question 13. The first correlation shows those who disagreed to question 13 create a well developed agreement with question 3. This is followed up by the same being true for questions 9, and 19. The next sets of trends are based on the results of the hypothesis study. The four hypothesis' are represented and again the trends follow the legend in table 3.

Table 3: Legend of Trends for Table 4

++	Well Developed Agreement
--	Well Developed Disagreement
T	Interesting Trend

Table 4: Results Table with Aggregate, Correlation, and Hypothesis data.

		Aggregate Data Average	Correlations			Hypothesis			
	Question		Disagree Q13	Agree Q16	Taught 6X	1	2	3	4
Process/Methos	1	Agree		++					
	3	Agree	++	++				++	++
	6	Agree			++	++			
	7	Agree							
	11	Neutral							
	12	Somewhat Agree							
	13	Neutral							
	14	Somewhat Disagree						T	
	15	Somewhat Disagree							
	19	Somewhat Agree	++						++
	21	Neutral							
Designer Characteristics /Qualities	18	Somewhat Agree					++		
	19	Somewhat Agree	++			++			
	22	Somewhat Agree							
	23	Somewhat Agree							
Educational	2	Strongly Agree				++		++	
	4	Somewhat Disagree				T	--		
	5	Somewhat Agree							
	9	Agree	++					++	++
	16	Somewhat Disagree						--	--
	17	Neutral							
Design Teams	8	Disagree							
	10	Agree							
	20	Somewhat Agree							

4.2: INTERESTING FINDINGS

From the aggregate data a number of very interesting results were found including those from the process/method set of questions. Brainstorming as we discussed in section 2.1 is a very broad term relating to idea generation. In this survey, section 4.2.1, the participants showed that the fundamental concept of brainstorming is useful with result tendencies that agree with the proven ineffectiveness of Osborn's original method. In addition to this, question 12 also noted an attribute of Osborn's brainstorming (avoiding criticisms) to be a source of confusion in the survey with a "somewhat agree" average. These two results show us that a level of common understanding exists but that an effort is needed to distribute the newer methods and to start to create a common language among engineering design professionals.

Another set of interesting results involves question 13 regarding analogies. In this survey a number of results focused on this item in the process/method set of questions. In the aggregate analysis the average response was neutral which speaks to the diversity of viewpoints seen in this survey. This is also mirrored very interestingly in question 14. As seen in correlation study between questions 3 and 13, the use of analogies in innovation processes is essential but a divide is created when concerning how they would correlate to fixation. This motivates a method which could provide tools for innovation with fixation proof steps. The question 13 correlation studies show that those in disagreement with question 13 were much more agreeable to questions 9 and 19 than all others. This shows that of those who do not think that analogies cause fixation also completely agree that an essential characteristic of a good design is the ability to decompose a problem. In addition to this they completely agree that it is possible to create an innovation process that overcomes fixation. When thinking about design methods it is very easy to bring up the various methods, tools, processes, etc that go into creating innovative solutions.

The next interesting results noted in this analysis involved the educational questions. It is shown that questions 2 and 9 have very positive results. First with question 2, was the ability to train undergraduates to be creative. Second, we saw that the participants agreed that it would be possible to create an innovation process that overcomes fixation (question 9). The optimism may be based on a number of factors but the bottom line is trends show more work going in this direction and the participants in this survey seem confident.

Another area of substance had to do with design teams and included questions 10, and 20. Participants were agreeable in regards to creation of environments for facilitating innovation, and including teams in the innovation process. These are interesting and intuitive responses that provide an avenue for research considering the current lack thereof.

The correlation study method provided insights that were not fundamental to the raw data and so afforded some interesting trends. When we look at question 6 on modeling of a design problem as it correlates to teaching experience we see the first signs of experience providing deeper insight into the raw data. For this question those who had taught 6 or more classes were more agreeable about question 6 then those with less experience than this. This was critical in providing a push to look further into experience based responses to questions. This result by itself is of interest and may point to the need for mentorship in the education sector to bring younger professors up to speed quicker.

Another correlation result of interest had to do with a relationship between question 22 and 9. The results illustrate a portion of participants who think that high levels of creativity are not necessary and at the same time it is possible to overcome fixation. Again, this group of participants seems to believe that a large range of creative people can be innovative with the correct process.

The hypotheses were a wonderful resource for extracting deeper meaning from the data. The first hypothesis brought up the idea that those with patents have a better understanding of what it takes to be innovative. In the evaluation of questions 6, and 19 we see a hint of this being true. In both questions a process/method is evaluated, and in both cases those with patents are more agreeable then those without. This is a very interesting finding with an essential proof to the usefulness of these tools in practice.

In the second hypothesis another experience based question is asked, this time based on the number of times that the participants have consulted in the past. These participants showed significantly more agreement with question 18 regarding personality types and creativity. This is also interesting when compared to hypothesis one considering they are both experience based. The difference may lie in the specifics of what it takes to create IP versus products.

An interesting result from hypothesis 3 was in the apparent difference between men and women's opinion on the early stages of design being considered as art. The responses by women suggested that they prefer the early stages of design be formalized. This result from hypothesis 3 points to a fruitful opportunity for gender specific research.

The final hypothesis study proved to have a very interesting result as well. Those participants over the age of 40 provided responses that depicted this group to be more agreeable with questions 3, and 9 regarding analogies, and overcoming fixation respectively. Again, this is in opposition to the hypothesis but more importantly is a realization that the younger participants had a hint of pessimism and may need more mentoring.

4.3: USING WHAT WE HAVE LEARNED

Given some of what we have learned in this study it would now be of interest to employ this feedback into a practical method. One of the most reoccurring themes found in this work has been the fact that innovation needs a dynamic method to be fully helpful for the broad spectrum of users. Whether the user feels that formalization in the early stages of design is necessary or not a method should take this into account and adapt for that user. This method should also be able to utilize the components that the participants from this survey noted as beneficial. Analogies were strongly displayed in the survey results as a necessary part of a design methodology along with brainstorming, or what we will call here idea generation. The design for transformation method is one such tool for guiding the user to better innovations with various idea generation possibilities as well as the use of analogies [29, 40]. Granted, this method is focused on the aspect of engineering design which has to do with multiple state systems but there are key details which directly link to the results of this survey analysis. The fact is, we are only starting to understand the broad needs of users in engineering design innovation and current methods will need to be evolved, along with new methods generated to create a more universal approach.

To explain the transformer design method we will first look at the definition of transformer, and then the principles and facilitators which are the core of the theory. A transformer is defined as "a system that exhibits a state change in order to facilitate a new functionality or enhance an existing functionality." A transformation principle is a generalized directive utilized to create transformation, and when embodied can singly create a transformation. A transformation facilitator is a design aid for creating mechanical transformation but their implementation does not solely create transformation. This hierarchy can be seen in Table 5 below with examples of the higher level principles. These examples can be viewed as analogies to guide the user to new solutions but more directly teach the user of the heuristics of this theory [40]. A wonderful result of this research provides analogies from the mechanical engineering domain as well as the biological domain as illustrated by the flying squirrel in the "expand/collapse" image in Table 5, which can allow for motivation without fixation.

Table 5: Transformation Principles and Facilitators.

<table>
<tr><th colspan="6">Principles</th></tr>
<tr><td colspan="2">Expand/Collapse
 [37]</td><td colspan="2">Expose/Cover
 [38]</td><td colspan="2">Fuse/Divide
 [39
]</td></tr>
<tr><th colspan="6">Facilitators</th></tr>
<tr><td>Conform with Structural Interface</td><td>Flip</td><td>Interchange Working Organ</td><td>Roll/Wrap/Coil</td><td>Share Power Transmissio n</td><td>Utilize Composites</td></tr>
<tr><td>Enclose</td><td>Furcate</td><td>Modularize</td><td>Share Core Structure</td><td>Shell</td><td>Utilize Generic Connections</td></tr>
<tr><td>Fan</td><td>Inflate</td><td>Nest</td><td>Share Functions</td><td>Telescope</td><td></td></tr>
</table>

In order to utilize the tools of transformational design a number of methods have been created and altered [40]. In order to better meet the adaptable requirement recognized from the above research it is necessary to have the idea generation tool be adaptable for the user. One such method for utilizing this theory provides for idea generation through the use of a Mind Map [13, 29]. This method starts with the objective stated and placed to create the center, or base, of the map. The principles then branch off of this base to initiate the idea generation. The next step is to utilize the facilitators to expand on concepts which can ultimately be embodied by the designer.

This tool opens up many opportunities for the user to modify the method to meet their own needs. . One such example is in the ability of the user to traverse back and forth along the tree. This, along with the transformer principles and facilitators will automatically open the user's eyes to specific embodiments and then snap the user back to entirely different solution options. In addition, the shear number and diversity of facilitators work to obstruct fixation as the volume of facilitators are rather different from one another.

Chapter 5: Conclusions and Next Steps

Through this experiment we have begun to layout the current state of engineering innovation and observe the fundamental impact innovation has on fixation through the use of a survey of domain professionals in the field. A wide variety of analysis methods were used to extract meaningful results including current trends in innovation and areas of interest in the engineering design innovation arena. This was a fundamental step of creating a baseline of current beliefs in engineering innovation. This baseline will allow for the advancement of innovation in engineering as a science through a variety of channels. These may include a more common set of topics and terms to work from as well as key relationships tying those components of innovation together.

To continue on in an endeavor to fully understand this field it may be useful to gather responses from participants in this study on what they think of the current analysis. This may serve as a proof in some regards concerning individual responses. In addition insights may be gleaned from these interactions about how to best take action with these results considering that the participants themselves may be leaders in specific fields described in this work.

Fundamental to this papers research is the distribution of literature to the professionals, educators, engineers, and scientists that utilize, teach and experiment with innovation tools. This work has served to frame a portion of this literature and research as well as open up avenues for advancement. In addition, this work may also serve to motivate interdisciplinary communication to drive engineering design further. This may first be accomplished by some of the steps taken here to refine the language used in industry.

Additionally, a first step has been made to alter a design method based on feedback from this survey. This work shows that there are many components that exist in modern design methodologies that are shown in this survey to be useful but aspects of them must change as a more global understanding of the needs of designers is realized.

Appendix A

Question Organization:
Process or Method Questions in Red
Designer Characteristics/Qualities Questions in Green
Educational Questions in Blue
Design teams and in situ Environment Questions in Black

Questions:
Brainstorming is an effective technique for creating innovative ideas.
It is possible to train undergraduate students to be creative.
The use of analogies is a necessary part of the innovation process.
Creativity is positively correlated with grade point average.
Undergraduate engineering programs inhibit creativity and innovation as the students proceed in the program.
Modeling of a design problem i.e. generalizing or clarifying it is a critical part of the early innovation process.
Designers / people become blocked (fixated) on particular solutions depending on how a problem is stated.
The presence of people from outside disciplines during ideation can hinder the ideation process.
It is possible to create an innovation process that overcomes impasses or fixations that may arise.
The physical design environment is critical to assist and empower innovation.
During idea generation all constraints should be suspended.
During idea generation all negatives or criticisms should be avoided.
The use of analogies can cause fixation during the innovation process.
The use of physical manipulables can impede innovation during idea generation.
The use of pictures of objects can impede innovation during idea generation.
The early stages of design should be considered as art not something that can be formalized or lends itself to formalization.
K-12 students exhibit a higher degree of creativity than higher education students.
Personality types or preferences have an impact on one's ability to be creative.
An essential characteristic of a good designer is the ability to decompose a problem into simpler and more manageable sub-problems.
Design teams can be more effective than individuals at creating innovation.
Every design problem requires a different solution method as applied by a designer or design team.
Innovative design outcomes depend upon the input of very creative individuals.
Innovative design outcomes depend upon the input of very open/creative individuals.

Appendix B

Survey Question: 26. Define the following terms relative to the design process…	
Response Category	***Participant Responses***
26-a. Creativity (N=28)	The term creativity, when used to describe an attribute of a person's work such as an engineering design or a drawing or an essay, usually indicates that it possesses both novelty and fitness for purpose. No matter how well suited a solution is for a purpose, if it is taken directly from past experience, it is generally not considered to be creative. Also, if a person is being different for the sake of being different, people will generally refrain from describing their work as creative.
	Ability to make new things or processes.
	It is very important in idea generation process. Many skills of creativity can be taught.
	Potential to come up with new idea or solution to design problem.
	The ability to find useful and effective solutions for design problems.
	Ability to generate ideas
	Creativity is a cognitive ability that assists designers in deriving solutions to new problems.
	the ability to generate concepts to resolve a particular design problem. the ability to re-frame a particular design problem and see it in a new perspective.
	ingenuity, flexible inventiveness, and clever imagination PS: I did not answer your last questions becuase non of the choices fit. My answer for all would be sufficient motivation/desire
	The ability to generate a variety of solutions to a problem where the variety has characteristics of quantity and quality and also contains uncommon aspects.
	Creativity is a process and an outcome--the development of something novel. It can be measured in terms of fluency (coming up with many ideas), flexibility (identifying ideas from multiple disciplines), and originality (new ideas). Other proposed metrics include the ability to elaborate an idea to a detailed level and usefulness.
	Seeing things in a new way - Looking at the same thing as everyone else, but seeing something different
	Ability to combine ideas and generate solutions
	With regard to design, creativity is one's ability to transform one's personal experiences into ideas for *new* methods, products, approaches, etc. for a given problem.
	Ability to generate unexpected solutions to problems. May also refer to thinking process and mental models - creative individuals may follow design

	processes that are unorthodox in order to arrive at novel solutions.
	flexibility in design
	Relating what has not been, or the not obvious to the problem at hand.
	the ability to synthesize own knowledge and generate both new concepts and new solutions
	The generation of ideas that are both novel and useful
	The ability of human beings to use their imaginations in order to create a solution to a functional problem, or to create an aesthetic effect.
	Bringing new perspective that was non-existent.
	The ability to provide a variety of candidate solutions to a design problem.
	is the process of searching the design space, whether feasible or infeasible, regardless of whether the area being searched has ever been considered previously or not.
	Ability to come up with original ideas.
	The ability to create a broad variety of potentially viable solutions to a problem.
	I view creativity as the ability to generate new ideas in the design process and to think out of the box.
	No constraints in thinking process
	performing the process in a manner that is new to the participant . I prefer to encourage students to think of creativity as a path defined by the individual
	Creativity is the ability to recognize the need and articulate the problem faced by either the designer or the end-user and create the artifact that satisfies the need.

Survey Question: 26. Define the following terms relative to the design process…	
Response Category	***Participant Responses***
26-b. Impasse (N=26)	An impasse generally describes an inability to move farther after some degree of progress has already been made. I'm accustomed to seeing the word in the context of negotiation. The term could be used for a more specific phenomenon in creative work, but I haven't seen the term used this way.
	Not being able to solve or go around a particular problem in the process design.
	Mental blockage during design problem. No solution to come up with.
	Unable to think of ideas to solve the problem.
	A block to creativity
	Impasse is the inability of a design team to reach agreement on a design

	solution.
	a state of frustration and inaction that exists at any point of time in pursuit of a design solution. its a state of not knowing what to do next.
	team cannot agree and progress devolves
	A place in a problem solving process where no further progress is being made toward a solution.
	Impasse is the inability to complete a task--such as solving a problem or generating a creative idea.
	An impasse is either a great way to cross off one of the design alternatives or a motivation for more work, discussion, information gathering or opportunity for innovation.
	Point of saturation where the mind cannot produce further ideas at that moment.
	A deadlock in the design process that may occur from a team or design conflict. To progress past an impasse, the designer(s) must first backtrack on the previous design actions and find an alternative course of action to follow.
	When two or more members of a design team cannot agree. Can result in conflict.
	problem I do not have the right tools or training to solve
	the situation when no solution can be found which usually is caused by disagreement on the interpreted constraints or requirements
	A point at which the creative process has stopped - new ideas are not formulated and it is not clear what direction to proceed.
	A standoff, or inability to make a decision. Sometimes caused by analysis paralysis when design teams are so consumed by analysis that they are unable to commit to a solution and begin to build it instead of sinking more time into their engineering model. Also can be caused by group conflict, when members of a design team have fundamentally differing perspectives on how to solve the problem-at-hand and are unable to agree on a common way forward.
	If removed, the design goal may not be achieved, or constraints may be violated.
	A situation in which the design team can't proceed (e.g., no more ideas, fighting over the best way to proceed, etc.)
	is when resolution can not be found, often due to disagreements between team members or the inability to thoroughly search the design space (see Creativity).
	Inability to resolve a conflict. In the context of the design process, the conflict would involve not meeting requirements, conflicting constraints, or incompatible ideas.
	A mental wall ... usually temporary or resolvable.
	a situation where a stumbling block has been reached and an opportunity for creative ideas to move forward.

	stuck
	A condition in which one (or more) indivdiual(s) are unable to find (or agree on) a following step in a process that will lead in the desired direction
	Impasse is a block/deadlock in the process of creating an artifact/product due to the inability to resolve conflicts between competing requirements.

Survey Question: 26. Define the following terms relative to the design process…	
Response Category	***Participant Responses***
26-c. Fixation (N=27)	I'll rely on Steve Smith here sine he was the one who introduced me to this term: The term fixation, in the present context, refers to something that blocks or impedes the successful completion of various types of cognitive operations, such as those involved in remembering, solving problems, and generating creative ideas (e.g., Dodds & Smith, 1999; Smith, 1994, 1995a; Smith & Blankenship, 1989, 1991; Smith & Vela, 1991).
	Not being able to think of alternative designs because of a tendency to switch back to one design.
	Focus on one idea or solution
	Unable to think of other ideas
	A block to creativity
	Fixation is a cognitive road block where a designer(s) cannot pass a particular solution to enable examination of others.
	a state of not being able to re-frame a problem or a concept and evaluate its pros and cons.
	Having a solution in hand and not be able to reaosnably consider alternatives
	describes the focus of an individual or group on a particular solution or set of solutions to such an extent that it becomes difficult to expand the solution set further.
	Fixation is the inability to move beyond an already generated idea.
	Difficulty seeing things in different ways from an original perspective
	A strong link to the wrong (unwanted) memory
	An obsessive interest in a generated idea (whether conciously realized or not) that causes a designer to miss or ignore alternative solutions.
	Tendency to cling to one idea, regardless of whether the idea is appropriate or not.
	a problem I have not anticipated or research before I began the design process
	Getting stuck with the low risk, familiar option.
	the situation when reasoning and solutions are only restricted to known ones
	Looking at, or framing, a problem in such a way that one cannot see alternative solutions to it
	When designers stop being creative and get caught up on a particular idea that may or may not be the best one. Often it's the first idea fixation where the first idea that comes to mind is the best-developed or sounds the most appealing (when compared to no ideas), such that even after more ideas are

	introduced they do not necessarily get the same level of development and consideration as the initial fixed idea.
	Common response or solution to a design problem, although the problem is explicitly stated to avoid it.
	Designer or team becomes locked-in on one aspect of the problem or on a single candidate solution.
	is when a specific concept, solution, or part thereof is unable to be ignored when the design space is being searched.
	When one idea is it overwhelms the mind and hinders the generation of new ideas.
	Inability to explore alternative solutions to a problem.
	Anchoring on several existing ideas and not looking ahead.
	following the traditional path
	Focus on a particular design solution so much that other alternatives are not examined. The focus can be caused by a degree of familiarity or a sense of relief that a workable solution has been found.
	Fixation is a cognitive behavior where a given solution/concept dominates the creation of the product without any space for alternative conceptions to be considered.

Survey Question: 26. Define the following terms relative to the design process…	
Response Category	***Participant Responses***
26-d. Analogy (N=27)	An analogy is a a relationship between one thing and another thing that is explored for the purpose of communication, problem-solving, learning, and so on. In reative work,analogy can be very helpful as it may suggest new alternatives that transfer from one domain into another.
	Comparision to existing/past desgns or solutions in order to find new designs.
	Generation of new ideas from similar ideas in other fields.
	Similar losed related problem or solution
	The mapping of createristic from an example you have seen before to a new solution.
	Applying concepts from one domain of knowledge to another, e.g., from nature into engineered products
	An analogy in teh design process is a means to communicate a design idea that exists in some form on another product, process, or system.
	The description of similarities between two seemingly disparate things in order to convey meaning.
	a solution to a similar problem or an alternative solution to the current problem
	an example from a different field or category that relates to a problem in such a manner that certain similarities between the original and the example facilitate a new idea or solution to a problem.
	Analogy is the application of an idea from one discipline in another.
	Making a structural connection with a system in a different domain.
	Process of abstracting solutions from different spheres to another sphere or domain.
	Something that exhibits similar aspects to a design solution or design problem, which may be referred to in order to help identify solution opportunities or clarify the problem being solved.
	When forming a mental model of a new idea, analogies allow individuals to draw on features of existing ideas. Analogies can help design process by fleshing out an idea, and can also serve as an inspiration or starting point for new ideas.
	Some thing that reflects the core concepts and provides knowledge of what is reasonable path to take
	Seeing functional similarities in different worlds.
	inference based on metaphor and similarity of structure, function, behavior, context, effect, etc. among natural or man-made objects
	A generalized notion used as a framework for interpreting information.
	Using concepts/constructs from the world-as-we-know-it to help describe,

	explain, clarify, or demonstrate concepts/constructs that have never before existed and are being generated on-the-fly.
	Following or mimicking the rules, shapes, patterns from other systems to the current design process.
	Looking at how the problem has been solved in other situations. A is to B as ? is to D. Biomimicry is one kind of design by analogy, but there are myriad other ways.
	is the technique of moving beyond the traditional design space to search seemingly unrelated areas and how they may relate to potential design concepts.
	Reformulating a problem by mapping it to another similar problem.
	Drawing upon concepts that are functionally or physically similar to the problem at hand.
	Bringing in ideas and methodologies from one area and using them to create methodologies and ideas in another.
	find similarity
	The identification of an object or scenario that has the a relevant characteristic similar to another object or scenario under consideration. Synectics describes four types of analogies, although few students or instructors can get what a symbolic analogy is.
	Analogy is a cognitive concept that describes/maps the relevant similarities between the two (target and source) concepts or things.

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