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UNDERSTANDING INNOVATION: A STUDY OF PERSPECTIVES AND PERCEPTIONS IN ENGINEERING

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Abstract
Well developed innovation processes are essential components for continued success of product and systems design throughout industry. Such processes build upon research advancements in innovation techniques and methods. To create such techniques and methods, studies are needed to examine the current state-of-the-art, as well as the corresponding teaching of such innovation processes in higher education. This paper contributes to this effort by studying a specific group of innovation researchers, teachers, and practitioners. The study was created to probe this 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 these questions with respect to the demographics of the participant group. Two deductive analysis methods are used, in addition to an inductive approach, consisting of a correlation analysis to compare responses to questions and understand trends across the participants. Results from the analyses emphasize the current perceptions of innovation by the participants and opportunities to refine research in improving innovation practices.

KEYWORDS: Innovation; Domain knowledge participant study; Ideation; Design by analogy; Cognitive science

1.0 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 the tools and behaviors of innovation, there is a fairly consistent theme that identifies or describes innovation as the successful implementation of creative and new ideas. One 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" [1, p.4]. The scientific study of innovation and innovation processes is clearly an important field of inquiry, and is apparent when reviewing the sheer 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, however, it is noted "research suggests that innovation activity today has little strategic foundation or

direction." [2] 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.

Forbes magazine in their 85th anniversary issue noted examples of historical innovation such as the telephone, transistor and automatic transmission [3]. A well known innovation is the improved assembly line, 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 performed in laboratory settings 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 emerges 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.

2.0 PRIOR WORK

There are many aspects of this research which warrant a prelude; however, space limitations prevent a comprehensive discussion of previous work. Instead, we cite relevant literature in broad categories of research. When considering innovation in engineering design, prior work takes many forms, including engineering tools, cognitive science research, and barriers to innovation. In previous research, factor or component level studies evaluate the effectiveness of some innovation methods such as brainstorming [6-15]. Other studies evaluate managerial innovation, and still more are undertaken to better understand the principles that facilitate an innovation niche in the engineering design space [11,12,16,18]. 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 [19-62].

3.0 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 support analysis by both quantitative and qualitative research methods. These questions were developed through a collaboration among the authors and participants of a workshop [62] 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 1 and 2 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

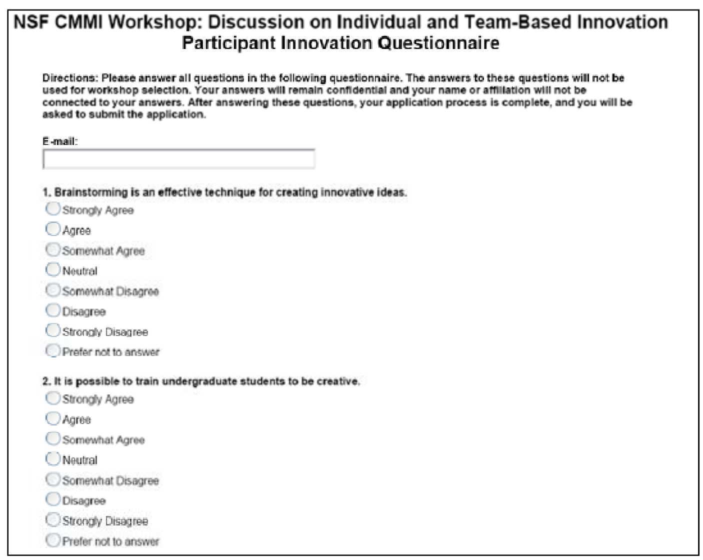
Invitation to Participate in an NSF CMMI Sponsored Workshop:
"Discussion on Individual and Team-Based Innovation"

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 1: Snapshots of web-based survey form 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 2: 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 agreement with statements using a seven-point Likert scale. The seven points are treated as an interval scale and were analyzed using a statistical rank-sum and t-test. 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

Four primary processes were utilized to evaluate the technical data for extraction of meaningful results. Figure 3 shows the research flow diagram associated with this work. Two underlying approaches to the work can be seen in Figure 3 as inductive and deductive workflows.

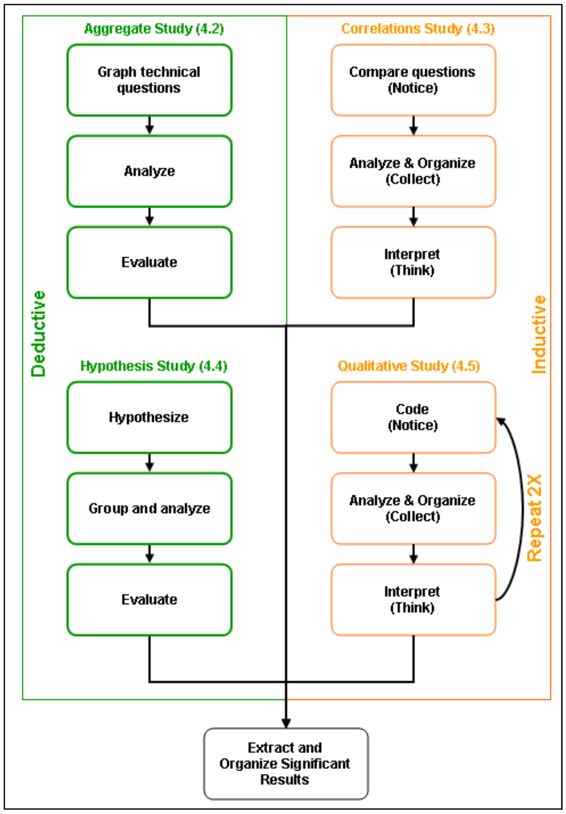


Figure 3: Methods used for evaluating survey data.

4.0 SURVEY RESULTS

The survey described above was administered to approximately 40 participants. This data and corresponding analysis are discussed below in the sections: demographic results, individual results of innovation questions, and qualitative results.

4.1 DEMOGRAPHIC/EXPERIENCE RESULTS

The first section of the query-based study elicited demographic information from the participants. The results indicate that the backgrounds of participants were broad, but the vast majority is well-founded in innovation education. Approximately 90% of the participants are engineering professors. A relatively large percentage of the participants (34.2%) were women, of which 84.6% were professors. When compared to the total percentage of women faculty in the United States, 11.8% [8], a large proportion of women attended, potentially indicating that there may exist a fundamental connection between women and a passion for innovation or design. The participants were well-distributed by age. The largest group, 42.1%, was in the range of 30-40 years old. Nearly as many participants aged 40-60 years (38.9%) were represented, while 18.4% of those surveyed were in the 20-30 year range.

The experience-based questions provide interesting insights into the professional activities of the participants. Fifty percent of those surveyed are named inventors on patents. This number is high compared to the percentage of named inventors across engineering faculty in general. A large number of participants had consulting (71.1%) and/or industrial experience (81.5%). Of those who responded, 71.1% have taught a product design course, and 63.1% have developed tools for innovative design. These results indicate that the participants were well-versed in engineering design innovation.

4.2 INDIVIDUAL RESULTS: INNOVATION QUESTIONS

The technical questions in this survey are 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, including brainstorming, ideation, fixation, creativity, and analogies. In addition, a set of multiple choice questions was used.

The technical questions were grouped into four categories: (i) Process or Method; (ii) Designer Characteristics/Qualities; (iii) Education; and (iv) Design Teams, In-Situ Environment.

As shown in Table 2, 23 technical questions were designed into the survey. Although the sequencing is not completely random, the questions from each of the four categories are scattered throughout the form. The creation of these groups allows systematic analysis of the raw data.

4.2.1 PROCESS OR METHOD

The first and largest of the categories of technical questions is the Process or Method category. This group includes questions 1, 3, 6, 7, 11-15, 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 were created for ease of visualization due to the large number of associated questions. In order to calculate the average and standard deviation the data was organized in interval form as shown in Table 1.

The first group, which includes questions 1, 3, 6, 7, 13 and 19, was organized based on strong positive tendency and question commonalities. Figure 4 shows the averages and standard deviation error bars of the results for each question. Results indicate that the average is high, typically in the "Agree" to "Strongly-Agree" range, with standard deviations that reinforce the likelihood of agreement.

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.

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

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 spectrum of responses and large standard deviation, however, suggest that a percentage of the participants are either familiar with or have experienced the limitations of brainstorming, especially regarding the originally coined method of Osborn [6], 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 [7, 8, 15-18, 57, 58].

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 previously 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.

The responses to question 6, regarding results on modeling of a design problem, show a strong trend to agreement, where the average equates to "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 support 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' responses place importance on modeling and may indicate a need for additional advancement and evolution.

The results for question 19 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 [17, 18, and 61]. The participants' responses suggest that this finding is true and may indicate the need for further research in this area.

The second group of questions, which includes questions 11, 12, 13, 14, 15, and 21, resulted in a much broader range of answers. Figure 5 shows the averages and standard deviation error bars of the results for each question in this group.

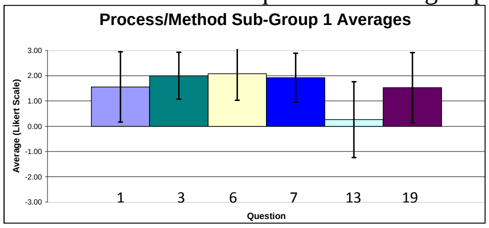


Figure 4: Process or Method Sub-Group 1 Averages with Standard Deviation Error Bars.

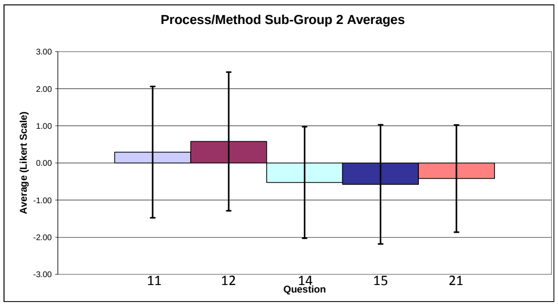


Figure 5: Process or Method Sub-Group 2 Averages with Standard Deviation Error Bars.

The average of question 11 shows a "Neutral" response with this statement. The participants' responses showed a very large distribution of answers, spanning all possible Likert ratings, as indicated by the error bars. 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 that in-depth cognitive, social, and engineering-domain studies are needed to resolve the degree to which this statement applies, and how to use this understanding to advance innovation processes.

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 [65]. We have all had instances, however, where physical artifacts led 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 the survey, a controlled experimental design study with a simple design problem demonstrated that physical models do not cause design fixation and tend to lead to higher quality ideas [66]. However, the role of physical manipulables needs to be understood further, identifying the factors and timing for their use.

For 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; however, recent literature shows that pictures of objects can provide useful analogies to spur ideas compared to a control group without such pictures [62, 63].

4.2.2 DESIGNER CHARACTERISTICS/QUALITIES

The second category of technical questions refers to the characteristics and qualities commonly associated with engineering designers. This group includes questions 18, 19, 22, and 23, and is another that resulted in a broad range of answers. Figure 6 shows the averages and standard deviation error bars of the results for each question in this 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 large variance. This is partially characterized by the bimodal distribution of the responses. 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 [67].

Question 22 responses show an average of "Neutral." The participants' responses show a wide variance 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 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.

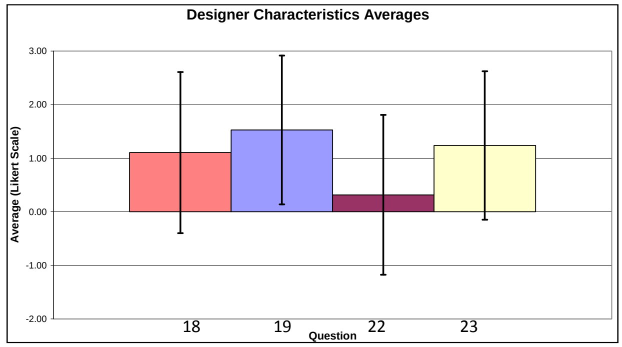


Figure 6: Designer Characteristics/Qualities Averages with Standard Deviation Error Bars.

4.2.3 EDUCATION

The third category of technical questions, numbers 2, 4, 5, 9, 16, and 17, includes a common thread to education as it correlates to engineering design. Figure 7 shows the group averages and standard deviation error bars of the results for each question.

Responses to 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 among the participants, and 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.

Responses to question 9 of the study show a strong trend to agreement. 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 [19, 24, 60]. Much research is needed in this area to ultimately warrant the optimism of the participants.

Responses to question 16 show 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.

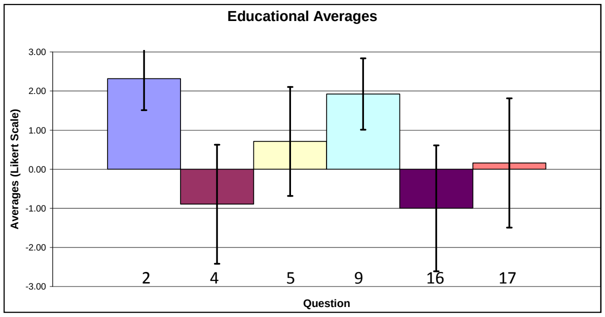


Figure 7: Education Averages with Standard Deviation Error Bars.

4.2.4 DESIGN TEAMS AND *IN-SITU* ENVIRONMENT

The next category of technical questions focuses on the team and environmental aspects of engineering design and includes questions 8, 10, and 20 (Figure 8).

Responses to question 8 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. Research is needed to determine strategies for choosing the composition of ideation teams to produce the greatest quantity, variety, novelty, and quality of ideas.

The average response for question 10 is "Somewhat Agree" to "Agree." The participants clearly believe in creating an environment that is conducive to innovation and innovation processes. The actual impact on environment depends on the conditions. Significant research is needed in this area to understand the beliefs of individuals or corporate entities. The intuitive belief by the participants in the importance of environment is interesting. The foundation of this intuition needs to be investigated.

Responses to question 20 show general agreement to with statement, where the average is between "Somewhat agree" and "Agree." This intuitive response by the participants is supported by the literature, but significant questions exist concerning appropriate methods and techniques for reinforcing the effective characteristics of teams while avoiding dysfunctional pitfalls.

4.2.5 MULTIPLE CHOICE

There are two multiple choice, two-part questions in the technical question section. The two questions asked participants to identify the most difficult aspects of generating innovative design solutions for students and for the participants. There are six possible answers: (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, and (6) prefer not to answer.

Question 24 relates to the students' experience. The results summarized in Figure 9 show that all of the choices 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.

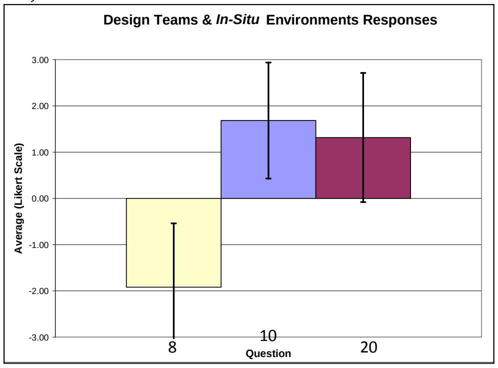


Figure 8: Design Teams & In Situ Environments Averages with Standard Deviation Error Bars.

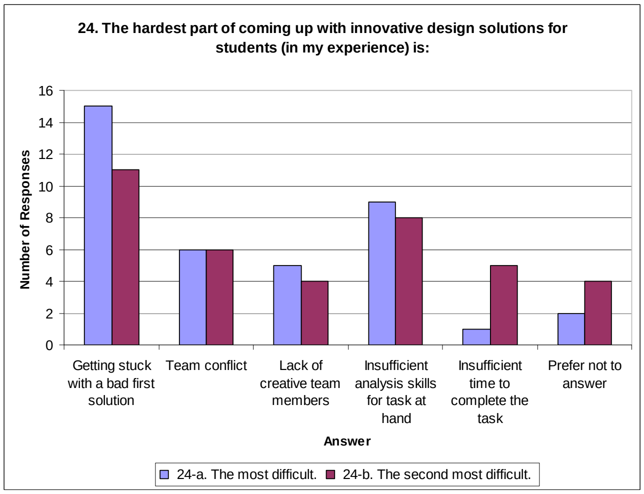


Figure 9: Innovative Design Difficulties for Students

The second of these relates to the participants' experience (see Figure 10). The results are similar to the previous question, but with a more uniform distribution among the possible responses. Again, the problem with the highest rating of difficulty is "Getting stuck with a bad first solution."

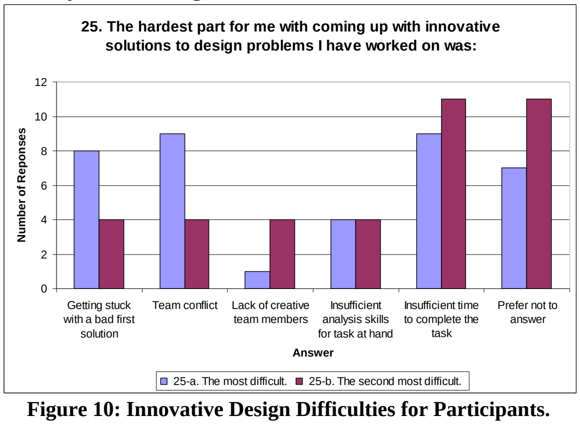


Figure 10: Innovative Design Difficulties for Participants.

4.3 SHORT ANSWER QUALITATIVE STUDY

We now consider a set of short answer questions that were posed in addition to the application each person submitted. These statements were intended to provide better understanding of the cognitive landscape in engineering design. This data requires qualitative analysis methods 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 indicate that, although there are commonalities in the language of innovation, there are no universal definitions. 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 heuristics and definitions are at the foundational level that we expect this research to inform.

4.3.1 INNOVATION TERMS

The data from the short answers in the survey were coded for themes by separate researchers and then compared and contrasted iteratively. Upon critical review by all researchers, main codes were chosen that accurately represent the themes within the participants' responses. The data were subjected to multiple iterations of coding and analysis by all researchers to strengthen the validity of the results. Themes were extracted from this qualitative data that provide avenues for understanding creativity, impasse, fixation, and analogy in relation to design.

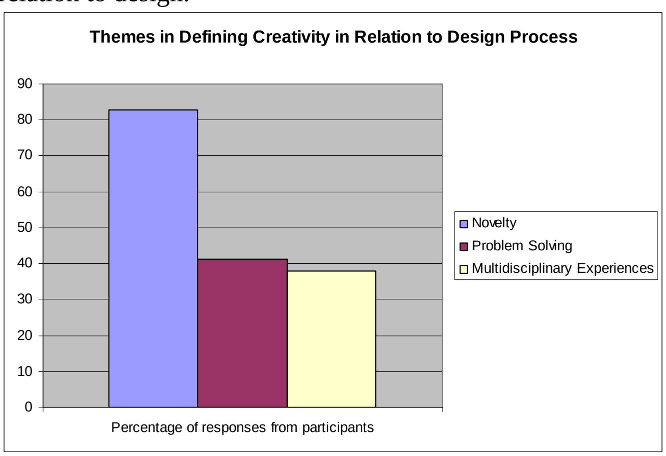


Figure 11: Themes in Defining Creativity.

Engineering educators explore ways that they can support and enhance creativity. One participant in this study shared, "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." As seen in Figure 11, these engineering educators reference novelty 82.76% of the time in relation to their definition of creativity. Furthermore, problem solving and multidisciplinary experiences emerge as key components in creativity in design processes. Within the theme of multidisciplinary experiences, participants' responses include multiple perspectives and unique personal experiences as aspects of being creative. One participant noted that creativity is "the ability to reframe a particular design problem and see it in a new perspective" and is complemented by another participant who states that it is "seeing things in a new way – looking at the same thing as everyone else, but seeing something different." As indicated in the responses of the participants, the multidisciplinary experiences, perspectives, and personal experiences are the foundation for (re)framing the design problem that leads to creativity. This sentiment is in many of the responses, including one that describes creativity as "one's ability to transform one's personal experiences into ideas for new methods, products, approaches."

The engineering educators identified impasse as a challenge during the design process Progress in the design process is the main theme that surfaces when participants considered impasse. Participants define impasse as a block to progress 60.71% of the time in their responses (Figure 12). The data suggest that problem solving and teamwork are also main topics that inform the way engineering educators think about impasse in design processes. One of the main issues connected to teamwork is conflict during idea generation and the problem solving process. Almost 40% of the answers related to teamwork as being a significant factor of impasse during design. One participant's response exemplifies this notion when defining impasse as "…a standoff, or inability to make a decision…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." Team formation techniques, development of communication skills, and conflict resolution tools are all important aspects of curriculum and teaching in engineering education to address these issues of impasse in design.

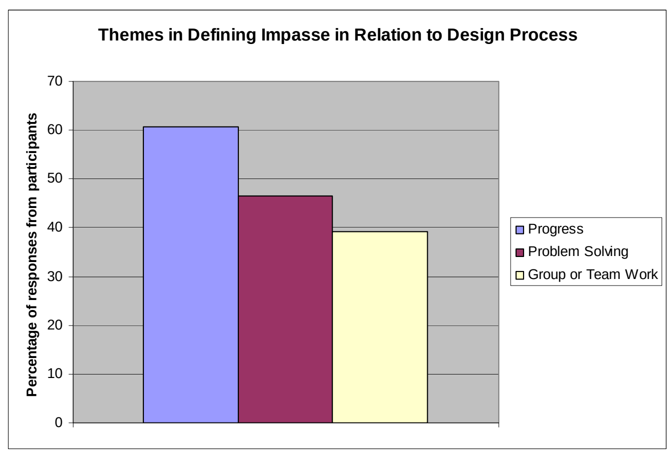


Figure 12: Themes in Defining Impasse.

Fixation is another notable challenge in the design process that deserves research in order to understand and improve engineering education. Fixation, as one participant describes, "is when a specific concept, solution, or part thereof is unable to be ignored when the design space is being searched." Whereas participants describe impasse as a block to progress in design largely due to conflict, fixation is described as a block to progress in problem solving because of an inability to generate ideas and a variety of solutions (see Figure 13). Indeed, almost 80% of the responses refer to blocks in problem solving, as indicated by one participant as "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". It is helpful to scaffold problem solving strategies into curricula and to teach across disciplines to provide multiple opportunities to practice and refine approaches that connect to the wide range of problems that design teams face.

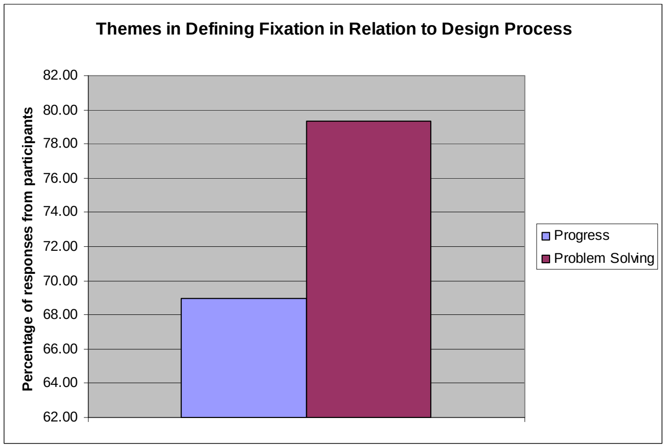


Figure 13: Themes in Defining Fixation

Analogy is the fourth component of design that participants define in their short answers. One participant suggests that, "An analogy is a relationship between one thing and another thing that is explored for the purpose of communication, problem-solving, and learning…It may suggest new alternatives that transfer from one domain into another." As shown in Figure 14, the data reveal that more than 60% of the responses included multidisciplinary experiences in relation to analogy. For example, one participant writes that analogy is "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." A specific example of crossing disciplines for analogy is seen in the participant's response that it is "applying concepts from one domain of knowledge to another, e.g., from nature into engineered products." The participants acknowledged that analogy is important in problem solving in 40% of their written responses. Discussion about problem solving was included in one participant response that offers "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 facilitates a new idea or solution to a problem" as a definition of analogy in design.

4.3.2 PARTICIPANTS' TOPICS OF INTEREST

The participants were given the opportunity to provide short answers to describe the "top three topics that interest me in the area of innovation or innovation processes are…" A number of interesting findings were gathered using the same analysis method described above.

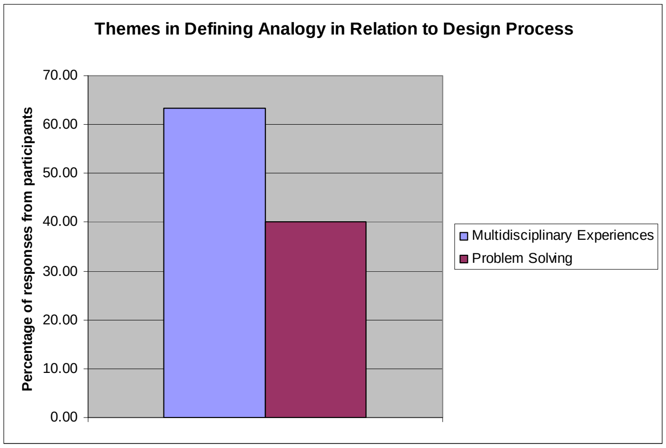


Figure 14: Themes in Defining Analogy.

Considering the first topic for each participant, 39% of the participants stated that they were interested in process/methods. This reinforces that fact that the participants are scientists and are motivated to advance the means of engineering design. The second interesting observation was that 14% of the participants were interested in education, or teaching of innovation. This ties together well with the initial finding that these scientists are principally educators with a real interest in advancing the tools used to educate students in innovation.

The global interests of the participants are interesting to consider as well. When combining the three topics of interest from all participants, we find that 14% of the statements show interest in design teams and how they can better innovate. A few non-obvious results emerged, such as roughly 5% of the participants expressed interest in metrics for innovation. Also, another 5% of participants showed interest in computer aided innovation.

5 RESULTS

Through this research a number of interesting results have been obtained and many opportunities have been uncovered. One prospect for further examination is re-interviewing the participants of this survey to learn more based on our initial insights. This could entail additional survey questions to probe the thought processes of the participants. Additionally, some correlations did not produce statistically significant results but did show interesting trends. These trends can be explored more deeply with a more focused set of survey questions.

5.1 INTERESTING FINDINGS

From the aggregate data a number of very interesting results were found. Brainstorming, as discussed in Section 2.0, is a very broad term relating to idea generation. The participants indicated that the fundamental concept of brainstorming is useful with the results tending toward agreement with research demonstrating the ineffectiveness of Osborn's original method. The responses to question 12 also reveal that an attribute of Osborn's brainstorming method, avoiding criticisms, is a source of confusion, with an average response of "somewhat agree". These two results demonstrate that a level of common understanding exists but that newer methods should be disseminated and a common language among engineering design professionals should be created.

Another set of interesting results involves question 13 regarding analogies. In this survey a number of results focused on this item. 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 between questions 3 and 13, the use of analogies in innovation processes is considered essential but the results are divided with respect to fixation. This indicates a need for developing methods specifically for alleviating fixation. The correlation for question 13 shows that those in disagreement with question 13 were much more agreeable to questions 9 and 19. This result indicates that respondents 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. Additionally, they completely agree that it is possible to create an innovation process that overcomes fixation.

The survey also revealed interesting results with respect to the educational questions. Questions 2 and 9 have very positive results. First, the respondents are optimistic that undergraduates can be trained to be creative. Second, the participants agreed that it is possible to create an innovation process that overcomes fixation (question 9). The trends indicate the need for more work in design education and the participants in this survey seem confident of successful improvement in this area.

Results related to design teams were revealed by questions 10 and 20. Participants were agreeable with respect to creation of environments for facilitating innovation, and to forming teams for innovation. These are interesting and intuitive responses.

The results from question 6 on modeling in design as it correlates to teaching experience show differences based on experience. For this question those who had taught six or more classes agreed more strongly with question 6 then those with less experience. This result may point to the need for mentorship in academia.

Another correlation result of interest is the relationship between questions 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.

Hypotheses are a wonderful resource for extracting deeper meaning from the data. A first hypothesis is based on the notion that those with patents have a better understanding of what it takes to be innovative. The evaluation of questions 6 and 19 support this hypothesis. In both questions a process/method is evaluated, and in both cases those with patents are more agreeable than those without. This is a very interesting finding that provides evidence of the usefulness of modeling and problem decomposition in practice.

With respect to a second hypothesis, the participants showed significantly more agreement with question 18 regarding personality types and creativity. This is also interesting when compared to hypothesis 1, considering they are both experience-based hypotheses. The difference may lie in the specifics of what it takes to create intellectual property versus products.

Analysis of a third hypothesis shows an apparent difference between men's and women's opinions on the early stages of design being considered as art. The responses by women suggest that they generally agree that the early stages of design can be formalized. This result indicates an interesting opportunity for gender specific research.

A final hypothesis study exposes a very interesting result as well. Those participants over the age of 40 provided responses that indicated this group is more agreeable with questions 3 and 9 regarding analogies and overcoming fixation respectively. Again, this result contradicts the hypothesis but more importantly indicates a hint of pessimism among the younger participants.

6 CONCLUSIONS AND NEXT STEPS

Through this research we have begun to understand the current state of engineering innovation and observe the fundamental link between innovation and fixation. 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 community. This fundamental step creates a baseline of current beliefs in engineering innovation. This baseline will allow advancement of innovation in engineering as a science through a variety of channels. These may include a more common set of topics and terms, as well as key relationships tying those components of innovation together.

We look forward to gathering from participants in this study reactions to the analysis presented here. These reactions will provide an opportunity to refine the analysis while providing additional insights on the best paths for future work. These reactions will be particularly valued since the participants are leaders in specific fields described in this work.

Fundamental to this research is the distribution of literature to the professionals, educators, engineers, and scientists that utilize, teach and experiment with innovation tools. In this paper we have tried to frame a portion of this literature and research as well as to indicate possible avenues for advancement. Additionally, this research may also serve to motivate interdisciplinary communication among engineering designers.

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