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Robert B. Stone

Innovation can be considered the driving force behind product design. This thesis strives to improve the ease at which innovation is achieved. Firstly by examining how design information is presented and comprehended by various personality types. The Myers-Briggs Type Indicator test is a quick, easy, and accurate way to determine a personality type that can be linked with a learning style. There is reason to believe that different individual designers may synthesize data and conceptualize ideas differently in a design environment. Therefore designers need to explore different ways to achieve their potential, more specifically by analyzing their individual learning style and how they view design information. This thesis also explores the use of a Functional Basis-TRIZ hybrid design methodology. By combining function based design and TRIZ a powerful tool was created that can be employed in a variety of engineering design contexts. It is proposed that the combination of a commonly used engineering design methodology (Function Based Design) with a more innovative contradiction solving methodology (TRIZ) more concepts that contain a higher innovation potential can be explored.

INNOVATION STRATEGIES FOR PRODUCT DESIGN

by
Anthony A. Nix

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Anthony A. Nix, Author

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Dr. Robert Stone assisted in the writing and analysis of all manuscripts. Dr. Kathy Mullet assisted with the analysis and writing of THE SEARCH FOR INNOVATION STYLES II. Ben Sherret assisted with the analysis and writing of A FUNCTION BASED APPROACH TO TRIZ.

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INNOVATION STRATEGIES FOR PRODUCT DESIGN

INTRODUCTION

in · no · va · tion (in′ə vā′ shən) n. 1 the process of introducing new methods, devices, etc. 2 a new method, custom, device, etc. [1].

One word, four syllables, yet so much power. Innovation is so desired that people write books on how to become more innovative, or improve innovation in a company [2, 3]. Innovation is traditionally considered to be reserved for for people who have the “gift,” a creative mind, or a way to help them view things differently. However, innovation, creativity, and imaginative capabilities exist in everyone, but how people process information and ideas plays a role on whether or not their output contains these qualities [4].

Professors who strive to reach all the types of learners in their classrooms use various teaching techniques to stimulate various learning styles [5]. Teaching to the different the learning styles is advantageous when conducting a heat transfer or machine dynamics class, but is difficult to implement in product design projects where students are asked to create a solution with less instructor guidance. Teaching innovation may not be possible, but nurturing it is what top Product Development companies such as IDEO, do best and is something that should be sought after in an educational environment [2].

Teaching or showing students the outlets that various personality types and their related learning styles use to reflect, think, and process data and the tasks at hand would allow a student to individually tailor their brainstorming structure to match their individual innovation style and achieve the highest innovation possible. Determining a way to correlate Myers-Briggs Type Indicator personality and learning styles with an appropriate innovation style to produce more creative and innovative products is expected to contribute to producing higher quality and higher number of concepts. Companies spend significant time and resources searching for innovative people when looking for ways to make their existing workforce more innovative may be a better approach [6]. By correlating personality type and information input needs, it might be possible to affect the design outcome, hopefully toward a more innovative product. Determining what individual designers need to be innovative in terms of work environment and research techniques durning the early stages of their education would allow them to develop these skills.

Teaching students how to increase their innovation potential is important but just as important are tools that help seed ideas that lead to innovation. There are many methods often employed during the design process that are taught to students, such as those by Pahl and Beitz, Ullman, Otto and Wood, and Cross [7-10]. Such methodologies include detailed portions of the design process but very few give a complete spectrum of the entire process [11]. In the next subsections, the crucial elements of this body of research on innovation are introduced.

Motivation for Innovation Research

Most designers believe that innovation is a good thing, something to strive for, and an accomplishment when achieved. Innovation drives product design. Fostering innovation in the workplace has been the quest of many companies in recent years.

Providing designers with all the pieces of the need information (customer needs, functionality, etc..) is critical when trying to design a quality product. Designers should be able to locate and understand this information through research, reading, experimenting with current products, or a walk through the park. Allowing an environment that encourages innovation is crucial for a designer to create the next great thing. The word environment is used here to describe the circumstances, objects, or conditions by which someone is surrounded [12], not just the physical aspects of the workplace.

Discussions with current students show the vast majority of engineers in training are competent in math and science but spend very little time practicing or improving their innovation skills. However skills in innovation can be developed and matured and are extremely useful in concept generation and tackling open ended problems [9]. An understanding of what an individual needs to be innovative is key. Tom Kelly wrote, “We all have a creative side, and it can flourish if you spawn a culture or environment that encourages it” [2]. Bringing the creative side out is different for every individual but accomplishing it can lead to great things.

Myers-Briggs Type Indicators

Innovation in individuals has its roots in individual learning styles and personality. The Myers-Briggs type indicator (MBTI) is the most familiar and common temperament assessment used today. It also has clear links to learning styles, is easy to use, and is easy to understand the results. These attributes make it the personality sorter implemented in this research [8]. The MBTI preference sorter is based off the psychology work and personality types studied by C. G. Jung. He proposed three dichotomies: Extroversion or Introversion, Sensing or Intuition, Thinking or Feeling. A fourth dichotomy was proposed by Katharine Meyers and Isabella Briggs Meyers, Judging or Perceiving[8], and I. Myers Briggs, created the preference sorter to place people within these categories. The reason for the MBTI test is to give individuals an understanding their preferences which is useful to help a person understand themselves and why they view options differently than some around them. It has become quite clear, after asking questions about type development to thousands of participants, that enough evidence has been found to suggest that this is a very real and powerful force in adult growth. If properly understood, a person’s type can assist adults throughout their lives in making more conscious choices and general understanding of themselves [9].

The first dichotomy, Extroversion or Introversion, looks at where people focus their energy. Extraverts tend to focus their energy on other people and physical objects as well as the “outer world” around them, where as introverts tend to focus energy on their “inner world” including their own concepts ideas and personal experiences. The second dichotomy, Sensing or Intuition focuses on how people perceive things. Sensing people tend to focus on facts, previous happenings, and happenings noted with one of the five senses whereas Intuitive people look at relationships, meanings, possibilities that were worked outside of the conscious mind. The third dichotomy, Thinking or Feeling, primarily deals with how a person makes judgment. Thinkers tend base their conclusions on logical knowledge, detaching themselves from the problem. Feelers on the other hand bring in personal and social experiences and values. The last dichotomy, Judgers or Perceivers, focuses on people’s attitudes on the outside world. Judgers prefer decisiveness and closure in dealing with the outside world while perceivers enjoy flexibility and spontaneity in their dealings [10].

MBTI has been studied for career placement as well. For example, INFJ’s are more likely to become psychologists or do other forms of counseling, and ESTJ’s are often bank officers or financial managers [10]. Another use of MBTI is combining different personality traits to create desired team dynamics [13]. However, there is a problem with this system. It works well to create a good team dynamic but leaves holes when it comes to certain tasks. While it is nice to know a person’s strengths and weaknesses this can lead to profiling a certain type to do a certain thing.

Tom Kelly said innovation begins with an eye. The act of observing how products are used, on a firsthand basis is the first step in designing a new and better product [2]. Letting their workforce do what they feel is needed to accurately observe a problem is all about letting people with various personality types capture information in a way they seem fit.

Product Design

Engineering design is the application of scientific knowledge to the solution of technical problems [7]. It involves taking something from its current state to a more desirable future state, using engineering techniques and principles. It is often said that that the "path" of design may be made more efficient if certain processes are applied. From such authors as Paul and Beitz, Ullman, Otto and Wood, and Cross [7-10] a general recipe for designers to follow has coalesced. Included are stages for defining the problem, generating multiple solutions, evaluating and choosing a solution, and embodying the solution. All methods include examining a need, developing a concept, evaluating or deciding on a concept, and refining that concept, however the steps that join these common segments is where the different methods vary. For example Otto and Wood identifies twelve steps: develop a vision, market analysis, customer needs analysis, competitive analysis, portfolio planning, functional modeling, architecture development, concept engineering, embodiment engineering, modeling, design for x, and robust design [9]. Dym and Little on the other had only has five steps: problem definition, concept design, preliminary design, detailed design and design communication [14]. One can see the similarities between these two accepted methods but also note the differences.

How to Use this Thesis

This thesis is a compilation of three research papers published at three different conferences. The research conducted in the first two manuscripts are an attempt to prove that innovative designs are a result of any person having viewed information in a way they needed to and not just having an innovative personality type. The last manuscript focuses primarily on the concept generation stage of design and merging two methodologies that serve in the concept generation facet; Function Based Design and TRIZ. These three papers share one common goal: improving innovation abilities in designers. This is not only what companies what but what individuals want as well. Everybody wants to make something innovative, something to share with the world that has never been done before even if not necessarily a product but just an idea or method. Companies, entrepreneurs, the lady sewing purses in her house all want this, to release something that is unlike anything else. These three papers discuss two different approaches to this, one that is person centric where the main point of focus is improving the innovation through the person and another that is tool centric where innovation is sought after by creating a tool to help the designer create more innovative ideas. Both paths are worthy of exploration and contain valuable pieces of information vital to the innovation puzzle. These paths can also be joined by creating or determining personality specific tools such as a tool that helps convergers by using that style. Despite the differences between the two paths the outcome is still the same, helping designers come up with more innovative ideas and the ability to do that is very powerful and sought after.

THE SEARCH FOR INNOVATION STYLES

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ABSTRACT

The Myers-Briggs Type Indicator test is known to be a quick and easy way to build good team dynamics. However the workplace is not always built around four person teams that you can easily change based on individual personalities. Research has shown that the various MBTI personalities associate with different learning styles. This gives reason to believe that different individual designers may synthesize data and conceptualize ideas differently in a design environment. If this is true, designers may need a customizable environment or they may need to explore different ways to achieve their potential. This paper examines how individuals with different MBTI personality types take in and view information during the conceptualization stages of product design and whether the way information is inputed is vital to an innovative product design.

INTRODUCTION

Innovation, creativity, and imaginative capabilities exist in everyone, but how people process information and ideas plays a role on whether or not their output contains these qualities. In academia, professors who want to reach all types of learners use various teaching techniques in classes to stimulate students with various learning styles [5]. This approach works well when instructing a heat transfer or machine dynamics class, but is difficult to implement in project-based courses – particularly product design projects where students are asked to create a solution with less instructor guidance. Teaching innovation may not be possible, but nurturing it is what top Product Development companies such as IDEO, do best [2]. Allowing outlets for the various personality types to reflect, think, and process data and the tasks at hand in a way that matches their individual personality and learning styles should not only improve morale but also lead to a more productive and innovative environment around them. Determining a way to correlate Myers-Briggs Type Indicator personality and learning styles with an appropriate innovation style to produce more creative and innovative products is expected to contribute to producing a higher quality and a higher number of concepts. Companies spend much of their time and resources searching for innovative people, when looking for ways to make their existing workforce more innovative may be a better approach. By correlating personality type and information input needs, it might be possible to affect the design outcome, hopefully toward a more innovative product. Determining what individual designers need to be innovative in terms of work environment and research techniques durning the early stages of their education would allow them to develop these skills.

BACKGROUND

Innovation

Innovation is the introduction of something new or a new idea, method or device [1]. Most design engineers believe that innovation is a good thing, something to strive for, and an accomplishment when it is achieved. Innovation is what drives product design. Without it there would be no touch screen phones or bluetooth headsets, for example. Fostering innovation in the workplace has been the quest of many companies in recent years. Consultancy companies such as IDEO, Smart Design, and DesignEdge have made their name around designing innovative and creative products. Scott Berkun worded innovation as:

> *"Any major innovation or insight can be seen in this way. It's simply the final piece of a complex puzzle falling into place. But, unlike a puzzle, the universe of ideas can be combined in an infinite number of ways, so part of the challenge of innovation is coming up with the problem to solve, not just its solution" [15].*

Providing designers with all the pieces of the puzzle is critical. Not all the pieces have to be sitting on the desk, but designers should be able to locate them though, whether it be through research, reading, experimenting with current products or a walk through the park. Allowing an environment that helps the designer is crucial to creating the next great thing. This paper considers the designer environment to be significant. The word environment is used here to describe the circumstances, objects, or conditions by which someone is surrounded [12], not just the physical aspects of the workplace.

Discussions with current students show the vast majority of engineers in training are competent in math and science but spend very little time practicing or improving their innovation skills. However skills in innovation can be developed and matured and are extremely useful in concept generation and tackling open ended problems [9]. An understanding of what an individual needs to be innovative is key. Tom Kelly wrote, "We all have a creative side, and it can flourish if you spawn a culture or environment that encourages it" [2]. Bringing the creative side out is different for every individual but accomplishing it can lead to great things.

MBTI Theory

The Myers-Briggs type indicator (MBTI) is the most familiar and commonly used temperament assessment today. It is based on the psychological theory by Jung [16]. In brief, the MBTI preference sorter identifies 16 types. The reason the MBTI test was created was to give individuals an understanding on why they proceed about tasks, view problems, or rank life goals differently than other people, i.e. their preferences. This knowledge could then be used to help this person view options differently. In one view by knowing in which areas you struggle, then and only then can you better yourself. It has become quite clear after asking questions about type development to thousands of participants, that enough evidence has been found to suggest that this is a very real and powerful force in adult growth. If properly understood, a person's type can aid adults throughout their lives in making more conscious choices [17].

MBTI Types

The MBTI preference sorter is based off of the personality types described by C. G. Jung. He proposed four dichotomies: Extroversion or Introversion, Sensing or Intuition, Thinking or Feeling, and Judging or Perceiving [16], and I. Myers Briggs, created the preference sorter to place people within these categories.

The first dichotomy, Extroversion or Introversion, looks at where people focus their energy. Extraverts tend to focus their energy on other people and physical objects as well as the "outer world" around them, whereas introverts tend to focus energy on their "inner world" including their own concepts ideas and personal experiences. The second dichotomy, Sensing or Intuition focuses on how people perceive things. Sensing people tend to focus on facts, previous happenings, and happenings noted with one of the five senses whereas Intuitive people look at relationships, meanings, possibilities that were worked outside of the conscious mind. The third dichotomy, Thinking or Feeling, primarily deals with how a person makes judgment. Thinkers tend base their conclusions on logical knowledge, detaching themselves from the problem. Feelers on the other hand bring in personal and social experiences and values. The last dichotomy, Judgers or Perceivers, focuses on people's attitudes on the outside world. Judgers prefer decisiveness and closure in dealing with the outside world while perceivers enjoy flexibility and spontaneity in their dealings [18].

Using these four dichotomies, 16 different personality or MBTI types can be observed in people. An understanding of these 16 types is a key to effective team building which in turn can lead to an innovative team performance. One could form a team with an ISTJ for their good concentration, and reliance on facts and logic, an INFJ to grasp a variety of possibilities and organizational skills and an ENFP to keep the group happy and provide some adaptability. Career choices often correlate with a person's MBTI preference. Table 1 shows a breakdown of engineering students' MBTI preferences, which is the group the research in this paper relates to. Note that, for instance, roughly one third of engineers prefer ISTJ or ESTJ. This career preference by personality type correlation has been studied for other career fields as well. For example, INFJ's are more likely to become psychologists or do other forms of counseling, and ESTJ's are often bank officers or financial managers [18].

TABLE 1: ENGINEERING MBTI PERCENTAGES [19]

ISTJ	ISFJ	INFJ	INTJ
16.50%	4.60%	2.70%	9.50%
ISTP	ISFP	INFP	INTP
6.50%	2.60%	3.90%	8.50%
ESTP	ESFP	ENFP	ENTP
4.20%	2.30%	3.70%	7.40%
ESTJ	ESFJ	ENFJ	ENTJ
12.70%	3.50%	2.10%	9.40%

Combining different personality traits can create powerful team dynamics both good and bad. However, there is a problem with this system. It works well to create a good team dynamic but leaves holes when it comes to certain tasks. While it is nice to know a person's strengths and weaknesses this can lead to profiling a certain type to do a certain thing. In product conceptualization, profiling a team's members as good innovators or a creative person can leave the other members out of brainstorming processes. Attempts to determine team roles based off an individual's MBTI personality type have been conducted. One strategy is to break down the types into sixteen roles in which each person has two roles, a judgement role and a perception role. Some examples of the different roles are: Inspector, Diplomat, Mockup Maker, Investigator. There are two main innovation roles, the INTP where N>I, which is the Visionary role, and ENTP where N>E, which is the Innovator role.(N>I refers to the person having a higher preference for N over S than I over E, a split of N=16 S=4, and I=12 E 8 would fall into this category, where each dichotomy is scaled between [-20,20].) One issue with this is that by assigning roles such as the Innovator, or the Visionary could hamper teamwork. If Person A is labeled the innovator, persons B, C, and D might feel that their designs are inferior even before a design comparison test has been completed. This lets person A run the concept show and the team could miss out on a stellar idea or insight by members B, C, or D. Doug Wilde stated that “But it is not only different types of expertise that people bring to the task. They also have distinct personalities and different ways of approaching and solving problems” [13]. Tom Kelly said innovation begins with an eye. The act of observing how products are used, on a firsthand basis [2]. Letting their workforce do what they feel is needed to accurately observe a problem is all about letting people with various personality types capture information in a way they seem fit. The research started in this paper is attempting to prove that innovative designs are a result of any person having viewed what they needed to in a way they needed to and not just having an innovative personality type. MBTI types are closely associated with learning styles and such was their main use for this project [20]. By knowing a students MBTI type, their learning style could be determined, therefore MBTI served as a mediator between learning styles and innovation.

Learning Theory

In the 1960‘s it became apparent that not all students learned the same way. Evidence was found that if the school systems were to help students become successful academically, they would have to develop different methods of teaching. Determining which of these methods would appeal to certain learning styles and how to implement them in the classroom was the next challenge. Work was done do correlate the environmental stimuli, emotionality, sociological needs, and physical needs with learning styles to help children learn the most in a classroom setting [21]. In 1976 Benjamin Bloom proposed the model shown in Figure 1 [22]. This model contains three important elements of learning: 1) Cognitive entry behaviors – the level of competence of the subject to be taught, 2) Affective entry characteristics – the extent of how motivated the student is to engage in learning the subject, 3) Quality of instruction - the instruction given appropriate to the learning style of the student. The model then takes these inputs and using “Learning Tasks” creates three outputs: Level and Type of Achievement, Rate of Learning, and Affective Outcomes. Affective outcomes concerns information such as how the student perceives their competence and how well they have learned. In theory, good Affective Outcomes have an effect on the Affective Entry Characteristics.

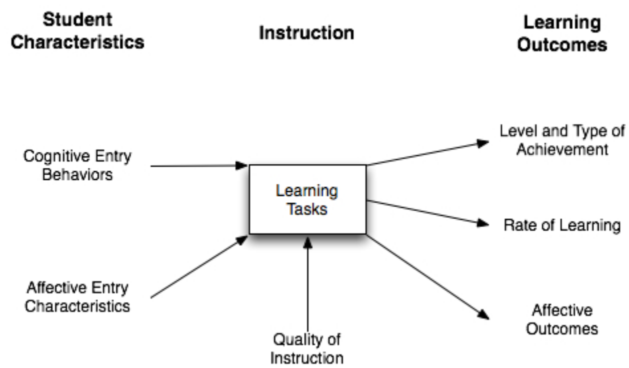

FIGURE 1: LEARNING STYLES FLOW[22]

In 1979 C.J. Margerison and R.G. Lewis created a relationship between learning styles and Jung's psychological types [20]. A graph of this relationship was created and is shown in Figure 2. The graph is divided up into four quadrants with each quadrant containing a different learning style. The upper left is an accommodation learning style of concrete experience blended in with active experimentation, basically a hands on approach or learn by doing. This quadrant contains sensors and perceivers.

The upper right quadrant, the divergence learning style mixes concrete experience and reflective observation. Containing only people with strong feeling type, the people with this learning style like doing something then taking time to reflect on what was done.

The bottom left quadrant or convergence learning style contains extraverts, thinkers, and judgers. This is the active experimentation and abstract conceptualization portion. This group would learn by proving their concepts through a series of experiments.

The last quadrant in the bottom right is the assimilation learning style. This style contains abstract conceptualization and reflective observation area, with intuitors and introverts being the main subjects in this area. The types here take time after examining concepts to reflect on how they work and where they might work. Being mostly abstract and theoretical the types here would not do much hands on work and would take significant time to examine their concepts.

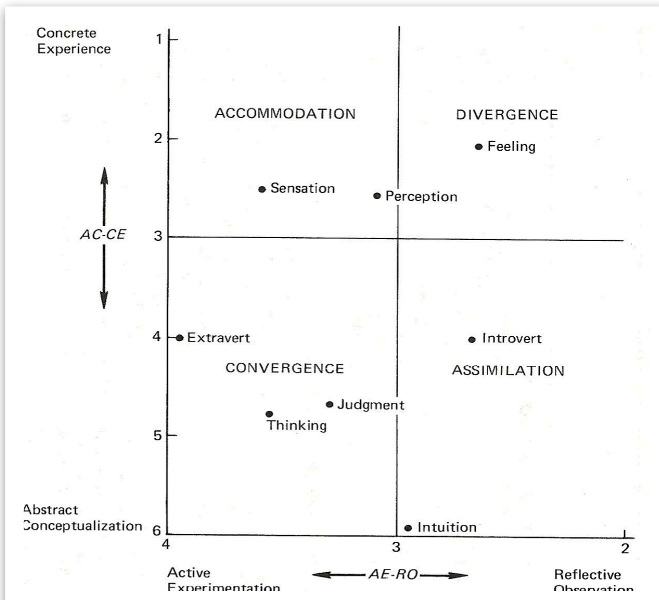

FIGURE 2: LEARNING STYLES MAP (IMAGE ADAPTED FROM[20])

The scales on the axes represent the scores from the Learning Style Inventory (LSI) test. This test was created to help assess individual learning orientations. In a study of 220 participants Margerison and Lewis studied the relationships between MBTI types and LSI scores and found significant canonical correlations between the two [20].

Appealing to all four learning styles help keep students engaged in the classroom. A person experiences and acquires preferences in the different learning styles from birth to around year 15. Then they move into a stage of specializing their preferred learning styles between the ages of 16-40. Since the majority of college students taking design classes are between the ages of 18-22, this is an advantageous time to teach them how to understand and use their preferred learning style in these classes and to support earlier development of these styles ahead of their peers[23].

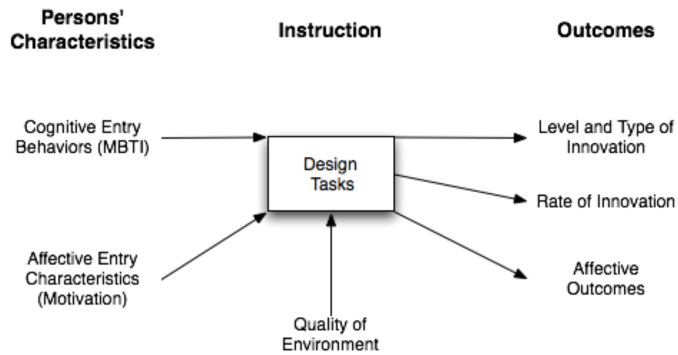

FIGURE 3: INNOVATION STYLES FLOW

RESEARCH

The Innovation Problem

Looking for a relationship between learning styles and the 16 MBTI personalities with innovation can give a better understanding of why some individuals may seem more innovative than others even though it is possible that those who do not seem innovative have an innovative side. Additionally, in terms of workplace dynamics, the ability to provide an environment that fosters innovation in all personality and learning types may lead to happy, creative, and productive employees (and result in innovative products). If an individual's needs for the environment around them are not met, that person might experience difficulties when trying to express ideas and create designs.

There are many reasons for attempting to learn how to bring out the innovator in people. As stated earlier, even though everybody has a creative side, they all access it differently. This creates a problem as what one person views as an insightful observation another may be completely lost upon another person. If there is an understanding of what the group needs to access their creative side, then allowing the team to explore these needs should create more creative and innovative results.

Rowena Reed Kostellow once said

> *"There have been many theories of design and many valuable ways of analyzing both graphic and three-dimensional situations, but the unique quality of this curriculum which I am about to present is that it is structured in a way which quite literally covers any combination of design relationships which you may encounter and enables you to organize the abstract relationships for yourself."*[24]

Reed Kostellow was referring to industrial design but the same idea can relate to product design as well. Presenting the design problem and relevant data in a multitude of ways that covers nearly every aspect of the conceptualization process allows a person to organize relationships in the way they see fit. One of the most frustrating things about teaching is that you rob one student to make sure another one understands, reaching one group while confusing another, which is why teaching individual students how to discover their own innovation style is better than than trying to generalize it [25]. There is an old saying "Give a person a fish; you have fed that person for today. Teach a person to fish; and you have fed that person for a lifetime." The same thing applies to innovation. Take a designer down an innovative path, and you have one innovative product; teach a designer how to access that designer's own innovation style and you have one of the most valued weapons in product design. In this section, the research done to correlate a specific learning style with their innovation style is reported. The approach followed involved specifying a design problem that looked to make an innovative leap in the form solution to a common need of circulating air within a room or space.

Research Questions

The problems of fostering innovation, why some people seem to show more than other, and how to bring out a person's innovative side lead to more questions than answers. The research reported here explores whether presenting information to a person in their preferred method of learning leads to more innovative results. If proven successful, the work may provide people the knowledge on how to research ideas for a product more successfully.

Following from Bloom's model on learning styles (shown in Fig. 1), the following analogy is proposed for innovation styles: Someone who has created an innovative product and is pleased with it should raise the motivation for creating another product. The analogous model for innovation styles is shown in Figure 3. This model contains three inputs, Cognitive Entry Behaviors, Affective Energy Characteristics, and the Quality of the Environment and three outputs, Level and Type of Innovation, Rate of Innovation, and Affective Outcomes. Environment is used here again not just discussing the physical characteristics of what surrounds the person but also including circumstances and conditions. Of the three inputs, Quality of Environment is the only one the third party such as a teacher or employer has control over. Understanding what individuals needs in an environment to be innovative allows a third party such as a teacher or employer to tweak it to obtain higher innovation levels.

The focus of this research is to determine if a correlation between a designer's MBTI personalities (the Cognitive Entry Behaviors) and the Level and Type of Innovation exists. Secondly, if the correlation exists, can the manner of information presentation to the designer (i.e., the Affective Entry Characteristics) affect their level of innovation.

Design Problem Implementation

The participants in this study were a collection of junior level mechanical and industrial engineering students. To assist team formation in their required junior design methodology course, all students had previously taken the Keirsey Temperament Sorter [26]. One person conducted and evaluated all exercises. This allowed all participants to be judged the same since more than just raw numbers was collected and studied. The exercise was done one participant at a time in an empty room. The average time was 19.95 minutes. All participants were shown a short six-slide presentation and were asked to create an air amplification and movement device using the principles shown on the slides. The first slide was just a title slide, and where the conducted gave a little information on the project. The second slide contained a functional model of the device. This model contained 6 functions: import air, guide air, change air, guide air, export air, and export pneumatic energy. This was the air flow chain portion of a fan's functional model. The next four slides all contained components or devices that used the same principles. They were shown a nozzle, an airfoil, a Venturi tube, and finally a carburetor. For each device there was a verbal explanation of how it worked and if the participants had any questions about them they were answered. Measures to avoid the word fan were taken to try to reduce tunneling or object fixation. The students were allowed to inquire about various aspects of the device, the most common of which was "Is it like a fan?" All participants were given a sheet of paper and pen to sketch out any ideas or designs they came up with throughout the exercise. A sampling of sketches is shown in Figures 6-9. Figures 6 and 7 are both from "Idea Runners" while Figures 8 and 9 are from the "No" group. One can see the orderly thinking and build on previous ideas from the the "Idea Runners" sketches, as the majority of the sketches from that group were arranged in this manner. The "No" sketches were more random and had less flow to them than the others.

Whenever a participant became stuck on a certain aspect of the design a prompt was given to nudge them to move past the blockage. Some of the common prompts pertained to: injection molded plastic components being hollow and, therefore, having the ability to guide air; the placement of the "black box" air supplier; and a variety of prompts to get the circular shape of the product. Therefore all the information presented to the participant was either verbal or in a slideshow configuration. As sketches were made a critique was given on the hindrances and insights that have surfaced since the last attempt. After each critique, the students were allowed to review the slides and complete another sketch. As they continued through the activity, notes on what the students designed and the “jumps” they made in moving towards the final project were taken.

“Jumps” were defined as the ability to skip a prompt or have an insight on the overall device. “Jumps” included, but were not limited to, bending an airfoil in a circle, using the device to channel the air supply, and determining that one could create a breeze with pressure differentials. Making “jumps” determined the level of innovation of the participant. At the end of exercise after all data was collected the students were shown the innovative product that they were trying to replicate with their design, the Dyson Air Multiplier (shown in Figure 4), and a short discussion.

FIGURE 4: DYSON AIR MULTIPLIER [27]

This device from Dyson claims to be a blade-less fan, using pressure differentials and aerodynamics to create a steam of air. Looking at this product from Webster’s definition, is it new? Check. Does it contain new ideas, methods or devices? Check.

With the satisfaction of both criteria it is fairly safe to say that this is an innovative product. This product was chosen because it contained a few certain criterion that were required for this exercise. The first being that since you could not currently (at the time of the study) purchase it, the students in the exercise were less likely to have used it or know how it works. Another reason was that it took a simple device that people have been using for over 150 years and accomplished the same task in a different way. This points to an innovative product that not everybody will immediately understand.

Based on the participant's design sketches and interaction with the experiment conductor, each participant was placed into one of three groups: 1) "Idea Runners", people who took the information given and received from inquiries and made good use of it, moving closer to the final product with most pieces of information; 2) the "Yes" group, made up of people who understood all the information and made one or two of the "jumps" and had a good understanding of how the principles were used in the final product; and 3) the "No" group, which consisted of people who did not make any jumps and did not even make connections between the principles shown and the final product. These judgements were made based off characteristics the conductor observed during the exercise. The first characteristic was mentioned above as the jump making ability, or the ability to make connections between pieces of seemingly irrelevant information. Another characteristic was the innovativeness or creativity of the students sketches. The first set of sketches were not always in the right direction, but were occasionally creative with interesting ideas being shown. Even though they were not used directly for this study, the fact that the student came up with a novel idea did hold some importance. Another characteristic noticed when judging the students was the "light bulb" effect. This was one of the biggest differences between the "No" group and the other two. When explained the solution and sketched why and how the fan worked participants in the "No" group either disbelieved it was possible or could not comprehend how it would work. With the other groups as soon as explained the solution, and "Oh, wow, why didn't I think of that" effect was noticed.

RESULTS

Participant Description

The participants of the study consisted of 34 junior level engineering students. In these 34 students, six were female; five were industrial engineers, leaving 29 mechanical engineers and 28 males. The MBTI breakdown between the 34 people can be seen above in Figure 9. One can clearly see that nearly 45% of the participants have an ISTJ personality types making it the dominant type amongst the sample, but the percentages between the MBTI types of the class total and those of the sample were similar, as you can see in the Figure 5. There were a few differences; the class had more ISTJ's and ESFJ's than the sample and some of the smaller groups, all less than eight percent of the class (less than 10 students), were not represented.

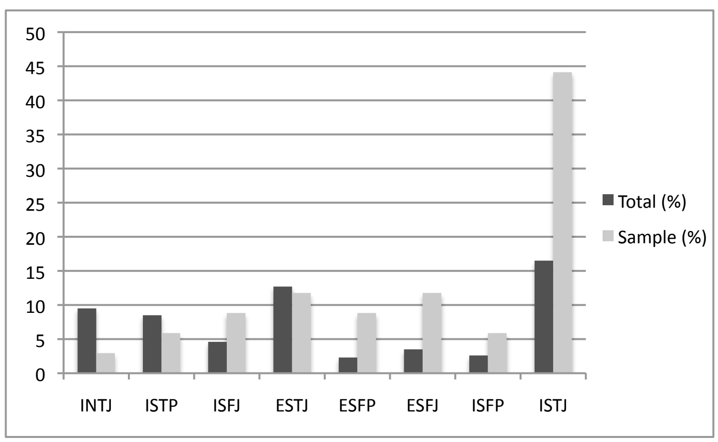

FIGURE 5: CLASS % VS PARTICIPANT %

Result Limitations

When looking at the results, one must remember some of the assumptions made by the authors and understand why they were made and what impact they had on the results. One assumption is that all of the MBTI results were correct. MBTI testing has shown to be effective and accurate [28], but there is a small possibility that the participant filled in a box wrong. Another assumption made was that the conductor could differentiate between the different levels of innovation that the students showed in the exercise. No issues were noted here as the students broke down easily into the three groups, based on their sketches, questions, and overall understanding of the exercise.

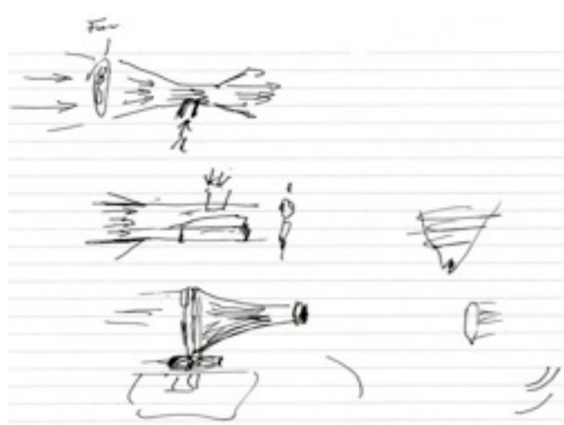

FIGURE 6: PARTICIPANT SKETCH 1

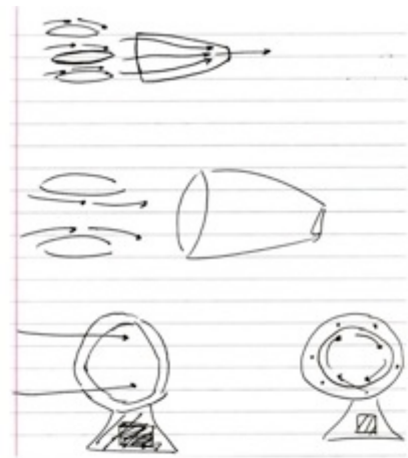

FIGURE 7: PARTICIPANT SKETCH 3

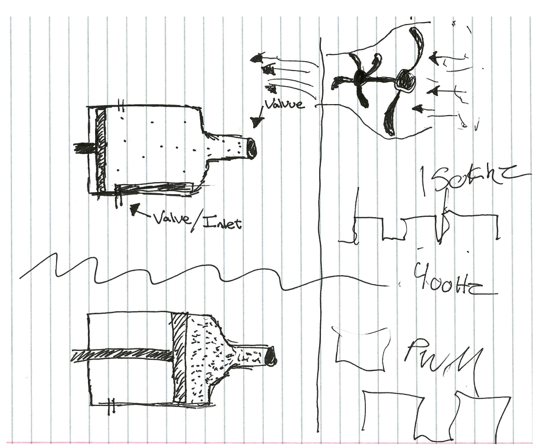

FIGURE 8: PARTICIPANT SKETCH 2

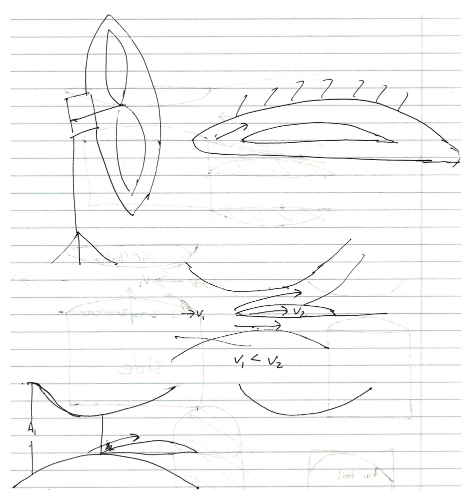

FIGURE 9: PARTICIPANT SKETCH 4

Once gathered, the results can be interpreted in various ways to understand what lies in the data. Since this research was done primarily to find out if a possible correlation between learning styles and innovation styles exist a T-test was not conducted with the data. One first would need to normalize the data and even then the small sample sizes (7 “Idea Runners,” 19 “No”) and variations in a self ranked test would give non-statistically significant results in a T-test, even if the results had merit because the data does not meet the conditions needed for an accurate t-test result [29].

Innovation Correlation

The 34 participants broke down into the three categories with 10 “Idea Runners,” six “Yes,” and 18 “No.” After determining which groups the participants fell into and using the raw MBTI test scores, Figure 11 was produced to help understand the numbers. The “yes” group was left out as the people in the group could have gone either “Idea Runner” or “No”. Table 2 shows the raw scores and MBTI types of the “Idea Runners.” As one can notice, all but one of the types were a xSTJ, with the non thinker only being four points away from a thinker type. The way the information for this exercise was presented lends itself to ”Convergence” presentation. The “Convergence Style works best in hypothetical-deductive reasoning, focused on specific problems, which is clearly related to the exercise used here. The information given falls into abstract conceptualization because the participants are trying to conceptualize a product that they have never seen and one in which new techniques are being used. The active experimentation comes into place because the participants are creating a design then their design is critiqued on what are possible hindrances or insights. This experimentation process allows the participants to adjust their design to improve it with every iteration. In Figures 3-6, one can see the iterations drawn by four of the participants. By looking back at Figure 2 we can determine that the population that does the best should consist of introverts, sensors, thinkers, and judgers, which is consistent with the data collected in which everybody was a sensor and judger, and 9 out of the 10 participants were a thinker. The population that had the hardest time interpreting the information and designing the product should be perceivers and feelers, which is also consistent with the data collected since no feelers or perceivers were in the "Idea Runner" group. Figure 10 makes it easy to see that the "Idea Runners" scored higher in both the judging and thinking categories when comparing the averages of the two groups. This places the "Idea Runners" in the convergence quadrant of C.J. Margerisons's graph in Figure 11, and the higher perceivers and feelers outside of that quadrant.

TABLE 2: “IDEA RUNNERS”

		I	E	N	S	F	T	P	J
ME	ISTJ	5.00	4.00	10.00	12.00	9.00	11.00	8.00	12.00
ME	ESFJ	3.00	7.00	7.00	13.00	12.00	8.00	2.00	18.00
ME	ESTJ	4.00	6.00	1.00	19.00	9.00	11.00	3.00	17.00
ME	ISTJ	7.00	3.00	5.00	15.00	3.00	17.00	6.00	14.00
ME	ESTJ	2.00	7.00	6.00	10.00	9.00	11.00	9.00	11.00
ME	ISTJ	9.00	1.00	9.00	14.00	1.00	20.00	7.00	13.00
ME	ESTJ	3.00	8.00	3.00	19.00	4.00	17.00	1.00	19.00
ME	ISTJ	7.00	3.00	4.00	17.00	3.00	17.00	1.00	19.00
ME	ISTJ	5.00	5.00	5.00	15.00	3.00	17.00	8.00	12.00
ME	ISTJ	10.00	0.00	4.00	16.00	9.00	11.00	2.00	18.00
Average		5.50	4.40	5.40	15.00	6.20	14.00	4.70	15.30

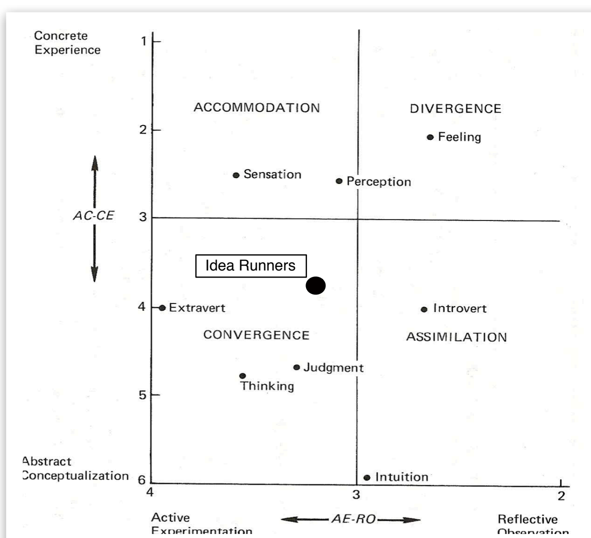

FIGURE 10: PLOT OF THE IDEA RUNNERS ON LEARNING STYLES

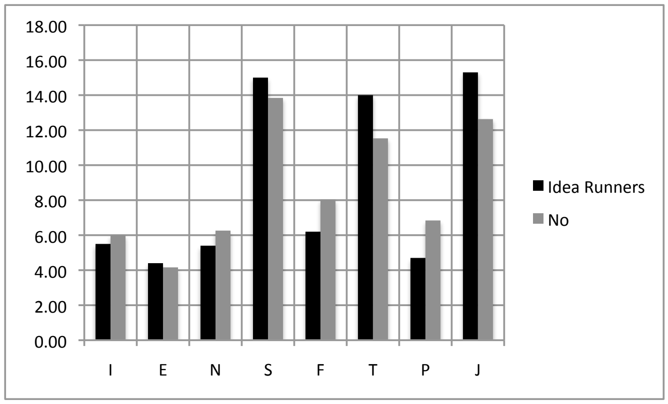

FIGURE 11: GRAPH OF AVERAGE “IDEA RUNNER” SCORE VS. NO GROUP SCORE

CONCLUSIONS/FUTURE WORK

The research here shows that the different learning styles of various Myers-Briggs personality types possibly correlate with how those types process information to create product concepts. Presenting information in a predetermined learning style made the participants who used that style more comfortable and produced better results when attempting to design an innovative product. Understanding what various designers need can benefit both in the classroom and the workplace. If a professor understands what a certain student needs to bring out the innovator in them, professor or advisor can make recommendations to the student on what style they should do to maximize their potential. This cannot only make the students project more successful but also teach the student how to access his innovation skills whenever a situation warrants them. One of the purposes of MBTI sorters is that people can take the information and learn about and improve themselves [28]. In education and the workplace, providing information to these types in the way they prefer and using the correct conceptualization techniques will allow organizations to achieve the most out of their design teams and create more innovative products.

One can use the results in many ways. From an educational standpoint, a professor could have an assignment asking the student to take a Myers-Briggs Type Indicator sorter and then use the results to study their preferred learning style. Then when the time comes to research the project, have the students do research that correlates with what they learned about themselves through their learning style study. From a business point of view, providing hands-on opportunities with products (such as benchmarking activities) for active experimenters and time to think and create theoretical models for reflective observers, would allow organizations to obtain the most from their individuals.

The next step to take on this topic is to design exercises for the other quadrants of C.J. Margerison's chart, Figure 3, to complete the correlations. If it can be determined that individual learning styles and conceptualization styles correlate, a relationship between different conceptualization techniques such as c-sketch, morphological matrices, 635, and brainstorming can be studied to see which types use them the most efficiently and can pull the most from them. Related work in this subject includes years of work done by Professors Doug Wilde and Jami Shah. Wilde has been involved in understanding MBTI in team settings and how to map them together to create great team dynamics as well as improving innovation amongst team members [13]. Jami Shah is currently involved in creating a standardized tests for determining design skills[30]. Studying team innovation has much merit and the same goes for creativity skills. However, innovation does not always take place in a team setting Knowing how to unleash individual creativity can address this situation. People may find themselves thinking about a project on the drive home, on a bike ride, or just on a lazy Sunday and providing them with information on how to be innovative while alone could be very useful. If the authors' future tests prove successful, work could be done to correlate these different measures with various styles of learning and innovation.

Innovation lies within the minds of everyone, but harnessing the creativity within can be a difficult process. Most people will agree if the result is more innovative products, perfecting this process is worth the time and effort.

ACKNOWLEDGEMENT

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THE SEARCH FOR INNOVATION STYLES II

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ABSTRACT

The Myers-Briggs Type Indicator test is known to be a quick and easy way to build good team dynamics and has been shown to improve group performance. Research has shown that the various MBTI personalities associate with different learning styles. This gives reason to believe that different individual designers synthesize data and conceptualize ideas differently thus having different needs and desires in a design environment. Providing designers with knowledge they can use to improve their innovation capabilities would not only help them create more innovative products but also improve their company and possibly change the very way a simple task gets completed today. This paper examines how Oregon State University junior level design students with different MBTI personality types take in and view information presented to them which is then used to conceptualize what hopes to be an innovative product.

Keywords: Personality, Learning Style, Innovation

INTRODUCTION

Innovation, creativity, and imaginative capabilities exist in everyone, but how people process information and ideas plays a role on whether or not their output contains these qualities. In the classroom, professors who want to reach all types of learners use a variety of teaching techniques to stimulate students with different personality types and learning styles [5]. This approach works well when instructing a heat transfer or machine dynamics class, but is difficult to implement in project-based courses – particularly product design projects where students are asked to create a solution with less instructor guidance and more team time and learning by doing. Teaching people to design innovative products may be extremely difficult, but nurturing it is what top Product Development companies such as IDEO, do best [2]. Allowing environments for various personality types to reflect, think, and examine information in a way that matches their learning style should lead to a more productive environment around them and help with creating innovative products. Determining a way to correlate Myers-Briggs Type Indicator personality and learning styles with an appropriate innovation style to produce more innovative products is also expected to produce a higher quality design and more concepts. Much time and resources are spent searching for innovative people, when looking for ways to make their existing workforce more innovative may be a better approach. By altering the presentation of design information it might be possible to affect the design, hopefully towards a more innovative product. Determining what individual designers need to be innovative in terms of work environment and research techniques during the early stages of their education would allow them to develop these skills. The research done here looks to explore a correlation between learning styles, information presentation, and innovative designs. This paper is a continuation of previous work done by the same author [31].

BACKGROUND

Innovation

By definition, innovation is the introduction of something new or a new idea, method or device [1]. Most designers believe that innovation is a good thing, something to strive for, and an accomplishment when achieved. Innovation drives product design. Fostering innovation in the workplace has been the quest of many companies in recent years. Scott Berkun worded innovation as:

> *"Any major innovation or insight can be seen in this way. It's simply the final piece of a complex puzzle falling into place. But, unlike a puzzle, the universe of ideas can be combined in an infinite number of ways, so part of the challenge of innovation is coming up with the problem to solve, not just its solution" [15].*

Providing designers with all the pieces of the puzzle is critical when trying to design a quality product. Designers should be able to locate the pieces through research, reading, experimenting with current products, or a walk through the park. Allowing an environment that helps the designer is crucial to creating the next great thing. The word environment is used here to describe the circumstances, objects, or conditions by which someone is surrounded [12], not just the physical aspects of the workplace.

Discussions with current students show the vast majority of engineers in training are competent in math and science but need to spend time developing their product development skills including creativity and innovation skills. However skills in innovation can be developed and matured and are extremely useful in concept generation and tackling open ended and real world problems [9]. An understanding of what an individual needs to be innovative is key. Tom Kelly wrote, “We all have a creative side, and it can flourish if you spawn a culture or environment that encourages it” [2]. Bringing the creative side out is different process for every individual but accomplishing it can lead to great things.

MBTI Theory

The Myers-Briggs type indicator (MBTI) is the most familiar and common temperament assessment used today[16]. In brief, the MBTI preference sorter identifies 16 temperament types. The reason for the MBTI test is to give individuals an understanding their preferences. This knowledge could then be used to help this person view options differently. It has become quite clear after asking questions about type development to thousands of participants, that enough evidence has been found to suggest that this is a very real and powerful force in adult growth. If properly understood, a person’s type can aid adults throughout their lives in making more conscious choices and general understanding of themselves [17].

MBTI Types

The MBTI preference sorter is based off the psychology work and personality types studied by C. G. Jung. He proposed four dichotomies: Extroversion or Introversion, Sensing or Intuition, Thinking or Feeling, and Judging or Perceiving[16], and I. Myers Briggs, created the preference sorter to place people within these categories.

The first dichotomy, Extroversion or Introversion, looks at where people focus their energy. Extraverts tend to focus their energy on other people and physical objects as well as the “outer world” around them, whereas introverts tend to focus energy on their “inner world” including their own concepts ideas and personal experiences. The second dichotomy, Sensing or Intuition focuses on how people perceive things. Sensing people tend to focus on facts, previous happenings, and happenings noted with one of the five senses whereas Intuitive people look at relationships, meanings, possibilities that were worked outside of the conscious mind. The third dichotomy, Thinking or Feeling, primarily deals with how a person makes judgment. Thinkers tend base their conclusions on logical knowledge, detaching themselves from the problem. Feelers on the other hand bring in personal and social experiences and values. The last dichotomy, Judgers or Perceivers, focuses on people’s attitudes on the outside world. Judgers prefer decisiveness and closure in dealing with the outside world while perceivers enjoy flexibility and spontaneity in their dealings [18].

An understanding of these 16 types is a key to effective team building which in turn can lead to an innovative team performance. One could form a team with an ISTJ for their good concentration, and reliance on facts and logic, an INFJ to grasp a variety of possibilities and organizational skills and an ENFP to keep the group happy and provide some adaptability. Career choices often correlate with a person’s MBTI preference. Table 3 shows a breakdown of engineering students’ MBTI preferences. Note that, for instance, roughly one third of engineers prefer ISTJ or ESTJ. This career preference by personality type correlation has been studied for other career fields as well. For example, INFJ’s are more likely to become psychologists or do other forms of counseling, and ESTJ’s are often bank officers or financial managers [18].

Combining different personality traits can create powerful team dynamics. However, there is a problem with this system. It works well to create a good team dynamic but leaves holes when it comes to certain tasks. While it is nice to know a person's strengths and weaknesses this can lead to profiling a certain type to do a certain thing. Attempts to determine team roles based off an individual's MBTI personality type have been conducted. One strategy is to break down the types into sixteen roles in which each person has two roles, a judgement role and a perception role. Some examples of the different roles are: Inspector, Diplomat, Mockup Maker, Investigator. There are two main innovation roles, the INTP where N>I, which is the Visionary role, and ENTP where N>E, which is the Innovator role. Doug Wilde stated that "... it is not only different types of expertise that people bring to the task. They also have distinct personalities and different ways of approaching and solving problems" [13]. These different problem solving approaches are crucial when trying to get the most out

Tom Kelly said innovation begins with an eye. The act of observing how products are used, on a firsthand basis is the first step in designing a new and better product[2]. Letting their workforce do what they feel is needed to accurately observe a problem is all about letting people with various personality types capture information in a way they seem fit. The research started in this paper is attempting to prove that innovative designs are a result of any person having viewed what they needed to in a way they needed to and not just having an innovative personality type.

MBTI types are closely associated with learning styles and such was their main use for this project [20]. By knowing a students MBTI type, their learning style could be determined, therefore MBTI served as a mediator between learning styles and innovation.

TABLE 3: ENGINEERING MBTI PERCENTAGES [19]

ISTJ	ISFJ	INFJ	INTJ
16.50%	4.60%	2.70%	9.50%
ISTP	ISFP	INFP	INTP
6.50%	2.60%	3.90%	8.50%
ESTP	ESFP	ENFP	ENTP
4.20%	2.30%	3.70%	7.40%
ESTJ	ESFJ	ENFJ	ENTJ
12.70%	3.50%	2.10%	9.40%

Learning Theory

In the 1960's studies were conducted and it became apparent that not all students easily understood the same teaching techniques. Research suggested that school systems needed to develop different methods of teaching in order to help students become successful academically. Work was done do correlate environmental stimuli, emotionality, sociological needs, and physical needs with learning styles to help children learn the most in a classroom setting [21]. In 1976 Benjamin Bloom proposed the model shown in Figure 12 [22]. This model contains three important elements of classroom learning: 1) Cognitive entry behaviors – the level of competence of the subject to be taught, 2) Affective entry characteristics – the extent of how motivated the student is to engage in learning the subject, 3) Quality of instruction - the instruction given appropriate to the learning style of the student. The model then takes these inputs and using "Learning Tasks" creates three outputs: Level and Type of Achievement, Rate of Learning, and Affective Outcomes. Affective outcomes concerns information such as how the student perceives their competence and how well they have learned. In theory, good Affective Outcomes provide reinforcing feedback for the Affective Entry Characteristics.

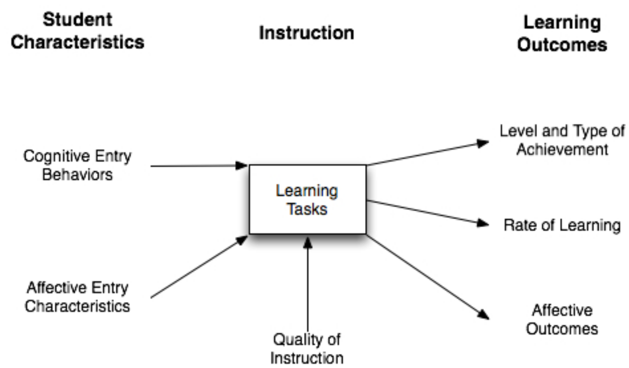

FIGURE 12: LEARNING STYLES FLOW[22]

In 1979 C.J. Margerison and R.G. Lewis created a relationship between learning styles and Jung's psychological types [20]. A graph of this relationship was created and is shown in Figure 13. The graph is divided up into four quadrants with each quadrant containing a different learning style. The scales on the axes represent the scores from the Learning Style Inventory (LSI) test. This test was created to help assess individual learning orientations. In a study of 220 participants Margerison and Lewis studied the relationships between MBTI types and LSI scores and found significant canonical correlations between the two[20].

Appealing to all four learning styles help keep students engaged in the classroom. A person experiences and acquires preferences in the different learning styles from birth to around year 15. Then they move into a stage of specializing their preferred learning styles between the ages of 16-40. Since the majority of college students taking design classes are between the ages of 18-22, this is an advantageous time to teach them how to understand and use their preferred learning style in these classes and to support earlier development of these styles ahead of their peers[23].

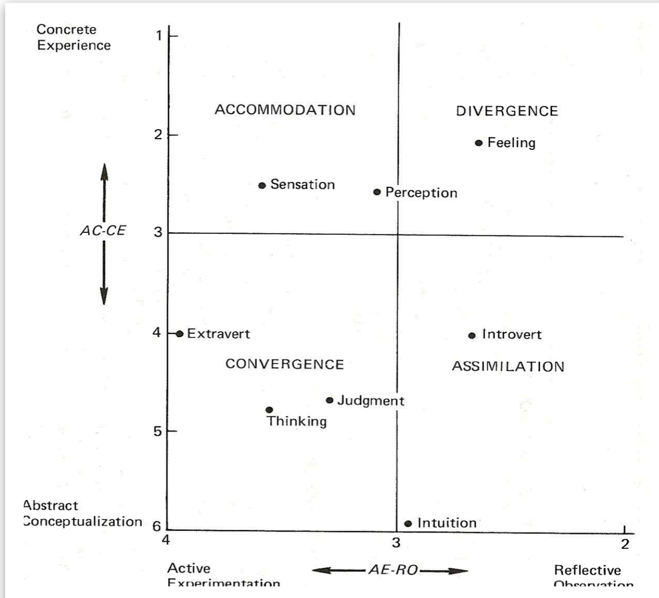

FIGURE 13: LEARNING STYLES MAP (IMAGE ADAPTED FROM[20])

RESEARCH

The purpose of this research is to determine if people are more innovative when receiving information in a particular learning style. The first step in doing this is defining a new construct of innovation style:

> ***innovation style*** *- the combination of learning styles and MBTI personality attributes that define a clear style of how an individual approaches solving a design problem.*

For consistency, adoption of the Margerison & Lewis [32] and Kolb [20] terminology was used for the four innovation style names: divergers, convergers, assimilators, and accommodators.

The Innovation Problem

Looking for a relationship between learning styles and the 16 MBTI personalities with innovation can designers understand their personal problem solving approach and aid in designing a more innovative product. Additionally, the ability to provide an environment that fosters innovation in all personality and learning types may lead to happy, creative, and productive employees (and result in innovative products). If an individual's needs for the environment around them are not met, that person might experience difficulties when trying to express ideas and create designs.

There are many reasons for attempting to learn how to bring out the innovator in people. As stated earlier, even though everybody has a creative side, they all access it in different ways. Therefore a problem exist when what one person views as an insightful observation may be completely be lost upon another person. If there is an understanding of what people need to access their creative side, then allowing the team members to explore these needs should create more creative and innovative results. Rowena Reed Kostellow once said

> *"There have been many theories of design and many valuable ways of analyzing both graphic and three-dimensional situations, but the unique quality of this curriculum which I am about to present is that it is structured in a way which quite literally covers any combination of design relationships which you may encounter and enables you to organize the abstract relationships for yourself."*[24]

Reed Kostellow claims that presenting the design problem and relevant data in a multitude of ways that covers nearly every aspect of the conceptualization process allows a person to organize relationships in the way they see fit. One of the most frustrating things about teaching is that you rob one student to make sure another one understands, reaching one group while confusing another, which is why teaching individual students how to discover their own innovation style is better than than trying to generalize it [25]. The approach followed involves specifying a design problem to help understand a possible correlation.

Research Questions

The research reported here explores whether presenting information to a person in their preferred method of learning leads to more innovative results. If proven successful, the work may provide people the knowledge on how to research ideas for a product more successfully.

Following from Bloom's model on learning styles (shown in Figure 12), the following analogy is proposed for innovation styles: Someone who has created an innovative product and is pleased with it should raise the motivation for creating another product. The analogous model for innovation styles was created and can be seen in Figure 14 [31]. This model contains three inputs, Cognitive Entry Behaviors, Affective Energy Characteristics, and the Quality of the Environment and three outputs, Level and Type of Innovation, Rate of Innovation, and Affective Outcomes. Of the three inputs, Quality of Environment is the only one the third party such as a teacher or employer has control over. Understanding what individuals needs in an environment to be innovative allows a third party to tweak it to obtain higher innovation levels.

The focus of this research is to determine if a correlation between a designer's MBTI personalities (the Cognitive Entry Behaviors) and the Level and Type of Innovation exists. Secondly, if the correlation exists, can the manner of information presentation to the designer affect their level of innovation.

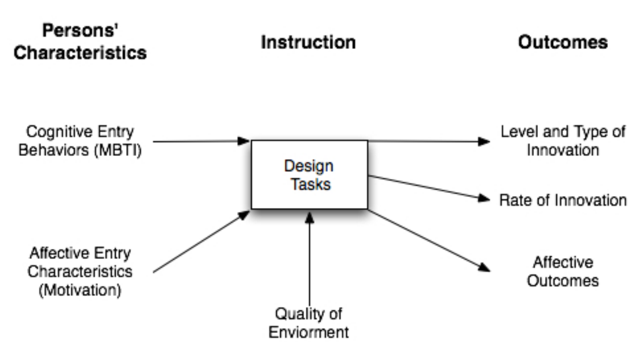

FIGURE 14: INNOVATION STYLES FLOW [31]

Measuring Innovation

In order to conduct the proposed research, a metric for innovation is required. Psychologists consider novelty and fluency, the number of ideas, to be the main measures of creativity for idea generation [33]. In this context, creativity is a related aspect of innovation. A number of different metrics for design problems have been used to evaluate idea generation techniques, including quantity of ideas, number of good ideas, practicality, novelty and variety [34-37]. Commonly used metrics to measure group idea generation are the quantity of non-redundant ideas and a quality rating [38]. Shah et al. [39, 40] developed a set of metrics specifically for the evaluation of engineering idea generation techniques including quantity, quality, novelty and variety of ideas. They noted the fact that engineering design (as well as apparel design) must meet a particular need and function thus requiring an expanded set of measures.

For this research, Donald Norman's three levels visceral, behavioral, and reflective [41] were used to analyze the results. The first level, visceral, is design that results in emotion from the viewer. In this level physical features such as look, feel, and sound are the featured. Visceral design revolves around initial reactions and therefore can be studied quite simply by analyzing reactions. The second level is behavioral design. This level is based of functionality, usability, how the product performs for the user. The crucial step in this level is matching customer needs with the functions of the product. In the last level, reflective design, the message or culture of the product is covered. What the product will mean to the user is studied and implemented into the design. Some of the questions and desires of the reflective portion of design are based on how the product will make the user feel, the self image they will project when using the product [41]. These three levels were used to analyze the final products of the study.

TABLE 4: PARTICIPANTS MBTI AVERAGE & STANDARD DEVIATION

	I	E	N	S	F	T	P	J	Type
Average	4.1	6	8.4	12	13	7.4	5.3	15	ESFJ
Standard Dev.	2.2	2.2	4.4	4.1	3.8	4.1	3.5	3.4	

Problem Implementation

The participants for this study were a collection of apparel design students entering the second term of their junior year. The first week of classes, all students took the Keirsey Temperament Sorter [26], which the results where then collected. The students were then asked to participate to complete an individual design problem, as presented by the author. This problem given was to design the ideal Oregon Winter Jacket. The deliverable was mostly up to the students but was recommended to just be rough sketches with annotations. The MBTI analysis provided information on which presentation style would be. The design problem was presented in a divergence style in that it was extremely people focused and open to appeal to the feelers. The other main group in the convergence style should struggle with this since they are not as people oriented and would rather have design details given to them over an open problem. The average score and standard deviation of the MBTI's of participants can be seen below in Table 4. A slight skew in the direction of a certain type, in this case ESFJ, is expected because certain professions tend to contain similar personality types [18].

RESULTS

Participant Description

The participants of the study contained 18 junior level apparel design students. In these 18 students, four were male. The MBTI breakdown between the 18 people can be seen above in Table 5. ESFJ was the prominent type with five participants of that type. One can see that only half of the total MBTI types are found in this sample. However all but one of the types ending in J, INTJ, were present.

TABLE 5: PARTICIPANT BREAKDOWN BY MBTI

ISTJ	ISFJ	INFJ	ENTJ
2	3	2	2
ESFJ	ENFP	ENFJ	ESTJ
5	1	1	2

Innovation Correlation

The work done by the participants was analyzed using Norman's three levels that were discussed earlier. This break down resulted into three groups. Participants that hit all three levels, participants that hit two levels, and participants that only hit one level. Looking at the work done, examples can be seen in Figures 15-18, it was noted that when all three levels were found in a product the result was more innovative and of higher quality. The most obvious gap between the three groups happens when looking at the one level sketches versus the 2 level sketches. This is shown in Figure 15 versus Figures 16, 17, 18. Figure 4 is mainly aesthetic based with very little function while Figures 16 and 17 go into detail about the jacket functions and how they are accomplished. Figure 18 takes the next step and slightly examines how the jacket will make the wearer feel when discussing the school spirit aspect. In Table 6 the results of the exercise can be seen. The green group hit the third level or did an in depth behavioral or functional analysis, and red group just hit the visceral level with maybe a very light look at behavioral. Because the gap in the quality of work and problem synthesis was fairly easy to find the division of the work into the two groups was fairly intuitive. A two tailed t test was preformed on the work and yielded positive results. The p-values of both the F (.007) and T (.024) fall below the .05 for significance, which is an excellent result for the exercise and shows that at least with this group the way in which the design information is presented holds great importance in the final design.

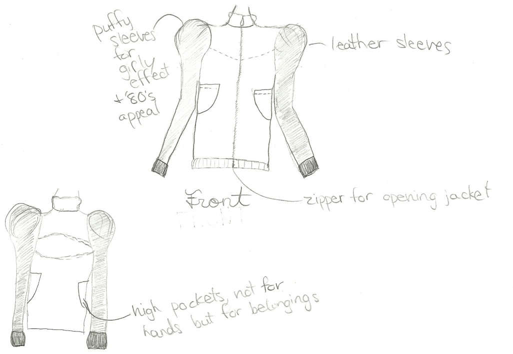

FIGURE 4: LEVEL 1

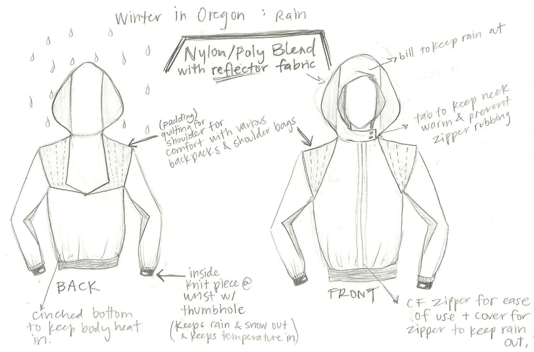

FIGURE 5: LEVEL 2

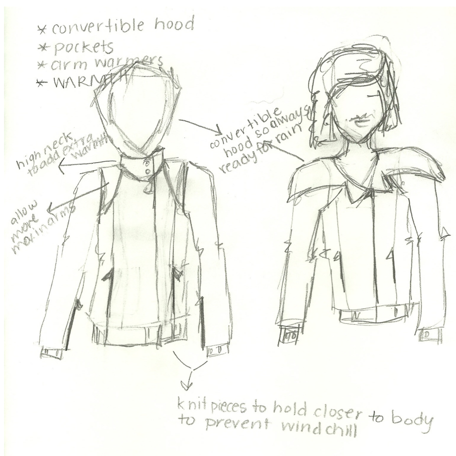

FIGURE 6: LEVEL 2

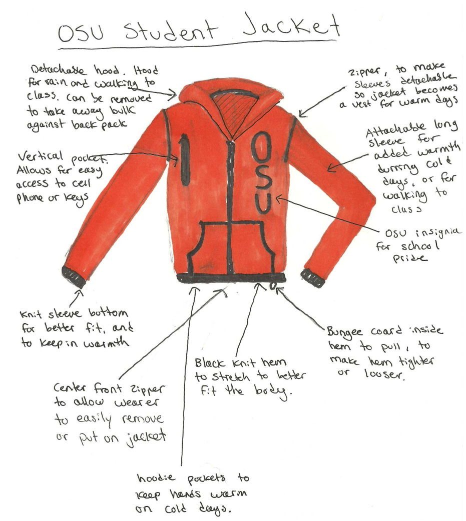

FIGURE 7: LEVEL 3

TABLE 6: TYPES, QUALITY, P-VALUES

Participant Number	I	E	N	S	F	T	P	J	Type
1	3	7	8	12	19	0	5	15	ESFJ
2	2	8	5	15	13	10	1	19	ESFJ
3	3	7	7	13	17	3	4	16	ESFJ
4	5	5	9	11	14	6	7	13	ISFJ
5	6	4	4	16	11	10	1	19	ISFJ
6	5	5	7	13	18	3	3	17	ISFJ
7	3	7	8	12	15	5	1	19	ESFJ
8	4	6	13	7	15	4	9	11	ENFJ
9	1	9	8	13	17	5	8	13	ESFJ
Stand. Dev	1.59	1.59	2.55	2.55	2.55	3.26	3.12	2.99	
Average	3.56	6.44	7.67	12.44	15.44	5.11	4.33	15.78	
P-Values	**0.172**	**0.237**	**0.464**	**0.59**	**0.007**	**0.024**	**0.253**	**0.209**	
Average	4.56	5.56	9.11	11.44	10.67	9.67	6.22	13.78	
Stand. Dev	2.60	2.70	5.78	5.32	3.24	3.64	3.73	3.60	
10	2	8	15	8	8	15	7	12	ENTJ
11	5	5	7	13	10	10	6	14	ISTJ
12	4	6	13	9	17	4	12	9	ENFP
13	8	2	12	8	11	9	10	10	INFJ
14	7	3	7	13	8	12	8	12	ISTJ
15	3	7	0	20	8	12	0	20	ESTJ
16	3	8	1	19	9	11	3	17	ESTJ
17	8	2	11	9	15	4	3	17	INFJ
18	1	9	16	4	10	10	7	13	ENTJ

CONCLUSIONS & FUTURE WORK

The work in this paper and in previous research [31] shows the importance of information presentation in design and offers support for the construct of an innovation style. The p-values obtained in this research do show statistical significance however the sample size of the exercise was not large enough to place large amounts of emphasis in this result. The result does show that there is more work to be done with this. Between the previous research and this work, two of the four innovation styles have been covered. The other two, assimilation and accommodation, should be studied to give completeness to this research. Another aspect of this research that is important is to cover a wide range of personality types. One of the current issues is that if you tailor a design problem for engineers only engineers will be able to fully comprehend the problem, and the same for apparel designers or other majors. That combined with the narrow focus of MBTI types in design fields, in this study only eight of the sixteen types were represented, which is the same total of the previous work [31]. However between the two studies 12 of the types have been present. Therefore it is crucial to branch out to various disciplines that partake in design to gain a selection of different types to work with.

A Function Based Approach to TRIZ

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ABSTRACT

Function based design methods - those that are largely a derivative of Pahl and Beitz's systematic approach - are a powerful tool employed in a variety of engineering design contexts. However, many other design methodologies exist and are useful in solving design problems. These methods include varying approaches from Suh's Axiomatic Design to Altshuller's Theory of Inventive Problem Solving (TIPS or TRIZ) to the business-motivated Ulwick's Outcome Driven Method. In this paper an attempt to merge the philosophy of functional design with the problem solving approach of TRIZ is undertaken. A framework is proposed combining functional modeling formalized by the Functional Basis with TRIZ. The process of merging the two methodologies is presented along with the key contribution, a matrix that relates the vocabulary of the Functional Basis with the 40 inventive principles of TRIZ. The use of the Functional Basis-TRIZ (FB-TRIZ) hybrid design methodology is described and a case study is presented demonstrating its use as well as the creative solutions that the approach affords.

INTRODUCTION

Many methods may be employed during the design process, as shown in prominent engineering texts including those from Pahl and Beitz, Ullman, Otto and Wood, and Cross [7-10]. These methodologies show many similarities. However, they do not completely align with each other; at best offering assistance to the designer in distinct steps in the design process and often in an incongruent fashion [11]. Other more holistic design methods have been developed such as Axiomatic Design, Theory of Inventive Problem Solving (TIPS or TRIZ), and Affordance Design [42-44]. These methods are not as commonly used and taught. This paper reports on the efforts of the authors to merge two prominent methodologies used in design - function based design enhanced by the Functional Basis and the TRIZ - into one streamlined approach. In order to communicate this hybrid methodology, the paper will (i) give a brief overview of engineering design and the two methods of interest, (ii) discuss the creation and mechanics of the new hybrid methodology, (iii) demonstrate the function and power of the new method with a case study, and (iv) discuss future work.

BACKGROUND

Engineering Design

While concepts of design and subsequent methodologies are present in many fields, this paper focuses on engineering design. Engineering design is the application of scientific knowledge to the solution of technical problems [7]. It is the path from the current state to a more desirable future state. Many have stated that the "path" of design may be made more efficient if certain processes are applied. From such authors as Pahl and Beitz, Ullman, Ulrich and Eppinger, Otto and Wood, and Cross [7-10, 45] a general recipe for designers to follow has been suggested. Included are stages for defining the problem, generating multiple solutions, evaluating and choosing a solution, and embodying the solution. Within each of these design processes there exist many specialized methodologies. This paper focuses primarily on the concept generation stage of design and merging two methodologies that serve in the concept generation facet: function based design and TRIZ.

Function Based Design

Function Based Design. Pahl and Beitz introduced function based design with their book Engineering Design: A Systematic Approach. Function based design allows an engineering connection between customer needs or requirements and the function of a product. Fulfilling this relationship allows for a design process that achieves a product that meets the expectations of the customer. Function based design allows for the analysis not only of the functions of the system but the flows throughout the system as well. This is useful as it shows how input materials, energies, and signals are transformed throughout the system. The popularity of this design approach has led to many design texts that have been published using or building upon this design method, (eg. Otto & Wood, Ullman, Ulrich & Eppinger, and Dym & Little) [8, 9, 14, 45]. These popular engineering design texts suggest the use of function based design in the conceptual design stage.

The primary contribution of function based design is the ability to use functional abstraction to help design products. Many prominent texts go over this abstraction process. The primary benefit of creating this abstraction that it allows the designer to focus on overall requirements and constraints by allowing the disregard of form and fixation. This disregard helps the designer generate more solutions since design fixation is lessened [9].

Another very important contribution of function based design is the concept of the functional model. A functional model is used to create an abstract representation of a product or what functions must be accomplished for the product to work. This representation assists the designer in developing unbiased solutions to what specific functions the product must accomplish by analyzing the functions and flows of the system and connecting those to engineering requirements. As one can imagine, this modeling process can and does vary from designer to designer, so to standardize the process of creating a functional model a Functional Basis was formulated [46]. The Functional Basis is a list of function and flow terms used to create functional models that intends to comprehensively represent the product design space. These specific words intend to unify the process and allow any designer to analyze another designers' functional models without getting lost in translation. The Functional Basis will be discussed further.

Functional design is extremely focused on satisfying product function. Therefore the products from this process tend to be highly "functional" in that they work well but sometimes lack a well executed customer interface or aesthetic. In fact, solving function alone may result in product forms with contradictions that arise in their operation. Implementing a contradiction solving approach with functional design is needed to address this issue.

Functional Basis. Development of a Functional Basis for design began with the intent to make function computable. Studies found that functional models lacked consistency from designer to designer, and it was postulated that creating consistency between the function and flow terms used would allow more accurate communication of information between people. Development of the Functional Basis started by analyzing terms used by Value Analysis, Pahl and Beitz, Hundal, and subsequent other authors methodologies [7, 47, 48]. The first Functional Basis contained terms broken into 3 levels of abstraction: class, basic, and flow restricted. Class being the highest level and flow restricted being the most specific[49]. This work was later revisited and the Functional Basis was reconciled with a similar effort at NIST [50] and evolved into the list currently used today. This list contains the same hierarchy used originally with three classes of abstraction: primary, secondary, and tertiary. There are three primary flow terms, 20 secondary flow terms, and 22 tertiary flow terms. The function terms are broken down into eight primary terms, 21 secondary terms, and 24 tertiary terms [46].

The Functional Basis not only allows for designers to communicate more effectively with each other using standard functional model language, but also a suite of computational tools to assist the design are also afforded by such a common language [46]. A key embodiment of this is a Design Repository which currently holds function and flow information for 6447 components found in 167 products from various domains[51]. There are many involved design tools that seek to make the large amount of data held in the repository of use to the designer. However, the most basic of these is, using a search function within the Design Repository, the designer may search all existing products to see how a function/flow pairing of interest has been addressed in a diverse array of products; to see how various "forms" have followed virtually the same "function". For example, a designer developing a new thermal shield on spacecraft might be prompted to investigate the coffee mug as both devices are looking to accomplish a similar function. This introduction of "out of the box" ideas promotes creative and novel solutions that have stood the test of time in other applications. Beyond the traditional search techniques, concept generation using the organized terms of the Functional Basis has been automated in recent years. One such example of concept generation can be found in Bryant et. al [52] where the formalized terms of the Functional Basis are needed to parse a database of existing design knowledge.

TRIZ

The Theory of Inventive Problem Solving (Russian acronym: TRIZ) was developed in the 1940's by Genrich Altshuller, a Russian inventor, patent clerk, and author [43]. Altshuller sought to develop a pattern that anyone could follow in order to create innovative solutions, and in doing so dispelled myths of the day that invention was random and possible by only a select few persons. To develop such a pattern, Altshuller and his colleagues performed an exhaustive search of more than 200,000 patents. From this survey, Altshuller found that many inventions were characterized simply by the application of principles to solve contradictions among technical characteristics. Once this pattern was recognized, both the characteristics found in the patents as well as the principles employed in their solutions were identified and then distilled into a reasonably comprehensive (estimated to cover over 90% of patents surveyed) set of 39 technical characteristics and 40 principles, a sample of which can be found through examples shown in this article with the full lists found the Table 7.

Perhaps the greatest contribution made by Altshuller was the connection of these two data sets. Based on information from the patents, he linked the principles to contradictions between technical characteristics using a matrix termed the "Contradiction Matrix". In this 39x39 matrix technical characteristics are listed on both the vertical and horizontal axes while the principles that may be used to address such contradictions are found in the associated cell. A subset of the matrix is shown in Table 8.

TRIZ design methods treat design as an inventive problem. In this light, there are

TABLE 7: THE LIST OF TECHNICAL CHARACTERISTICS AND PRINCIPLES [43].

List of Technical Characteristics	List of Innovative Principles
1. Weight of mobile object	1. Segmentation
2. Weight of stationary object	2. Extraction
3. Length of mobile object	3. Local quality
4. Length of a stationary object	4. Asymmetry
5. Area of a mobile object	5. Consolidation
6. Area of a stationary object	6. Universality
7. Volume of a mobile object	7. Nesting
8. Volume of a stationary object	8. Counterweight
9. Speed	9. Prior counteraction
10. Force	10. Prior action
11. Tension/Pressure	11. Cushion in advance
12. Shape	12. Equipotentiality
13. Stability of composition	13. Do it in reverse
14. Strength	14. Spheroidality
15. Time of action of a moving object	15. Dynamicity
16. Time of action of a stationary object	16. Partial or excessive action
17. Temperature	17. Transition into a new dimension
18. Brightness	18. Mechanical vibration
19. Energy spent by a moving object	19. Periodic action
20. Energy spent by a stationary object	20. Continuity of useful action
21. Power	21. Rushing through
22. Loss of energy	22. Convert harm into benefit
23. Loss of substance	23. Feedback
24. Loss of information	24. Mediator
25. Loss of time	25. Self Service
26. Amount of substance	26. Copying
27. Reliability	27. Dispose
28. Accuracy of measurement	28. Replacement of mechanical systems
29. Accuracy of manufacturing	29. Pneumatic or hydraulic construction
30. Harmful factors acting on an object from outside	30. Flexible films or membranes
	31. Porous materials
31. Harmful factor developed by an object	32. Changing the color
32. Manufacturability	33. Homogeneity
33. Convenience of use	34. Rejecting and regenerating parts
34. Repairability	35. Transformation properties
35. Adaptability	36. Phase transition
36. Complexity of a device	37. Thermal expansion
37. Complexity of control	38. Accelerated oxidation
38. Level of automation	39. Inert environment
39. Capacity/Productivity	40. Composite Materials

three core steps to applying the TRIZ method. First, the designer should decompose

the system, analyzing each component and determining the system's characteristics in language congruent to the technical characteristics presented by TRIZ. The key task in this first step is to identify problems or contradictions that exist in the current system and decide whether to focus on improving positive characteristics or decreasing negative characteristics of the system.

Second, the designer should clearly state the contradictions that exist within the system, remembering that a contradiction occurs when the improvement of one characteristic will cause a negative change in performance of an opposed characteristic. For example, one might wish to increase the size of a vehicle while requiring no additional need for power.

Finally, the contradictions stated in step two might be resolved using the Contradiction Matrix. Further examples of a TRIZ solution may be found in "40 Principles; TRIZ Keys to Technical Innovation" [53] as well as in the case study section below.

TABLE 8: A SELECT PORTION OF THE TRIZ CONTRADICTION MATRIX [43].

		Characteristic that is getting worse			
		Weight of a mobile object	Length of a mobile object	Speed	Power
	Weight of a mobile object	X	8,15,29,34	2,8,15,38	12,36,18,31
	Length of a mobile object	8,15,29,34	X	13,4,8	1,35
	Speed	2, 28, 38, 13	13,14,8	X	19,35,38,2
	Power	8,36,38,31	1,10,35,37	15,35,2	X

While the TRIZ methodology involves many higher-level tools such as ARIZ (Algorithm of Inventive Problem Solving) and Substance Field Analysis [43], arguably the most accessible and frequently used contribution from TRIZ is the Contradiction Matrix. This matrix may be used to solve a wide variety of conflicts found in design problems in many different domains.

It should be noted that while the Functional Basis and TRIZ have many differences, at the fundamental level, they are very similar. Each design method seeks to introduce the designer to information from previously successful designs, mined through empirical analysis of design data from a variety of sources. The expectation is that novel ideas may be generated introducing high quality and proven "out of the box" concepts. In this way, Functional Basis and TRIZ are natural candidates for a combination that could yield innovative results.

INTEGRATION OF TRIZ INTO FUNCTIONAL BASIS

Review of Methodology Combinations from Literature

The work presented in the following sections of this paper represents the authors' effort to combine the powerful conflict resolution tool of TRIZ into the all-encompassing design methodology proposed by Pahl and Beitz wherein functional models are one of the key artifacts used by the designer in the abstraction of the design problem.

The concept of comparing and combining design methodologies is not unique. Examples include the comparisons of TRIZ and Axiomatic design [54, 55], the supplemental use of TRIZ in the Robust Design Framework [56], and a comparison of function based design and TRIZ [57]. TRIZ has been integrated with several problem solving tools often used in function based design: Quality Functional Deployment, Taguchi's methods, Axiomatic, Six Sigma, value analysis, Design for Manufacture and

Assembly, Failure Mode and Effects Analysis, as well as others [58, 59].

Despite being integrated with these tools TRIZ was not found to have ever been integrated into a functional ontology such as that set forth by Pahl and Beitz or the Functional Basis. However, it should be noted that the larger suite of TRIZ associated tools does include a functional modeling component. Such functional decomposition in TRIZ is referred to as Functional Analysis. More details may be found in Gadd's book Triz for Engineers: Enabling Inventive Problem Solving [60]. Several important observations are afforded by this literature review. First, it appears that beneficial results may be obtained when seemingly contradictory design methods are used to complement each other. Second, while TRIZ has been used as a complimentary method to other design methods or tools, and while the concept of functional modeling has been introduced into the TRIZ framework, little work has been done to integrate TRIZ into the broader function based design methodology.

While the Malmqvist et al. study did seek to compare the two methodologies of function based design and TRIZ, the work offered little information as to how the two might be used in a congruent manner. However the authors did state that TRIZ contains solution-finding tools that are more powerful tan the function based correspondents. Also found was a partial mapping between the design principles used by the two methodologies and it was stated that "A more powerful methodology may result if the methodologies are unified [57]." It was suggested that the resulting methodology would use function based design as the underlaying process and integrated TRIZ at points throughout it. This work seeks to offer a clear explanation describing the implementation of TRIZ in the overall design process of function based design.

Development of the FB-TRIZ Matrix

In order to integrate the two methodologies, the authors sought to find a way to merge the powerful problem resolution methods employed by TRIZ into the more all encompassing design process of Pahl and Beitz. First the authors identified the concept generation stage as an adequate location to integrate the TRIZ in the overall framework of function based design. This agrees with the literature which suggests TRIZ as a tool to be used in the "early stages of design" [57] and identified as a method fit best for concept generation [8].

Once the location of the merger was identified, connections between the two methodologies were required. This was not trivial as contradictions are the cornerstone of TRIZ but they are not typically mentioned in function based design. The authors looked to the subject-verb nature of the Functional Basis as well as word tendencies in TRIZ. It was found that the technical characteristics of TRIZ were typically a property of an object or product (volume/density of object, energy, etc) as are the flows found in the Functional Basis (all grouped under the three main classes Material, Energy, and Signal). Conversely, the principles in TRIZ nearly all involve some action (prior action, dispose, do it in reverse) while the functions listed in the FB are all verbs or action words (branch, channel, connect, etc.).

In order to pursue these connections, each TRIZ innovative principle was reviewed by the authors and subsequent functions that the principle applied to were identified. For example, the principle "spheroidality" is defined by Altshuller as "Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes. Use rollers, balls, spirals, and replace linear motion with rotational motion" [53]. From this description it was identified that the spheriodality principle could apply to the functions "shape material" and "convert translational energy to rotational energy". These functional terms involve changing the shape of the material or changing a linear motion to a rotational motion which coincides with the TRIZ principle of spheroidality. In this manner the entirety of the 40 principles were processed and connected to the terms of the FB. Once these links were made, the list of terms was inverted in order to show the connections in reverse. Table 9 shows the result of the work, the FB-TRIZ Matrix. As can be seen, the list of functions from the

FB is presented on the left side of the table while the subsequent TRIZ principles associated with each FB term are given in the three columns of the table to the right. These show which of the primary flow types (material, signal, and energy) the principles apply to give a fundamental connection to the typical function-flow pair that describes product functionality. Some of the principles identify specific flows or energy types. This is shown by superscript numbers that are can be explained by the caption below the matrix. As a check, each technical characteristic of TRIZ was

TABLE 9: FUNCTIONAL BASIS-TRIZ CORRELATION MATRIX

		Material	**Energy**	**Signal**
Branch	**Separate**	1, 2, 15, 27, 30, 40	1, 2	1, 2
	Distribute	3, 24	3, 11	3, 24
Channel	**Import**	39 [1]	8[2], 37[3]	
	Export	2, 27, 34	2	2
	Transfer	10, 24, 34		24
	Guide	12, 15, 17	13	
Connect	**Couple**	6, 7, 8, 24, 39	6	6, 8, 24
	Mix	5, 33, 39, 40	5	5,
Control Magnitude	**Actuate**		9[4], 15, 18[4]	4, 15, 26[5]
	Regulate	16, 20, 21	16, 19[4], 20[4], 21, 38	16, 19, 20, 21
	Change	4,14, 31, 32, 33, 34, 35, 36[6], 38, 39[1]	9, 13, 20, 35, 37, 38	10, 32[5], 35
	Stop	11		15
Convert		17, 22, 29[7], 36	14[8], 19, 22, 28[9], 37	22
Provision	**Store**	5, 7, 10, 25, 26	9, 10, 25	
	Supply	10, 11, 24, 39	10	10
Signal	**Sense**	23	23	11, 15
	Indicate			23, 32
	Process			23
Support	**Stabilize**	7		
	Secure	5, 7		5, 7
	Position	5, 10, 12, 13, 17, 18	5	5, 10, 13

correlated to a flow class of the Functional Basis. Then the entire row of the FB-TRIZ Correlation Matrix was reviewed to make sure that the associated principles were captured in the flow column of Table 9. Each principle was reviewed to make sure it was relevant for the function flow pair.

One contributing factor to the difficulty of merging the two lists was the fact that the FB was constructed based on clear grammatical rules while little, if any, attention was given to grammatical rules in TRIZ. Additionally, a portion of the TRIZ principles seemed to suggest evaluation of material selection while the FB does not cover this realm. Although these differences did exist, the overall strong correlation between the actions suggested by TRIZ principles and the actions listed as functions in the FB made meaningful connection between the two lists possible.

It should be noted that the 40 TRIZ principles shown in Table 7 were not developed to be used as stand-alone solutions but were rather created based on the observation of solutions to technical contradictions between attributes of a system. Although the methodology presented in this paper might seem to advocate the use of the 40 principles without any contradictions, and this is the case on the most rudimentary level, unidentified contradictions exist many places in the function of devices, and thus in the functional models. Therefore, although not identified, the principles are addressing previously unidentified contradictions when employed using this method. In this way, principles will be identified that would not previously be identified using TRIZ as a stand alone method, wherein the designer must identify the contradictions. This lessens the amount of work on the part of the designer because identifying the contradictions posed by the product is often challenging.

Use of the FB-TRIZ Matrix

Another use of the FB-TRIZ Matrix is the allowance in the case study below. In general the process is very similar to the function based design approach presented by Pahl and Beitz as well as Otto and Wood. Once the design team has entered the concept generation stage, after they abstracted the problem and created a black box and then functional model, the team may consult the FB-TRIZ Matrix for additional concepts. As this method introduces the team to new and innovative principles that inspire concepts which are not necessarily covered in other concept generation tools (even using TRIZ alone), the authors expect many novel design concepts to arise from the use of the FB-TRIZ Matrix. Another use of the FB-TRIZ correlation matrix is helping the designer solve contradictions in the prototyping phase. When encountering difficulties and problems while prototyping the component solution of a given function, the TRIZ innovation principles can be applied to the problem. The first step when using the FB-TRIZ Matrix is to do an analysis at the black box level. This analysis should identify the main function of the system. If this does not yield the desired results then the black box model can be decomposed down into a functional model for further analysis. This procedure is illustrated in the following case study.

CASE STUDY

In order to demonstrate the power (or function) of the integration of TRIZ into the Functional Basis framework, the authors sought to implement the hybrid methodology on a case study. A design problem involving an ice breaker ship was chosen. This example was presented in Altshuller's book "40 Principles: TRIZ Keys to Technical Innovation" and is defined as follows: Icebreakers are necessary in the winter to free waterways in order that cargo may continue to be transported. The speed of the current icebreaker should be increased three fold while the power requirements remain the same [53].

TRIZ Approach

Altshuller identifies two technical contradictions: First, the speed is to increase while the power must remain the same. Second, Productivity of the icebreaker should increase while again power must stay the same. Once these contradictions are identified, the TRIZ contradiction matrix may be used to identify appropriate principles. In this case six principles are identified in the two matrix cells pertaining to the two contradictions. Three of these six principles are discussed further. First, it is noted that principle #19 (periodic action) may be implemented to accomplish the desired improvements in the icebreaker by incorporating some ramming motion into the working of the icebreaker. Second, from principle #35, the transformation of properties, the designer is prompted to think about changing the physical shape of the icebreaker as it interacts with the ice. Third, principle #2, extraction, proposes the removal of some component of the ship. Finally, principle #10, prior action, suggests that some action might occur prior to the contact of the ship with the ice.

The combination of each of the concepts put forth by the principles lead Altshuller to propose a ship with a fully submerged hull with only thin vertical blades that rise on each side of the ship and travel the length of the hull connecting the ship's cabin and deck to the submersed hull. Because these thin blades are the only part of the ship at the water/ice line of the boat, the icebreaker may cut through the ice much faster, accomplishing the goals of the design problem posed.

While, the new icebreaker design proposed by Altshuller theoretically accomplishes the optimization goal as stated in the design problem, the solution proposed gives rise to many other problems. For example, the ship configuration suggested only affords a narrow range of cargo weight as most of the buoyancy for the ship comes from the fully submerged part of the hull. In addition the hydrodynamic performance of the ship in heavy seas is of concern. This critique is not meant to discount the TRIZ solution but instead seeks to identify the power of TRIZ to introduce novel solutions to problems that might otherwise be solved with traditional and existing concepts.

The Functional Modeling/TRIZ Hybrid Approach

Following functional modeling protocol, first the customer needs are identified. Clearly in this case the need for a passable waterway is paramount. Additional customer needs might be to minimize cost and maximize the rate of ice removal.

These needs are congruent with those stated in the TRIZ handbook [53].

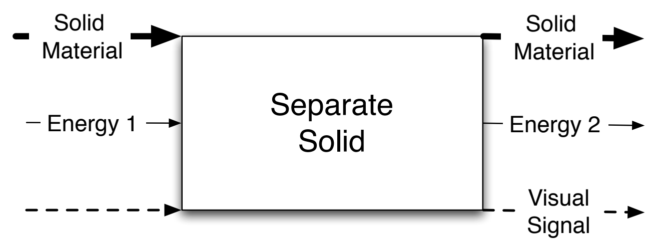

FIGURE 19: ICEBREAKER BLACK BOX MODEL

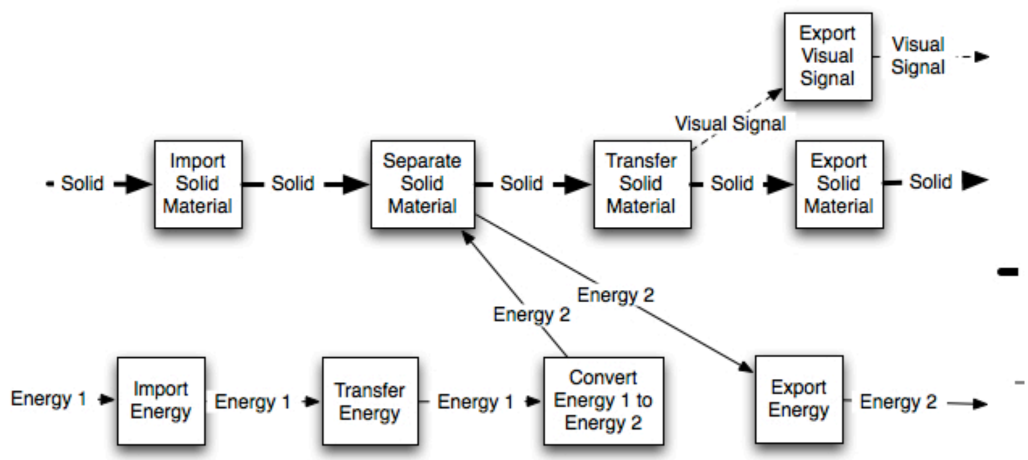

FIGURE 20: ICEBREAKER FUNCTIONAL MODEL

After the customer needs are identified, first a black box model, Figure 19, and then a functional model, Figure 20, for the ice breaker may be composed using vocabulary of the Functional Basis. The black box and functional model used for this study was generated by the authors who are experienced functional model creators. The black box model isolates the overall function as “Separate Solid” - obviously the key function of an icebreaker vessel. The functional model contains such functions as “Separate Solid”, “Transfer Solid”, “Convert Energy” and “Export Solid”. After identifying the functions needed for the product the FB-TRIZ Correlation Matrix can be used. The black box model analysis in Table 10 only returned one of the six principles identified in the icebreaker problem, extraction. The functional model analysis in Table 11 shows the TRIZ principles correlated with the key functions of the model. identified five of the six principles: extraction, prior action, periodic action, transformation of properties, and accelerated oxidation. Once the TRIZ principles are identified, several interesting and novel solutions may be gathered using the FB-TRIZ Correlation matrix shown in Table 9 to enrich the concepts generated by traditional functional modeling methods.

TABLE 10: PRINCIPLES FROM ICEBREAKER BLACK BOX [53]

Functional Basis Functions	**TRIZ Principles**
Separate Material	1, **2**, 15, 27, 30

TABLE 11: PRINCIPLES FROM ICEBREAKER FUNCTIONAL MODEL [53]

Functional Basis Functions	**TRIZ Principles**
Separate Material	1, **2**, 15, 27, 30
Export Material	**2**, 27, 34
Transfer Material	**10**, 24, 34
Convert Energy	14, **19**, 22, 28, 37
Guide Material	12,15,17
Change Material	4, 14, 31, 32, 33, 34, **35**, 36, **38**, 39
Export Visual Signal	**2**

Generating Concepts

The authors picked four principles generated from the functional model: 1, 14, 27, 15 to investigate. This included three principles from the black box model (separate material principles: 1, 15, 27) and another from functional model (change material/ convert energy principle 14). These functions where chosen because they were deemed functions that played important roles in the icebreaker's overall function. The authors then applied the innovative principles chosen in the generation of four concept sketches.

Concepts Generated:

Principle 1: Segmentation

"Divide an object into independent parts, make and object sectional, increase the degree of an object's segmentation"[53].

From principle one, a ship with multiple hulls such as a catamaran is suggested. This was shown in Figure 21. Two smaller ships completing the same task might be employed with favorable results and is another concept that could be developed with this principle.

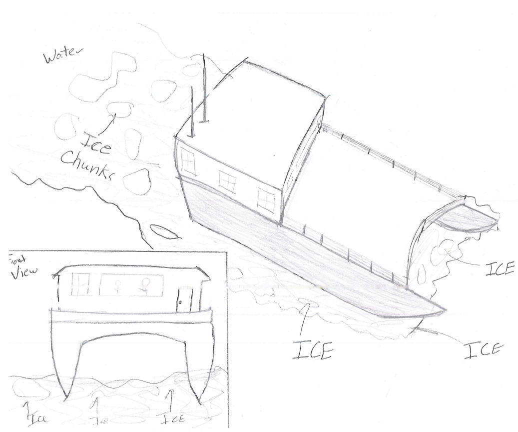

FIGURE 21: PRINCIPLE 1 SEGMENTATION SKETCH

Principle 14: Spherodality

"Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes. Use rollers, balls, spirals. Replace linear motion with rotational motion; utilize centrifugal force."[53].

Principle 14 suggests the translation of linear motion to circular motion. From this obscure recommendation, a novel and functional concept may be generated. In such an icebreaker, a large circular blade (much like that of a pizza cutter) may be pressed down on the ice in front of the bow of the vessel, effectively lifting the bow of the icebreaker out of the water. As the boat motors ahead, the rotational blade rolls over the ice, scoring it deeply, preparing the ice for removal from the path. See Figure 22 for details.

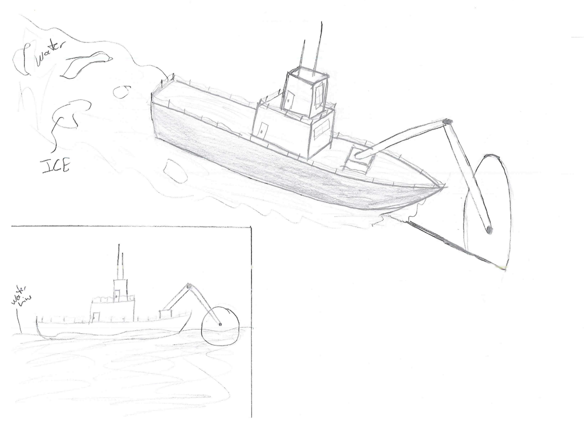

FIGURE 22: PRINCIPLE 14 SPHERODALITY SKETCH

Principle 27: Dispose

"Replace expensive object with a cheap one, compromising other properties." [53].

A temporary or disposable icebreaking apparatus is suggested by principle 27. In this case, a faux bow may be fixed to either the icebreaker or the cargo ship itself. The temporary bow should have ice breaking properties not capable with a permanent bow. For instance, this bow might have a very low angle of incidence, be long and sharp. While such a bow might not be favorable in open water, it may be positioned when ice is present and may offer considerable economic incentive when applied to the cargo ship alone as shown in Figure 23.

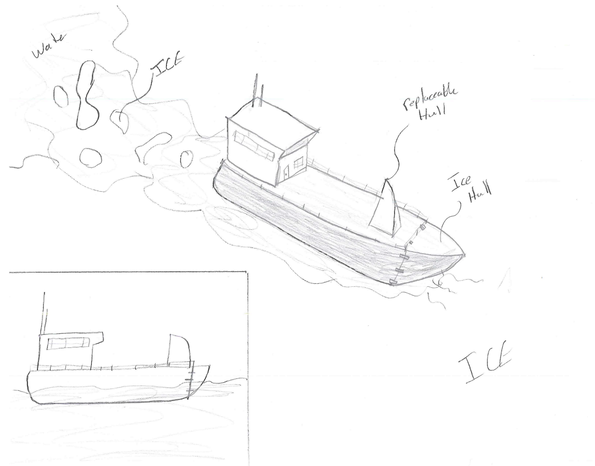

FIGURE 23: PRINCIPLE 27 DISPOSE SKETCH

Principle 15: Dynamicity:

". . . Divide and object into elements capable of changing their position relative to each other." [53].

A possible solution suggested by principle 15 is shown in Figure 24. In this solution, a blade similar to that of a plow used for soil is attached to the bow of the boat. This not only divides the ice as a standard hull would but also increases the degree to which the segments of removed ice may "change their position relative to each other" and therefore be removed from the path of the ship

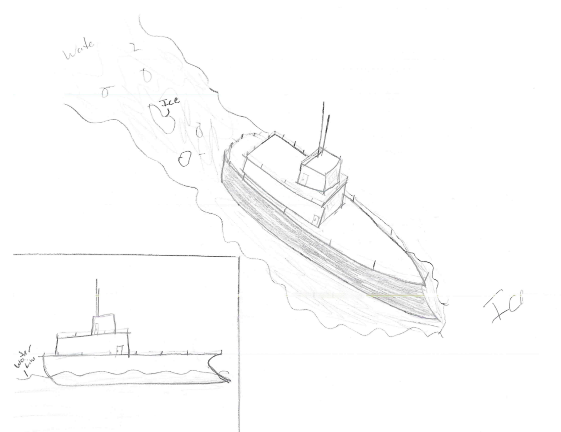

FIGURE 24: PRINCIPLE 15 DYNAMICITY SKETCH

Comments of Case Study

When reflecting on the case study presented, several noteworthy items may be identified. First, the FB-TRIZ Matrix generated four concepts that appear to the authors to be on similar level of quality as those generated using the stand-alone TRIZ method as shown by Altshuller. However, the authors acknowledge that this hybrid methodology is best suited for use early in the design process when generations of many innovative solutions is paramount. Once the functional model was complete for the design problem, the use of the FB-TRIZ Matrix was straight-forward given an understanding of the TRIZ principles. Second, as anticipated, while there was a degree of overlap in the innovative principles generated by Altshuller using contradictions identified by him, there were several new principles generated by the FB-TRIZ Matrix. This is to be expected as contradictions generated by the designer will naturally vary. This is an advantage of TRIZ as often the context within which the solution will be embodied causes slight subtleties not addressed by other design methods. However, by using the FB-TRIZ hybrid method there is also value in the systematic generation of innovative principles facilitated by following function based design and using the FB-TRIZ Matrix.

CONCLUSIONS/FUTURE WORK

The Functional Basis-TRIZ Correlation Matrix allows designers following the systematic approach to and associated method of the function based design approach to draw upon the innovative power of TRIZ. Upon construction of a functional model using the Functional Basis, the designer may use the FB-TRIZ hybrid method to elicit applicable innovative principles from TRIZ and therefore increase the total number of innovative concepts generated.

Many important tasks await this project. First, future work must include the addition of authentic case studies of this hybrid method approach. A somewhat trivial case study, as shown in the TRIZ literature, was presented in this paper in order to demonstrated the mechanics of the new method. However, studies are needed to investigate the actual contribution that the FB-TRIZ hybrid method can make to a design team working on a real world problem. Additional studies could seek to quantify the effects of this method in the concept generation stage when compared to some of the more traditional concept generation methods. A study using four test groups, one using no method, one using TRIZ, one using function based design, and one using the FB-TRIZ hybrid method would allow for an analysis on concepts generated by this method in comparative to the other methods. The results of this study could be analyzed using the metrics introduced by Shah [61]. This would allow for a more rigorous review on the quality of the concepts produced by the FB-TRIZ hybrid method.

There is also work that needs to be done in the validation of the FB-TRIZ Correlation Matrix. The authors did extensive reviews attempting to achieve the best correlations possible, but to identify these correlations as fact, the matrix should be reviewed by other TRIZ/Functional Basis experts for completeness and accuracy. Another way to examine the accuracy of the matrix is examine functions in current products and see if the components used to solve those functions follow the innovative principles.

Additionally, the present work only aims to facilitate the manual use of TRIZ for designers. An important extension of the FB-TRIZ hybrid method is the investigation into the integration of TRIZ into the computer automated design tools made possible by archived design knowledge. This integration could take many possible paths and one possibility is the re-evaluation of the designs contained in a design repository with tags that connect both technical characteristics as well as the innovative principles outlined by TRIZ.

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CONCLUSION

The research in the first two manuscripts show that the different learning styles of various Myers-Briggs personality types correlate with how those types process information to create product concepts, more importantly the level of innovation in those concepts. After presenting the design information in the preferred method of a predetermined learning style helped the participants of that style produce better results when attempting to design products. Understanding what learning style designers need can benefit both in the classroom and the workplace. If a professor understands what a certain student needs to bring out the innovator in them, they can make recommendations to the student on what style they should do to maximize their potential or run various exercises that would appeal to the different styles. This could make the student's project more successful leading to a higher affective entry characteristics as well as teach the student how to access their personal innovation skills whenever a situation warrants them. This research helps fulfill one of the purposes of MBTI sorters, people taking the information and learning about and improving themselves [28]. In education and the workplace, providing information to these types in the way they prefer and using the correct conceptualization techniques will allow organizations to achieve the most out of their design teams and create more innovative products.

The p-values obtained in this research do show statistical significance in the second study group. In the first group the p-values were close enough to be considered inconclusive on a possible correlation. However the sample sizes of the exercises ran were not large enough to place large amounts of emphasis in this result. The result does show that there is more work to be done with exploring this correlation. There are also a few confounding factors that need not be overlooked. One of the main ones is domain knowledge. There was an attempt to control this by using participants that were all at the same level in school and had undergone the same classes. However neither the grades they received in those classes nor any experiences outside of the classroom were considered thus some of the students may have had more experience with the object being designed than others allowing an unfair advantage. Another confounding factor is the amount of MBTI types in each study. Each study contained eight of the MBTI types which is half of the total. The engineers where given information in the convergence style because all four types that should be innovative in that style were represented and same with the apparel designers and the divergence style. Despite the tailoring of the information away from those missing types, one can not conclude how the other eight groups would have done. It is hard to control both of these factors together as most groups with the same domain knowledge will have have very similar MBTI types and groups with a vast array of MBTI types will usually have different areas of domain knowledge.

The last manuscript presented a framework and tool to help render innovative ideas. The Functional Basis-TRIZ Correlation Matrix, which allows designers following the systematic approach to design put forth by Paul and Beitz and built upon by many others, also allows the user to draw upon the innovative power of the TRIZ contradiction matrix. After the construction of a functional model using the Functional Basis, this method allows the use of the FB-TRIZ Correlation Matrix to assist the designer in choosing relative and innovative principles from TRIZ. This approach is expected to increase both the total number of concepts generated as well as their innovation potential. Two important tasks await in the future of this project. The first task is the inclusion of additional authentic case studies of this hybrid method approach. The addition of these case studies will help with the verification of this method. A somewhat trivial case study, as shown in the TRIZ literature, was presented in the third manuscript in order to demonstrate the mechanics of the new method.

There are many steps to continue and complete the innovation styles research. One of the first is creating and implementing design exercises for the two quadrants not discussed, accommodation and assimilation. One of the struggles with creating these is finding a group suitable to do the design exercises with. The participant group needs to have enough of the corresponding type in it so that enough people do well, but at the same time enough of the non corresponding type to have other results to compare it too. Another study to complete is looking at a multi discipline design project. For example, an exercise that combined both apparel designers and mechanical engineers could be done possibly using a tent or backpack, something both functional and textile. Doing a study with multiple disciplines helps relieve a few confounding factors such as domain knowledge and would also give a group of participants with a more evenly split MBTI types thus allowing for more accurate results. Another important factor in these studies is the judging of the innovativeness of the designs. The author did the vast majority of the judging and even though the judging was done not knowing what MBTI type did the work it is still based on the authors opinions of innovation and no matter how much he has studied and read about innovation one opinion is not enough to accurately judge all of the work completed by the participants. Therefore in future exercises it is recommended that there be a panel of judges and that the innovativeness of the designs be decided by them instead of the lone judger to remove any bias.

There is also work to be done with the innovation tool, the FB-TRIZ hybird to be used with the FB-TRIZ correlation matrix. Early work on the correctness of the matrix could be done by using the current functional models in the repository. If one could find correlations between how components were used to solve functions and the innovative principles that align with that function an analysis could be done to show the accuracy of the FB-TRIZ correlation matrix. However, studies are needed to investigate the actual contribution that the FB-TRIZ hybrid method can make to a design team working on a real world problem. Additional studies could seek to quantify the effects of this method in the concept generation stage when compared to some of the more traditional concept generation methods by comparing, the number of concepts, the quality of concepts, and the innovation achieved by the concepts, as well as other to be determined criteria. Proving that the FB-TRIZ hybrid method increases the aforementioned attributes is crucial to showing its worth in the design community. Another worthy endeavor with the FB-TRIZ hybrid method would be introducing it to other design programs such as apparel design. There is not much overlap between the two disciplines in design methodology despite doing very similar things. Showing that this hybrid method works for other disciplines would be a great step in the acceptance and use of it.

The work done in these papers show that innovation is not just for someone who is special or has the ability to see things differently than other people. By understanding oneself and using simple tools anyone can achieve innovative results. The ability to help people achieve innovative designs is important, as these products can help with a problem in a simple task, find solutions to difficult processes, or raise the standard of living in third world countries. The first two papers showed how individuals with a basic understanding of their personality can use different information presentation techniques to improve their understanding and innovation potential towards a design. The work in these two papers also explores the effect of this in multiple disciplines, engineering and apparel design. The last paper includes the use of an innovation tool to help the designer develop innovative ideas. These can be used together to create better, more developed designers. By using the innovation styles data one can fit design methods and tools that are most appropriate to that style and achieve more innovative designs. Innovation is something that can be nurtured by using knowledge of ones personality and tools such as the FB-TRIZ correlation matrix. This is best summed up in the quote below.

> *"Creative thinking is not a talent, it is a skill that can be learnt. It empowers people by adding strength to their natural abilities which improves teamwork, productivity and where appropriate profits."*
>
> *— Edward de Bono[62]*

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