AC 2011-815: BODY-STORMING, SUPER HEROES AND SCI-TECH PUBLICATIONS:TECHNIQUES TO ENHANCE THE IDEATION PROCESS

Daniel D. Jensen, U.S. Air Force Academy

Dr. Dan Jensen is a Professor of Engineering Mechanics at the U.S. Air Force Academy where he has been since 1997. He received his B.S. (Mechanical Engineering), M.S. (Applied Mechanics) and Ph.D. (Aerospace Engineering Science) from the University of Colorado at Boulder. He has worked for Texas Instruments, Lockheed Martin, NASA, University of the Pacific, Lawrence Berkeley National Lab and MSC Software Corp. His research includes development of innovative design methodologies and enhancement of engineering education.

Kendra Crider, U.S. Air Force Academy

Kendra Crider is a major in the US Air Force and an assistant professor at the Air Force Academy in the Engineering Mechanics department. Maj. Crider's areas of interest are in systems engineering, concept generation, students' retention of academic material, and optics. She is currently working with a group of undergraduate capstone students to design and develop an energy harvesting prototype that will be used to power health monitoring systems.

Kristin L. Wood, The University of Texas, Austin

KRISTIN WOOD is the Cullen Trust Endowed Professor in Engineering and the University Distinguished Teaching Professor at The University of Texas at Austin, Department of Mechanical Engineering. Dr. Wood's current research interests focus on innovative product design, development, and evolution. The current and near-future objective of this research is to develop design strategies, representations, and languages that will result in more comprehensive design tools, innovation processes, innovative manufacturing techniques, and design teaching aids at the college, pre-college, and industrial levels. Contact: wood@mail.utexas.edu

John J Wood, U.S. Air Force Academy

Dr. John J. Wood is currently an Associate Professor of Engineering Mechanics at the United States Air Force Academy. Dr. Wood completed his Ph.D. in Mechanical Engineering at Colorado State University in the design and empirical analysis of compliant systems. He received his M.S. in Mechanical Engineering at Wright State University and his B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in 1984. Dr. Wood joined the faculty at the United States Air Force Academy in 1994 while serving on active duty in the U.S. Air Force. After completing his Ph.D. in 2002, he returned to the Air Force Academy where he has been on the faculty ever since. The current focus of Dr. Wood's research is the continued development of empirical testing methods using similitude-based approaches. This approach provides significant potential for increasing the efficiency of the design process through a reduction in required full-scale testing and an expansion of the projected performance profiles using empirically-based prediction techniques. Dr. Wood's research also includes the development of robotic ground and air vehicle systems using innovative conceptual design techniques for current technology implementations, as well as futuristic projections, applied in the framework of a senior capstone design course.

Body-Storming, Super Heroes and Sci-Tech Publications: Techniques to Enhance the Ideation Process

Abstract

The ideation (concept generation) step in the design process likely has the most potential for designers to exercise their creativity. According to Ulrich and Eppinger[1], the greater the number of concepts developed early in the design process, the more likely the final product is to satisfy the customer's needs. Many techniques are used during the ideation or concept generation phase in order to enhance designers' ability to innovate[2]. These techniques may include 6-3-5 (sometimes called Brain Writing or C-Sketch), Design by Analogy, Mind Mapping, Morphological Analysis and TIPS/TRIZ. In an attempt to augment this set of ideation techniques, we have developed, implemented and assessed three new techniques whose goal is to enhance the ideation process. The first technique involves a very physically oriented process where the designers actively play the role of the systems that they are working to develop. We call the technique "body-storming" as it, in some ways, mimics the brain-storming technique, but in a much more physical manner. The second new ideation technique involves imagining how superheroes and cartoon characters might hypothetically address the specific design requirements. The third technique uses the Sci-Tech publications *Popular Mechanics* (*PM*) and *Popular Science* (*PS*) to seed the ideation process.

1. Introduction

Innovation and creativity are central to the engineering design process. Numerous versions of the "design process" have been proposed[1,3-5]. Two examples are captured below in Figures 1 and 2. Figure 1 shows the process as depicted by Ullman[3] and Figure 2 provides a similar description from Ulrich[1]. In both these cases, and in the majority of other portrayals of the design process, one of the steps in the overall process is identified as "concept generation" (CG). As shown in Figure 3 from Otto & Wood[4], the CG step itself can be separated into a set of subprocesses. Note the dual paths depicted in the figure, which divide the process into two categories, basic and more advanced. Similarly, Shah[6] also uses two categories that he refers to as intuitive and directed. The upper path in Figure 3 corresponds to the directed type CG methods and the lower path to the intuitive methods. The goal of the intuitive methods is to create an environment that enhances creativity for the designer allowing for maximum opportunity to produce innovative solutions. Classic examples in the intuitive category include brainstorming and morphological analysis. The goal of the directed methods is to follow more of a step-by-step or systematic process to develop a solution. Technical information combined with fundamental physical laws play a key role in this directed method set of CG techniques.

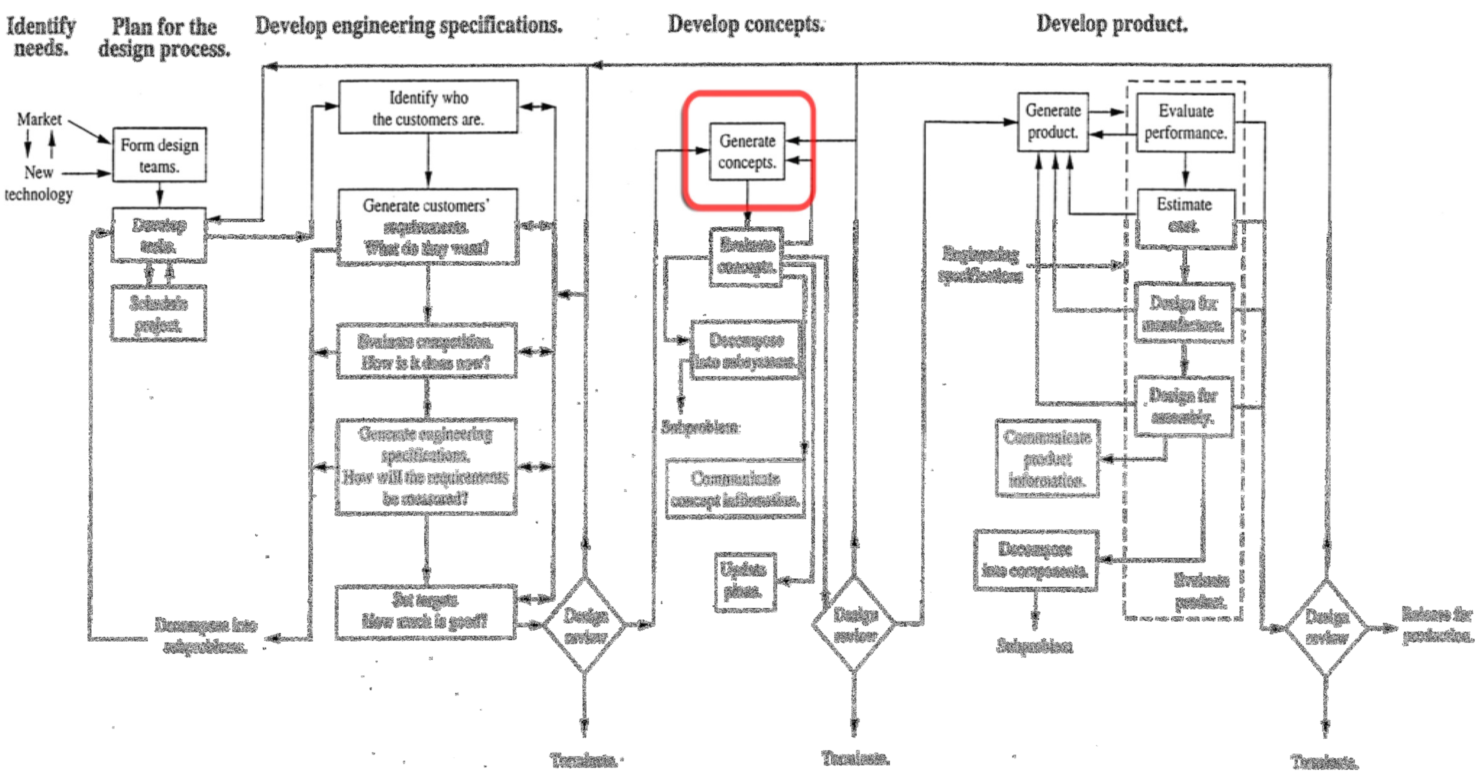

Figure 1 – Ullman's Depiction of the Design Process[3]

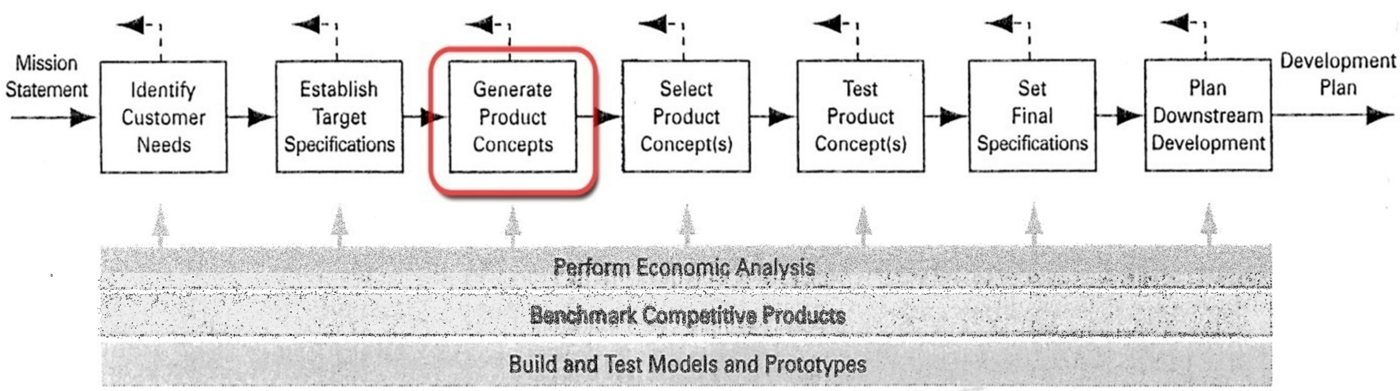

Figure 2 – Ulrich & Eppinger's Depiction of the Design Process[1]

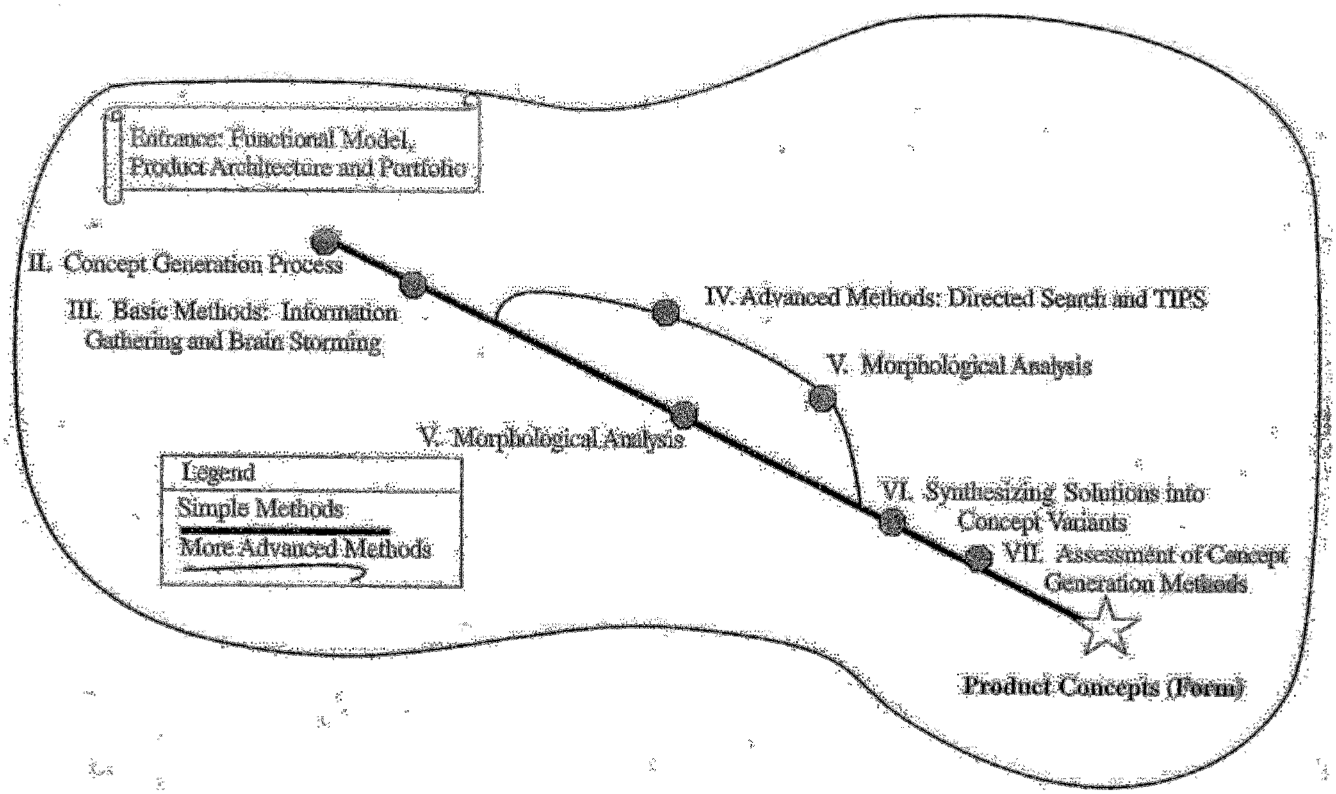

Figure 3 – Otto & Wood's Depiction of the Concept Generation Process[4]

This paper introduces three new ways to generate concepts as part of the intuitive method. They encourage creativity for all involved. The techniques developed and their results are presented in the following sections and include:

- Body-Storming
- *Popular Mechanics/Popular Science* investigations
- Superheroes/Cartoons

These three techniques were used by three different senior capstone design teams in conjunction with other concept generation methods. These other methods included:

- 6-3-5 directed brainstorming[3]
- Transformational Cards[5]
- Generation by analogy[7]
- Informal discussions with stakeholders

Each capstone design team consists of 7 to 10 undergraduate seniors. They work on their project for two consecutive semesters in the same academic year. The three senior design capstone projects that used one or more of the new concept generation techniques are the Robotics Capstone Team, the Energy Harvesting Capstone Team and the Micro Air Vehicle (MAV) Capstone Team at the United States Air Force Academy's Engineering Mechanics department. Each of these teams is multidisciplinary having cadets from both the Systems Engineering Management major and the Mechanical Engineering major. The MAV and Energy Harvesting teams have Electrical Engineering majors and the MAV team has a student from Biology.

The Robotics Capstone Design team is working on systems that have the ability to be lowered from the ground surface through an 8-inch diameter bore hole, to a depth of up to 100-feet into a tunnel or cave with an approximate cross section of 4 feet by 4 feet. The robot is tasked with navigating over difficult terrain, including the ability to overcome a 24-inch vertical step to perform intelligence, surveillance and reconnaissance (ISR) missions. Applications for this technology include rescue missions in mines, homeland security missions along the border or military operational missions where tunnels are being used to transport or store contraband. These robots must be able to operate in tight spaces and navigate through water and mud, and over ledges, large rocks and even climb stairs. The small size constraints (based on the 8 inch insertion/extraction bore hole) and the aggressive navigation requirements for these systems pose extremely significant design challenges.

The Energy Harvesting Capstone Design team is developing systems that can harvest energy from the environment to power structural health monitoring systems on bridges. Based on the aging infrastructure of our country, significant concerns exist for the safety of structures such as bridges. The 2007 collapse of the I-35 bridge close to Minneapolis is a tragic example of this critical need. The team desires autonomous monitoring systems that can function without the need for maintenance for long periods of time (up to 10 years). The power systems must not only power the sensors on the bridge but also intermittently transmit the data to a relay station which can push the data forward for analysis. These long term, maintenance free power needs preclude the use of batteries; hence the need for an energy harvesting system.

The MAV Capstone Design team is working to develop a small remote controlled aircraft that can be used for surveillance purposes. Typical uses for this type of system include surveillance of potential crime scenes, intelligence gathering at disaster locations and military reconnaissance. One of the critical issues with this sort of system is the relatively short battery life. It is common for a 1-3 pound aircraft to have sufficient battery life to maintain flight for only about 30 minutes. Obviously, this causes significant mission degradation. One solution for mitigating this shortcoming is to have the systems "perch," allowing the system to continue its surveillance mission, but in a lower energy expenditure mode. To facilitate this "perching," the team would like the MAV to have the capability to land in a very small area (for example a window ledge), have some rudimentary maneuvering capability (so it can point its surveillance sensor) and relaunch to proceed to the next critical surveillance location. Developing an MAV with these three new capabilities (land in a small area, maneuver and relaunch) is the focus of this team's design efforts.

2. New Concept Generation Methods

Body-Storming Concept Generation

"Will this new robot concept fit through an 8-inch hole?" "I don't know; the robot is square(ish) and the hole is round." "Once inside the tunnel will it be able to maneuver over, around or through the obstacles we expect to encounter?" "I don't know; how hard can it be?" "Let's find out!" This casual dialog during a recent brainstorming session is what sparked the idea that there is no substitute for personal experience. Immersing yourself in the project scenario to the greatest extent possible can lead a design team to some very enlightening realizations concerning the problem limitations and constraints.

The Robotics Design Team thought they completely understood the problem at hand until they flipped over desks, tables and chairs, scrounged up pieces of wood and cardboard boxes and tried to recreate the environment their robot would see in operation. A similar technique was previously proposed developing functional models where the designer "becomes the functional flow" in order to investigate the functional sequence[4]. The team built a full-scale mock-up tunnel with a cross section approximately four feet by four feet. Inside the mock-up cardboard boxes were used to simulate a two-foot vertical shear step, a requirement for the project. After building the mock-up, the team went to work investigating how to tackle the problem of getting a ground robotic vehicle through the tunnel environment including maneuvering over the two foot step. The team convinced its smallest member to act as a simulated robot in an attempt to identify what problems might be encountered navigating through the tunnel environment (Fig 4). The "humanoid" robot successfully made it over the step obstacle and through the tunnel simply by climbing over the boxes but with significant physical energy exertion. He also observed that had he been any smaller, or larger, he would have encountered significant problems getting over the step obstacle within the confines of the mock-up tunnel. Team observations and subsequent discussions eventually spiraled into the genesis of a new conceptual design to attempt to alleviate the projected navigation difficulties.

Figure 4 - Body-Storming

Other team members explored the tunnel as well. Discussions after each person's experience helped the team conceptualize new solutions addressing dimensional, weight, force and other issues they had not previously considered. This allowed free-form brainstorming which drove the team members to diagramming conceptual ideas.

Figure 5 - Body-Storming Improves the Quality and Quantity of Concept Generation

Even though the “body-storming” concept generation method created a few bumps and bruises for some of the team members, the pain was forgotten with a realization of the volume and quality of new design ideas the team as a whole was able to produce (Fig 5). For the next design team meeting, each member was tasked with refining each of their new conceptual designs. This process resulted in each member of the design team generating between 5 and 10 new concepts or concept derivatives. This was a significant achievement considering the team had already been diligently brainstorming for several weeks. The body storming method increased the number of concepts by about 25%. The value of this new technique was in the new perspective it allowed the design team to gain followed by the implementation of more traditional brainstorming methods. As the Robotics Team demonstrated, the result was a multiplication in the number of conceptual ideas available for feasibility analysis. The method also helped the students gain an initial level of physical experience prior to the development of first generation prototype models.

It should be noted that the physical adaptation nature of this conceptual innovation design process has a limited field of application. For example, this technique, while well suited for developing experiential understanding of mobile robots interacting with a very diverse and challenging navigation environment, is much less suited for the development of an ergonomic computer mouse. The applicability of the technique to a design problem must be evaluated by the design team through traditional evaluation methods, previous design experience or through a trial demonstration.

Superheroes/Cartoons Concept Generation

How do they do it? Fly, see through brick walls, teleport themselves and control the environment…these are just a few examples of feats that human beings in and of themselves cannot perform. But superheroes and cartoon characters can perform these feats and any others limited only by the imagination of the design team. They are not constrained by the laws of physics as humans are. In an effort to think outside the box and generate new ideas, the Energy Harvesting Team came up with the idea of looking at what superheroes and cartoon characters can do that is outside our realm of reality. This could stretch the imaginations of the team members to develop new ways to use the energy in the environment. For example, the X-Men character Storm has the ability to control the weather. The concept of controlling the weather gave the team the idea of using aspects of the weather to gather energy; notably, lightning. Lightning specifically did not filter into one of the team's final options due to the safety concerns associated with directing lightning at or near a bridge, but this demonstrates the power of abstract and creative thought processes associated with looking at the powers and abilities of superheroes and cartoon characters.

In order to gather a list of these characters, the team, along with several mentors, performed a 6-3-5 concept generation session in order to write down as many characters and their associated powers and abilities as possible. The team came up with 26 different ideas using this method. The process was not only a lot of fun for all but was quite productive in breaking down inherent barriers that would constrain normal systems (as opposed to superheroes).

Popular Science/Popular Mechanics Based Concept Generation

Our development and implementation of the *Popular Mechanics*/*Popular Science* (*PM/PS*) technique was based on two assumptions:

1- The belief that the students are not familiar with emerging technologies that might be directly applicable to their design and

2- The belief that exposing the students to emerging, innovative technologies will spawn creativity in the concept generation phase of their design.

This new concept generation technique was inspired, in part, by the work of Saunders, Seepersad and Holtta-Otto[8], which used *Popular Science*, *Popular Mechanics* and other similar periodicals to uncover engineering characteristics inherent in award-winning innovative designs. Team members are asked to review copies of *PS/PM* periodicals and search for technology which is relevant to their project. Not only are they encouraged to find technology that might be directly applicable to their design (for example a new energy harvesting device), but also to look for emerging technology that they might use in ways that the original inventor did not anticipate. This technique was used by all three design teams (Robotics, Energy Harvesting and MAV). Below are the instructions provided to the students.

You have received 2 relatively recent copies of both Popular Mechanics *and* Popular Science*. We want to use these to enhance our Concept Generation process. In order to accomplish this we propose the following process:*

1- *Do 100 jumping jacks, 50 pushups and get a large cup of strong coffee.*

2- *Spend a minimum of 20 minutes on one of each magazine looking for technological inspiration that could be applied to our project. The intent is to identify component or system technology applications that could be used in whole or in part to enable our system to perform its intended function. The technology does not have to be "innovative" or "leading edge", but rather a departure from its intended design purpose. This enabling technology could be directly applicable (and relatively obvious) to improving the system's function (e.g. lightweight battery with 30% more capacity). However, the ideas that we are most interested in are ones where some technology can be used to change the way to perform a primary function or meet a critical capability (e.g. capture the material expansion energy from flux capacitor super heating of the robot structure) that will provide a technology "leap" on the innovation "S" curve.*

3- *As a team, discuss the results of your research. Identify insights into either your specific results or your process; how you mentally processed or organized the information, methods that either did or did not work and any conceptual innovations or ideas that may have resulted from your research.* ***Each person should document the results of the session.***

4- *Repeat the individual review process with the remaining 3 (or more if desired) magazines using the team discussion as a guide to help improve your creativity. Prepare 5 slides per student describing the technology that you propose to use, how you'll use it and what capability it addresses.*

3. Results

Overall, each of the three new concept generation methods was useful for each team that used them, although the students on each of the three capstone teams had some varied opinions about how useful the new methods were in improving the quality and quantity of conceptual ideas. The body-storming technique was used only by the Robotics Team. It is hypothesized that this method has a very specific design audience. The method was not used by either the Energy Harvesting Team or the MAV Team for the simple reason that is would not have the same potential for creative success as it did for the Robotics Team as previously discussed. The team members were able to crawl through a simulated tunnel environment and observe the motions, decisions, constraints, etc. that would also determine a robot's behavior. If man could fly we could also potentially use this method in the concept generation of MAVs. However, in its current form it seems to be constrained to applications where humans can mimic the behavior of design product and, as a result, learn much from being immersed in a simulated environment. It was definitely a success for the Robotics Team and led to the generation of between 5 and 10 new conceptual ideas from each team member. The students also enjoyed this exercise and it helped them take more ownership of the project.

The Superheroes/Cartoon exercise was accomplished by the Energy Harvesting Team. The team came up with an additional 26 ideas from this exercise. The team had developed 28 concepts prior to using the Superheroes/Cartoon and *PM/PS* concept generation methods. The students and mentors who participated enjoyed the exercise. The primary lesson learned from this experience is that the students felt like most of the ideas they gathered using this technique had already been gathered through multiple other methods of concept generation. They believed that it would have been more useful to have done it earlier in the Concept Generation phase of the Design Process.

The *PM/PS* investigation, having been used by all three teams, was useful and helped each of the teams come up with a least one new idea that they had not yet considered. In addition, it helped the teams become familiar with emerging technology that was relevant to their project. Overall, the three teams came up with approximately three dozen new ideas using this method and the students commented that they enjoyed looking through these magazines. Their comment was that it was more interesting than reading through journals and doing patent searches. The instructors commented that the exercise appeared to significantly increase students' motivation.

4. Conclusions

The information documented in this paper shows that there are new and creative ways to generate ideas to solve problems in order to increase the number of possible solutions. One of these new methods might be the eye-opener for the students to significantly better understand the problem. Overall, the three methods presented in this paper were very useful and generated in excess of 75 new ideas. Therefore, we recommend considering using any or all of these methods in conjunction with other known concept generation methods during design work, understanding, though, that each of these methods will not work for all design projects. It is up to the design team and mentor to decide which concept generation methods are most appropriate for the type of work they are doing.

The findings presented in this paper are not intended to be a thorough quantitative measure of the quality of these three methods. Instead, it is a qualitative introduction to the new ideas with the intent of doing more work with them in the future. The authors also encourage other design and capstone instructors to try the methods in class and share their results.

The intent was to generate new ideas to add to the quantity of concepts available for inclusion in the concept evaluation phase of the design process. Several ideas were filtered out early in the process due to their feasibility (i.e.: lightning based on the X-Men character Storm). Others were duplicates of previously conceived ideas. However, there were also totally new ideas worth considering that each team garnered from the new concept generation methods they used. Overall, the ideas were not judged to be better or worse than those already generated; that was not the goal. The goal was to increase the number of ideas to choose from; thereby, increasing the likelihood of an innovative solution that best meets the customer's needs.

Future work should include a more formalized setup with control and experimental groups. A control group could be a previous year's group work with the experimental group being a future year's group work. This assumes, though, that both teams will have the same project purpose and customer needs. Some schools participate in a yearly competition that does not use the previous year's project. This type of project would be a good candidate for the experiment.

5. Acknowledgements

This work is partially supported by grants from the Air Force Research Labs (AFRL/RW, Eglin AFB, FL, AFRL/RXQ, Tyndall AFB, FL and AFRL/RB, Wright Patterson AFB, OH), grants from the Office of the Secretary of Defense's Office of Corrosion Policy and Oversight and from the Defense Threat Reduction Agency as well as a grant from the NIST/TIP program, a National Science Foundation under Grant No. CMMI-0555851, and, in part, by the University of Texas at Austin Cockrell School of Engineering and the Cullen Trust Endowed Professorship in Engineering No. 1. In addition, we acknowledge the support of the Department of Engineering Mechanics at the U.S. Air Force Academy. Any opinions, findings, or recommendations are those of the authors and do not necessarily reflect the views of the sponsors.

6. References

1. Ulrich, K., Eppinger, S., *Product Design and Development*, McGraw Hill, 2000.
2. Jensen, D., Weaver, J., Wood, K., Wood, J., Lindsey, J., "Techniques to Enhance Concept Generation and Develop Creativity," ASEE Annual Conference, Austin, TX, June 2009.
3. Ullman, D., *The Mechanical Design Process*, McGraw Hill, 1997.
4. Otto, K., Wood, K., *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall, 2001.
5. Dym, C., Engineering Design: *A Product Based Introduction*, Wiley, 2000.
6. Shah, J., "Experimental investigation of progressive idea generation techniques in engineering design," ASME design Theory and Methodology Conference, Atlanta, GA, 1998.
7. Linsey, J., Wood, K., and Markman, A., 2008, "Increasing Innovation: Presentation and Evaluation of the WordTree Design-by-Analogy Method," *Proceedings of the ASME Design Theory and Methodology Conference*, New York, NY, 2008.
8. Saunders, M., Seepersad, C., Holtta-Otto, K., "The Characteristics of Innovative, Mechanical Products," *Proceedings of the ASME International Design Engineering Technical Conference*, San Diego, CA, Aug., 2009.
9. White, C., Wood, K., Jensen, D., "From Brainstorming To C-Sketch To Principles Of Historical Innovators: Ideation Techniques To Enhance Student Creativity," ASEE Annual Conference, Louisville, KY, June 2010.