

DETC2010-28985

UNDERSTANDING INNOVATION IN STUDENT DESIGN PROJECTS

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ABSTRACT

Over the past few years, academic institutions have become aware of the importance of innovation in education, as well as its broader role in strengthening the economy. Creativity and innovative thinking are not easily taught in the classroom, but they can be developed through practice and experience. Evaluating innovation as part of product design courses has thus become very important to increase the probability of students becoming innovators in the real world.

Innovation tournaments provide universities with an opportunity to develop innovative design thinking in students while they gain practical experience. Understanding design innovation at a deeper level in the context of student design projects is critical to develop realistic perspectives among students. Determining the appropriate dimensions for understanding and measuring innovation is the main objective of this paper. Toward that objective, we conducted initial experiments in conjunction with an innovation award to develop and assess innovation metrics. The results reveal several dimensions of innovation: differentiability, creativity, need satisfaction, and probability of commercial success emerged as key dimensions. This research also assesses the perception of innovation, contrasting the perceptions of judges from industry with the views of academically oriented judges.

INTRODUCTION

The decline and commoditization of manufacturing knowledge has caused innovation to emerge as a key area of global and national importance (George, 2006; NSB, 2007). In the United States, innovative industries account for over half of exports, represent 40% of national economic growth, and employ 18 million Americans who earn 40% or more than the average US wage (Gutierrez, 2007). It is well known that early stages of design processes account for a significant portion of the cost committed to design and are also the stages where significant innovation can occur (Ullman, 2003). Consequently, preparing engineering students to compete globally (NSB, 2007; NAE, 2005) through learning design innovation has become a growing priority in universities throughout the nation.

In the scientific community, these concepts are well known: “You are what you measure” and “You cannot prove what you do not measure” (Hauser, 1998). But is this also true when measuring abstract concepts such as innovation?

The main goal of this paper is to extend and develop understanding of what constitutes innovation in student design projects, and to integrate this with the process of learning design innovation. We use the *Design Innovation Award* as a means to create a conversation among students, faculty and industry judges to understand, promote and measure innovation in student design projects. The main purpose of the award is to encourage students to develop and link creative thinking,

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opportunity recognition, and implementation of design tools and methodologies into a practical concept. Opportunity recognition, a creative activity itself, is the bridge that connects breakthrough ideas to the initial innovation (Colarelli, 2001). By making design innovation an integral part of student design projects universities will develop new capacities in students, increasing their probability of success as contributors and participants in the creative economy.

UNDERSTANDING INNOVATION

Innovation has been studied in great detail from market and global economic perspectives, especially in terms of company performance outcomes. However, the link between design and economics has not been studied as much. There is currently no way of measuring innovation in academic contexts, nor is there a validated “Innovation Index” available in the design literature for measuring innovation in student design projects. In addition, innovation is a loosely defined concept, and often confused with invention. The inputs such as the context of the opportunity recognition, financial constraints and the outputs such as market success measures, feedback mechanisms, financial metrics and patents awarded, are different in student design projects compared to real world project settings.

The first problem when trying to measure innovation is to develop a shared understanding of the concept. There are many definitions of this term, many of which are based on creativity, invention, and knowledge. For example: 1) “The successful implementation of creative ideas within an organization” (Amabile, 1996); 2) “Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out in to practice” (Fagerberg, 2004); and 3) “The embodiment, combination, or synthesis of knowledge in original, relevant, valued new products, processes or services” (Luecke and Katz, 2003). For the purpose of student design projects that lack of commercial proof of success, we suggest a more operational definition: “Innovation is a new match between a need and a solution. The novelty can be in the solution or the need; or in a new marriage between both existing need and solution” (Terwiesch, 2009).

Innovation with societal impacts is enabled through social entrepreneurial ventures, defined as “applying practical, innovative, and sustainable approaches to benefit society in general, with an emphasis on those who are marginalized and poor” (Schwab). These kinds of innovations have resulted in bringing solutions to remote locations where the major concern is helping people solve everyday problems. In this form of innovation, value is generated by social welfare, not by profit generation.

All of these definitions have something in common: There is novelty involved, and innovation always generates value. Value can come in the form of profit in an economic activity (as in products available on the market), social welfare, or environmental protection (e.g., in the case of governmental policies). Adopting a single definition for a complex concept as

innovation can create a barrier for understanding; instead, it is preferred to describe it practically, where all definitions can coexist. Therefore, we describe innovation as the practical application and use of creativity and discovery to create value. The development of the dimensions of innovation in this paper is directly linked to this description.

The need for an operational definition of innovation has arisen because of the complexity of the innovative process and its primary role in the productivity of a nation. The OSLO manual lists four areas of innovation: Product innovation, Process innovation, Organizational innovation, and Marketing innovation (Figure 1).

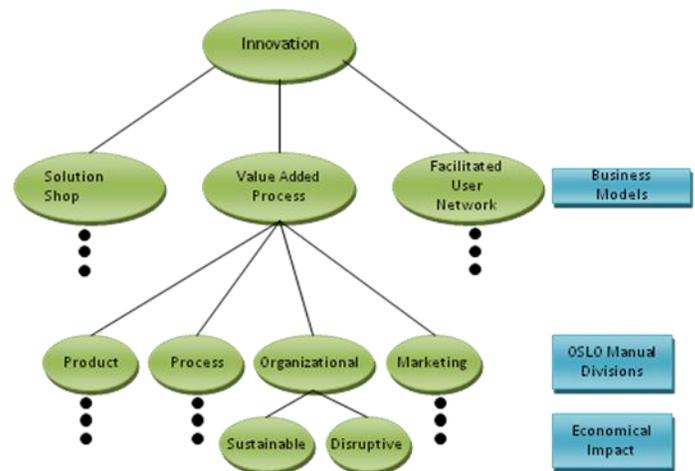


Figure 1: THE LEVELS OF INNOVATION

Product and process innovations are related to technology; in contrast, marketing and organizational innovations cover a very large range of innovations. The OSLO manual uses a clear and unambiguous classification system that enhances the capability to measure. Innovation management metrics is a critical discipline for both academics and practitioners. Isolating output indicators of innovation activities provides a strong motivation for research workers. The indicators are the result of observing inputs such as R&D expenditures and quantity of patented inventions. Adam Jaffe (1989) demonstrated that university and industrial R&D had a statistically significant effect on the number of patents originating from a given geographical area. Product innovations have a tendency to cluster geographically. Economists have ventured to develop models of innovation based on innovative production functions. However, these models suffer from gaps in validity and from omission.

Although a number of studies have researched innovation in industry from a market perspective, fewer studies have focused on the connection between the market understanding and educational views of innovation. We see the student design projects and the innovation award as a means to understand and enhance innovation in student design projects.

UNIVERSITIES AND DESIGN-INNOVATION

Design plays an integral part in any organization where innovation is important. Thus it comes as no surprise that in recent years increased emphasis has been placed on design in the engineering curricula. Even so, engineering design education has still not received much research attention (Sobek, 2007). Production of creative ideas is the starting point and one of the key steps in the innovation process. Universities and other organizations, as they have become aware of this, have started innovation competitions to develop creative thinking while reducing the ideas to prototypes.

Creativity can be encouraged through well thought out design courses. Design and design processes are learned through practice; however, the generation of creative design ideas and innovation outcomes that have impact on the market often results from complex multi-disciplinary, non-sequential, interactive, communicative, and highly social processes (Maier et al., 2005; Maier et al., 2008; Walthall et al., 2009). In learning design and innovation, students must acquire complementary skills from each other (peer-learning), and the underlying communication among team members is critical during this time. A recent national policy review is promoting understanding of innovation processes, indicating "new ways need to be developed to capture data on those interactions, and new data need to be developed to characterize the eventual outcomes" (Lane, 2009).

In order to translate design ideas into outcome, innovation requires an organization system, a vocabulary, a conceptual framework, and a rationale. Innovation for its own sake is not useful; value needs to be sought in innovations (Kim, 2005). Viewing innovation as an ability that comprises opportunity, understanding, and solution creation requires practical skills that are encouraged through student design competitions.

PROBLEM DEFINITION

Industry—where identifying the best ideas and placing them on the market is crucial—also struggles to find ways to measure innovation. Identifying which business ideas have real commercial potential is one of the most difficult challenges that company executives face. (Kim, 2000)

In academic contexts, university level design course staff and/or judges of innovation in design competitions are tasked with the evaluation of product innovation projects. Being able to evaluate a design project concept in the absence of guidelines, shared understanding or proven metrics is a challenge. In addition, the choice and development of the problem area is another added challenge.

Product, as a term, is used to cover both goods and services. Product innovation can use new knowledge or technologies; it can also be a combination of existing knowledge or technologies. The development of a new use for a technology solution can also be considered product innovation. Significant improvements can be achieved by introducing changes in components, materials, or other characteristics while

also improving the performance. Process innovation in this context is the implementation of significantly improved production or delivery methods, including major changes in techniques, equipment, and software (Davenport, 1992).

In a design projects competition, where ideas have not been implemented and hence have not yet generated proven value, it is difficult to assess the comparative innovation value. In this project, we identify dimensions of innovation and initial tests of metrics that assess innovation value of student design projects.

METHODOLOGY

Each semester an innovation award is given to the most innovative project from the senior design capstone course at Purdue University (ME 463). Students typically work on open-ended design problems in collaborative teams for 15 weeks. The course promotes the broadening of skills in leadership, teamwork, communication, project planning, innovation, design, and entrepreneurship. Students gain experience in application of the core fundamentals in mechanical engineering and course materials to practical design problems.

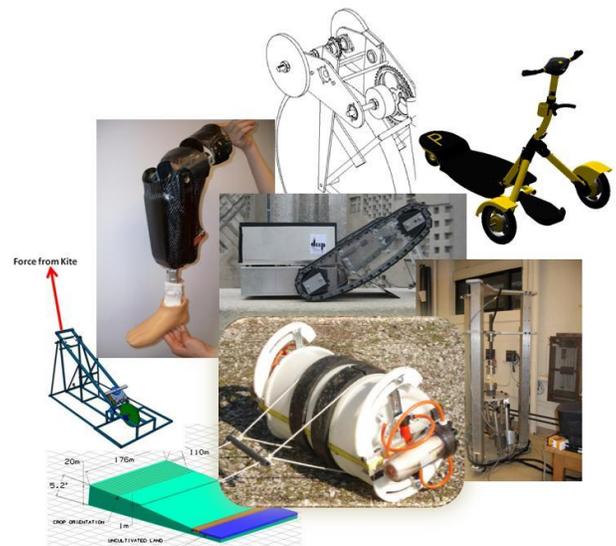


Figure 2: EXAMPLES OF ME463 PROJECTS

Some examples from the 2009 projects are shown in Figure 2, and include a laptop computer deployment system for a wheelchair, a desalination system for developing nations using solar evaporation and condensation, a rehabilitation device for post knee surgery, an "EPOD" or all-electric two person vehicle for on-campus transportation, a bicycle incorporating "regenerative braking," and a wind energy technology based on kite-boarding. Comparatively evaluating these diverse projects, which create value to the customer in many diverse market segments and use different sets of technical knowledge, is a challenge.

Innovation metrics and/or guidelines have been a major concern since the establishment of the innovation award tournament. One of the main objectives of this research is to be able to measure innovation as a long-term concept, specifically to predict value generation. Confronted with this need, we embarked on a structured evaluation pro forma to enable a team of judges, comprised of experts drawn from both industry and academia, to assign scores and weightings. For the last two tournaments, a search for the appropriate dimensions of innovation was undertaken. Figure 3 shows the methodology that has been followed.

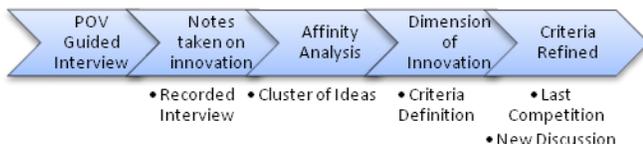


Figure 3: METHODOLOGY FOLLOWED

During the first competition, when this research started, a guided interview with the judges was conducted using a LiveScribe™ Pen. This device records and associates a recorded section with what is being written in a notebook. By using the notes as an index for recorded voice, key ideas can be tracked down easily. This interactive interview allowed the judges to explain their point of view (POV), as well as the factors they considered more important when referring to innovation. Many different concepts were expressed and recorded for later evaluation.

The content of these interviews was analyzed using an affinity diagram by extracting keywords and themes regarding innovation characteristics and clustering related concepts. Several exemplars emerged and an innovation rubric was developed. The judges, who had backgrounds in both industry and academia, were asked to read and weight the criteria in the rubric. No restrictions were enforced during this weighting process. The judges could designate one or several of the criteria to be insignificant, thus not giving any weighting; conversely, they were allowed to give a high weighting to one single criterion.

Once the competition started, judges provided their judgment on each weighted factor on a 10 point rating scale. While expertise based bias cannot be eliminated, it was minimized by clearly defining the impact of the scope of each factor. Judges from industry tended to give a greater weight to design features that would contribute to product success in terms of factors such as marketability, profitability, and novelty. In contrast, academic judges tended to place greater emphasis on features such as evidence-based approach, engineering knowledge, depth of design process and research, and methodology. The diversity in judging perspectives allowed a final judgment to be made both on result and process factors.

In the following semester, during the second innovation award competition, the judges improved on the innovation rubric framework. All judges gathered before the tournament and reviewed the criteria of the previous competition. Some of the most important concepts were refined, and criteria believed to be overlapping or not as valuable were eliminated. In their judging, the industry specialists resorted to four key dimensions, shown in Figure 4: (1) differentiability, (2) chances of market success, (3) level of need satisfaction, and (4) creativity. The rationale for the four key dimensions is that one cannot remember the details of a rubric when evaluating the projects individually. While the judges retained the rubric on hand, they preferred to use these four dimensions as the overarching criteria as guidelines for judging the teams. These identified dimensions provided the research team with greater insight into developing a new set of dimensions for innovation.

RESULTS AND DISCUSSION

One of our goals was to find an effective way to judge innovation and develop metrics among a set of student design projects. The judging criteria and innovation dimensions have undergone development and revision over the past three innovation awards. People from both industry and academia gathered before the final event and refined the dimensions of innovation.

Industry judges agreed on the criteria they considered the most important when defining innovation: differentiability, creativity, probability of adoption, and need satisfaction. In addition, the industry judges stressed market success factors as well as wide application of the underlying ideas embodied in the design project. On the other hand, academic judges stressed the need for students to translate what they learned in the curriculum into technical innovations in the product through creativity (see Figure 5). The academic judges also considered prototype performance and use of depth of analysis and modeling (critical thinking) as an important factor. Both groups of criteria were important to the academic judges, but the first was considered more relevant to industry-oriented views of innovation. Techno-nationalists and techno-fetishists oversimplify innovation by equating it with discoveries announced in scientific journals and with patents for cutting-edge technologies developed in university or commercial research labs. But since they rarely distinguish among the different levels and kinds of know-how, they ignore the contributions of the other players—contributions that don't generate publications or patents (Bhide, 2009).

The difference in innovation perspectives between industry and university judges can be further reduced by developing a consensus for evaluating the innovation projects. We used the academic rankings of the final eight projects and compared it to industry rankings to promote discussions in the final selection.

DIFFERENTIABILITY

Completely New: No Such Solution exists
Striking, Original, Unusual
Novelty
Extreme Results: Non-trivial

CREATIVITY

Creative idea transformed and executed
Implementability
Number and Quality of Creative Ideas
Interesting and Imaginative

PROBABILITY OF ADOPTION

Felt need for the product/process/service
Degree of competitive pressure
Chances of market success
Chances of Long Term Market Success
Level of Customer Support

NEED SATISFACTION

Adaptability to changing needs
Ability to meet targets
Satisfaction of quality.
Productivity

Figure 4: INDUSTRY PREFERRED INNOVATION METRICS

There is a need to measure the potential-value of a creative idea and its potential of market success in Student Design Projects. Judges attempt to identify the idea with the greatest probability of success, the one that understands and attacks the best opportunity. The discussion of the project rankings among judges allowed final opinions to emerge guiding them towards the final rankings. We found that an innovative idea from all key perspectives that could generate the most value is likely to be ranked the highest by the judges. This conclusion is directly supported by the description of innovation that we provided based on both the practical application and use of creativity, and especially the value it generates. Although judges often show a bias to their particular experiences and industry sectors in terms of their weightings of the dimensions of innovation, we see this as an opportunity for discussion to bring out their viewpoints and develop a shared understanding. The value of the innovation as perceived by each of the judges, was observed to be directly related to their individual experiences and knowledge. This observation needs further analysis. The innovation dimensions allow the industry judges to develop a shared understanding and also involve the university judges to engage in a positive conversation about innovation. Although one could use the dimensions of innovation as metrics to rate, get a weighted sum and rank the projects, we recommend that it be used as a guideline and promote discussions among the judges for the final ranking.

From an educational perspective, educating students for a higher probability of success in contributing to an innovation economy is very critical. This process of emphasizing innovation dimensions plays a very important role in embedding it as a part of the design process. It also brings together the market perspective with a technical innovation in

academia to create higher value products. With greater constraints in design, such as energy and environmental constraints, innovation in design becomes very important. One cannot manage what you don't measure or understand. Innovation dimensions motivate managers and help students to focus on what matters in the process.

Future research in this area can involve many directions. We will link the previous experiences in student judges to their emphasis in innovation and study how the discussions among them can remove any biases. In addition student teams can be formed so that they as a whole have a better capacity for innovation by providing complementary skills needed for different areas of the design innovation project. An innovation scorecard for classroom use will help expose students earlier to the reasons behind innovation measurement. In the future, we hope that our research will expose how to incorporate innovative design thinking and level of innovation among students without compromising the technical depth in the projects. Finally our experiences with the design award will create a common language of innovation between industry and university as related to educational objectives for students in design.

DESIGN PROCESS

Soundness and Robustness of design
Is repetitiveness possible?
Alignment of process to goals
Compatibility.
Use of formal systems and tools

PERFORMANCE OF PROTOTYPE

Effectiveness (occurrence of positive changes as a result)
Observability of results (outcome)
Technical Innovation Audit results
Product performance benchmarking
Cost effectiveness

SOCIAL AND ENVIRONMENT CONSIDERATIONS

Social acceptability of innovation
Socially responsible product innovation
Compatibility with existing practices and beliefs
Sustainability (eco and green design)
Environmental damage

EXHIBITION OF CRITICAL THINKING

Synthesis of various studies using an explicit analytical framework
Customer focus of outcomes
Depth of analysis using sophisticated techniques
Product not on the radar of investors into R&D

Figure 5: OTHER INNOVATION METRICS

ACKNOWLEDGEMENTS

The authors would like to thank Thomas J. Malott, a Purdue mechanical engineering alumnus, and his wife, Sandra for both funding, actively taking part, and promoting the discussions in the innovation awards. We also like to acknowledge the industry judges for having shared their valuable time in discussions prior to the award and participating actively in the awards process. We would like to thank Professor's Dave Anderson and John Starkey for serving on the judging team. In addition our thanks goes to the several instructors for the design projects.

REFERENCES

- [1] Adams, R., Turns, J., and Atman, C. J., 2003, Educating Effective Engineering Designers: The Role of Reflective Practice, *Des. Stud.*, 24, 275–294.
- [2] Adams, Richard, Bessarnt J, Phelps R., Innovation Management Measurement: A Review, *International Journal of Management Reviews*, 2006.
- [3] Amabile, T.M., Creativity and Innovation in Organizations, *Harvard Business Review*, 1996.
- [4] Banerjee, Prith. Wedding Innovation with Business Value: An Interview with the Director of HP Labs. 3 Feb. 2010. *McKinsey Quarterly*. 3 Feb. 2010 <http://https://www.mckinseyquarterly.com/strategy/innovation/wedding_innovation_with_business_value_an_interview_with_the_director_of_hp_labs_2522>.
- [5] Bhide A., Where Innovation Creates Value, *McKinsey Quarterly*, February 2009.
- [6] Davenport, Thomas H. *Process Innovation: Reengineering Work Through Information Technology*. New York: Harvard Business School Press, 1992.
- [7] Fagerberg, J., Mowery, David and Nelson, Richard, *Innovation: A Guide to the Literature*, The Oxford Handbook of Innovations. Oxford University Press, 2004, pp. 1-26.
- [8] George, B. (Dec. 16, 2008) *The Innovation Economy*. *Business Week*.
- [9] Gina Colarelli O'Connor, & Mark P Rice. (2001). Opportunity recognition and breakthrough innovation in large established firms. *California Management Review*, 43(2), 95-116.
- [10] Gutierrez, C.M., Remarks at the China-U.S. Innovation Conference, http://www.commerce.gov/NewsRoom/SeretarySpeeches/PROD01_004893, Editor. 2007: Beijing, China
- [11] Hauser, John, Katz Gerald, *Metrics—You Are What You Measure*, *European Management Journal*, vol 16, issue 5, Oct. 1998.
- [12] Jaffe, Adam, Manuel Trajtenberg, and Rebecca Henderson. 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations, *Quarterly Journal of Economics*; 63, 577-598.
- [13] Kim W. C., and Mauborgne, R. *Blue Ocean Strategy*, Harvard Business School Press, 2005.
- [14] Kim, W. C., and Renee Mauborgne. *Knowing a Business Idea When You See One*. *Harvard Business Review* Feb.-Feb. 2000: 129-37.
- [15] Lane, Julia. *Assessing the Impact of Science Funding*. *Science Magazine* 05 June 2009: 1272-1275
- [16] Maier, A.M., C.M. Eckert, and P. J. Clarkson, A meta-model for communication in engineering design. *CoDesign*, Dec 2005. 1(4): 243-254.
- [17] Maier, A.M., C.M. Eckert, and P. J. Clarkson, Exploration of correlations between factors influencing communication in complex product development. *Concurrent Engineering: Research and Applications*, 2008. 16(1): 37-59.
- [18] Luecke, R. and Katz, R., *Managing Creativity and Innovation*, Harvard Business School Press, Boston, MA., 2003.
- [19] National Academy of Engineering Committee on Engineering Education, (2005). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. 2005, Washington, D.C.: National Academies Press
- [20] National Science Board, (2007). *Moving Forward to Improve Engineering Education*, National Science Foundation.
- [21] OECD 2005, *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, OECD Publishing, ISBN 9264 1308
- [22] Schwab Foundation in Social Entrepreneurship. <http://www.schwabfound.org/sf/SocialEntrepreneurs/index.htm>
- [23] Sobek, D.K., Vikas K. Jain, *Relating Design Process to Quality: A Virtual Design of Experiments Approach*, *J. Mech. Des.* 2007.
- [24] Terwiesch, Christian. *Innovation Tournaments: Creating and Selecting Exceptional Opportunities*. Harvard Business Press, 2009.
- [25] Ullmann, D. G., *The Mechanical Design Process*, McGraw–Hill, Boston, 2003,
- [26] Walthall, C.J., Devanathan, S., Kisselburgh, L.G., Ramani, K., & Hirleman, D. A framework for evaluating wiki as a medium for communication within engineering design teams. *Proceedings of the ASME 2009 IDETC/CIE*, San Diego, CA, 2009.

