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Collaborative Research: Identifying and Assessing Key Factors of Engineering Innovativeness

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Matthew W. Ohland is Professor of Engineering Education at Purdue University and a Professorial Research Fellow at Central Queensland University. He has degrees from Swarthmore College, Rensselaer Polytechnic Institute, and the University of Florida. His research on the longitudinal study of engineering students, team assignment, peer evaluation, and active and collaborative teaching methods has been supported by over $12.8 million from the National Science Foundation and the Sloan Foundation and his team received Best Paper awards from the Journal of Engineering Education in 2008 and 2011 and from the IEEE Transactions on Education in 2011. Dr. Ohland is past Chair of ASEE's Educational Research and Methods division and a member the Board of Governors of the IEEE Education Society. He was the 2002–2006 President of Tau Beta Pi.

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Jessica Menold is a doctoral student in mechanical engineering at the Pennsylvania State University. As an undergraduate at Penn State she was heavily involved with a STEM outreach program called the engineering ambassadors. She currently works as a graduate mentor for entrepreneurial student groups on campus as a part of Penn State's Lion Launch Pad team. Her interests in entrepreneurs, as well as engineering education, has led her to the study of innovation in engineers, working with Dr. Kathryn Jablokow. Her current research focuses on understanding innovation in engineering professionals and students, and she is collaborating with a team at Purdue to create a tool to measure innovativeness among engineers.

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Abstract

Significant resources are spent nationally and locally to foster innovativeness of engineers, yet confusion remains about critical knowledge, skills, and abilities necessary to enable innovativeness throughout the engineering innovation process. This collaborative research project combines expertise in cognitive diversity with expertise in assessment and entrepreneurship to characterize and assess innovativeness in practicing engineers and engineering students. First, we conducted a large-scale interview study involving forty-five engineering innovators with diverse backgrounds in engineering discipline, gender, ethnic, and geographic diversity. These interview data were analyzed to determine the key characteristics of engineering innovators. Next, we conducted an in-depth literature synthesis to understand different ways in which these innovative engineer characteristics were currently identified, and we have begun to assess existing needs for new engineering innovativeness assessment instruments. These studies will inform the development of scales designed specifically for measuring engineering innovativeness.

Introduction

Scientific and technological innovations have fostered our economic and social prosperity for the past two centuries[1], accounting for nearly half of the economic growth in the U.S. in the last 50 years[2]. Innovation is recognized as the "most important ingredient in any modern economy"[3]. Yet, as former Commerce Secretary Locke stated in 2010, our nation's innovation system appears to be "broken", adding that the U.S. has not adjusted to a new global marketplace where foreign countries and foreign companies have the ability to outpace their American counterparts[4]. Global competition is redefining the process of innovation[5], and the leadership role that the U.S. had in the world is fading[4]. There has never been a clearer imperative to improve the innovative capacity of U.S. college graduates, especially engineers.

While research on innovation and innovators is profound, many of these studies are not specific to engineers. In this study we address this gap by exploring engineers' views of innovation and innovators who create and implement innovations in order to develop socially accepted descriptions of these phenomena. More specifically, three research questions were examined:

- How do engineers define and describe innovations and the innovation process?
- What are the characteristics or knowledge, skills, and attributes that enable engineers to translate their creative ideas into innovations that benefit society?
- How do these individual characteristics that enable engineers to be innovative vary across the stages of innovation?

Literature Review

According to the definition of innovation adopted by NSF's Engineering Advisory Committee[6], innovation is the development of novel products, services, and processes that benefit society. But what *makes* engineers "innovative", and what are the key factors that enable innovative behavior? While this question has extensively been studied in the business domain, there are no empirically developed and tested models particular to the engineering domain(s) and characteristics of engineers who innovate. The key factors and the relative importance of factors that we currently know from innovation research[7,8,9,10,11,12,13,14], may vary *within* the context of the innovation process. While some factors that support innovation may be necessary across the entire process, different skills, knowledge, and attributes may be more important in some stages and in some technical domains or contexts than others. In this project. We explore and document these diverse factors and their respective impacts on innovative behavior and success.

Review of Measurement Scales on Innovation

Attempts to define and measure "innovativeness" date back to the 1970s. Some scholars focused on a general definition and assessment of innovativeness[9,12,1516,17], while domain-specific work[10,13,18,19] tended to focus on consumer behavior.

- Jackson Personality Inventory[17]. Jackson describes an innovator as "a creative and inventive individual, capable of originality of thought; motivated to develop novel solutions to problems; values new ideas; likes to improvise"[20] focusing on the early stages of the innovation process.
- The Innovativeness Scale (IS). With this sale, Hurt, Joseph, and Cook[11] measures general willingness to change and ability to adopt new ideas, which are aspects of innovative behavior but do not represent the full scope of innovativeness.
- Kirton[12,21] describes a bipolar continuum of creativity and problem solving from those who are (generally) "more adaptive" to those who are "more innovative", with the "management of structure" as the underlying factor that distinguishes them. According to Kirton, more adaptive individuals focus on efficiency and implementation within existing frames of reference, while the more innovative reorganize and restructure frames of reference as part of their problem solving, leading to more disruptive solutions.
- Leavitt and Walton's Open Processing Scale (OPS)[22,23]. This is a domain-specific assessment of innovativeness and measure the adoption of new products or so-called "innovative consumer behavior".
- Price and Ridgway[13], Goldsmith and Hofacker[10], and Flynn and Goldsmith[18], investigated people's "tendency to learn about and adopt innovations (new products) within a specific domain of interest"[10]. While useful for studies focused on consumer behavior, these results do not encompass the engineering-related factors we propose to measure.

Recently, a few researchers have focused on qualities required by engineers to be successful innovators[14,24]. Fisher, *et al.*[24] interviewed 10 experts to elicit their mental models about personal attributes, skills, processes, and environments for innovation, in terms of "promoters" (e.g., interdisciplinary thinking) and "inhibitors" (e.g., lack of confidence). Many of the scales as well as Ragusa's Engineering Creativity and Propensity for Innovation Index (EPCII)[14] focus primarily on the initial stage of innovation as opposed to our comprehensive approach.

Methods

Data Sources

To inform the full study an exploratory convenient interview-based pilot study of engineering innovativeness was conducted with engineering innovators.

Participant Selection and Sampling Process

Study participants were identified using a purposeful criterion and snowball sampling methods. We recruited participants by contacting engineering professionals in multiple disciplines and locations to act as connectors and also recruited using snowballing through engineering innovators. This process took about 6 months. The data were collected through interviews with experienced and recognized engineering innovators who described engineers who were innovative including themselves. The interview and data collection process took about 8 months.

Data Analysis

This study of engineering innovativeness was set in an interpretivist framework and developed a socially co-constructed description of engineering innovativeness. The data analysis process started by transcribing 45 interviews averaging 76 minutes each and 3460 total minutes. The emergent results were discussed in weekly project team meetings. Data were analyzed until categorical and theoretical saturation are achieved. Through an inductive analysis and a grounded theory approach, theoretical models were developed. Finally, we compared our findings with existing literature and documented our analysis and findings.

Results

We have completed a series of studies to develop a socially constructed set of key innovativeness factors. First, we conducted exploratory interviews with eight individuals who are recognized engineering innovators, innovation managers, engineering entrepreneurs and/or scholars of innovation – each covering a variety of technical disciplines and industries.

Second, we collected interview data from a group of 45 engineering innovators, ensuring engineering discipline, gender, ethnic, and geographic diversity. These interview data were analyzed through a qualitative study to determine whether the key factors identified in the first study were prevalent among a larger and more diverse group of participants.

Next, we conducted an in-depth literature synthesis to understand different ways in which these innovative engineer characteristics were currently identified, and we have begun to assess existing needs for new engineering innovativeness assessment instruments.

The key findings of our studies co-constructed with engineering innovators are:

1. *A definition of engineering innovation*: Engineering innovators described innovation similarly stating an improvement in a product or process that has value to users and is implemented sustainably and profitably in a community or marketplace in a community.

   "In my mind, innovation is recognizing a need, or a gap, or a circumstance that could be better and then bringing to bear new ways of putting things together, [things] that usually exist, to be able to meet that need, or that gap." ***Richard***

   "Simply put, it's a new way of doing things. It's breaking tradition and taking a new approach to solving an old problem. I think an innovation is actually only truly innovative if it is delivered to the world and widely adopted, and enjoyably used." ***Riley***

2. *A two-stage definition of the engineering innovation process*: the front-end, or discovery and development stage, and the back-end, or implementation and adoption stage. Engineering innovators defined the innovation process as having a front-end (discovery and development stage) and a back-end (implementation and adoption stage). Engineering innovators also embraced a pipeline innovation model.

   "So an idea is a creative seed of what could be. An invention is the translation of the idea into something that could be viable, but the true innovation has vetted the idea and invention and made it a sustainable business proposition." ***Carol***

3. *Five critical characteristics of an engineering innovator*: Among the characteristics of innovative engineers identified by engineering innovators, five characteristics were the most prevalent: Deep Knowledge, Active Learner/Curious, Vision/Caring, Team Manager/Leader, Risk Taker.

   - ***Deep Knowledge***. "So, having that exposure, that experience across the real broad spectrum of solutions was really helpful. The people in my career that have been really innovative have tended to basically [be] interested in virtually everything. And, they've got something beyond what I'll call a cocktail party level of familiarity with subjects. They know a broad base of subjects deeply enough that it can provide meaningful contributions and information to problem solving." ***Pierre***
   - ***Active Learner/Curious.*** "All the people I know who are really good innovators are inquisitive, constantly seeking new ways to do it better." ***Doris***
   - ***Vision/Caring.*** "They're forward thinking. They live in the future and that may be frustrating to those who want them to live in the present... but their heads are in the future." Dana "[Innovators] want to make impacts. They want to change the world somehow. They get value out of that." ***Ian***
   - ***Team Manager/Leader.*** "You find out that working with other people is much more enjoyable, that [you] can leverage not only their talents but some of their energy." ***Aubrey***

- ***Risk Taker.*** "[He had] just a total lack of fear of not knowing how to do something. He would go after it and pursue those things. And he would have fun with it. I think that's the way his mind worked, to see the humor in situations, and go off on a bizarre tangent just for the fun of it and then come back [and say]: Here's what we really have to address, and figure out what's going on." ***Toni***

4. *The uniqueness of the social construction of the characteristics of an engineering innovator*: Each engineering innovator uniquely described the characteristics of an engineering innovator.

5. *Five critical characteristics of a non-innovative engineer*: people who fail to challenge the status quo, are not collaborators, someone who minimizes risk, is not persistent, and is focused on a narrow domain of knowledge or expertise rather than a more diverse knowledge and skill base.

   "I can describe people that don't [innovate]. They tend to stay within the system, and stay within the rules. They stick to their objectives and to an extent that they oftentimes can't achieve their objectives because they're not networking." **Aubrey**

   "[Non-innovators] are the ones that cannot get out of the short-term, or say this is the way we've always done things. I see that a lot ...whether they don't see [the value of the innovation], or they think it's too much work. Gee, if I've got to develop a whole supply chain, that's too much work." ***Ted***

Future Research

Our future work will focus on three things: (1) developing and validating an instrument to fully measure the characteristics of engineering innovativeness, (2) investigating how the characteristics of engineering innovativeness differ in the stages of innovation and in different engineering domains and contexts, and (3) initiating a database of engineering innovativeness that enables an evaluation and benchmark of the innovativeness of engineering students and engineering practitioners. With our new validated instrument in hand, engineering educators in academia and engineering managers in the workplace will be able to provide students and personnel with insight into their unique "brands" of innovative potential and manifest ability, and then guide those students/personnel in appropriate directions for professional growth.

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References

[1] National Science Board (2007). *A National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System*, Arlington, VA, National Science Foundation, http://www.nsf.gov/nsb/documents/2007/stem_action.pdf.

[2] Department of Labor (2007). *The STEM Workforce Challenge: The Role of the Public Workforce System in a National Solution for a Competitive Science, Technology, Engineering, and Mathematics (STEM) Workforce*, Washington, D.C.

[3] Kelley, T. and J. Littman (2001). *The Art of Innovation*. New York: Doubleday.

[4] Locke, G. (2010). *Remarks at Kauffman Foundation States of Entrepreneurism Address*, Washington, D.C., U.S. Department of Commerce, http://www.commerce.gov/NewsRoom/SecretarySpeeches/PROD01_008812.

[5] Friedman, T. L. (2005). *The World is Flat: A Brief History of the Twenty-First Century*. New York: Farrar, Straus & Giroux.

[6] Castillo, S. (2010). Minutes of the Directorate for Engineering Advisory Committee Meeting, National Science Foundation, Arlington, VA, Oct. 20-21, 2010.

[7] Ferguson, D.M., J. Cawthorne, B. Ahn, and M.W. Ohland, “Engineering Innovativeness,” in press, Journal of Engineering Entrepreneurship, December 2012.

[8] Genco, N. (2010). "An Experimental Investigation of the Innovation Capabilities of Engineering Students," *American Society of Engineering Education*, Austin, TX.

[9] Goldsmith, R. E. (1990). “The validity of a scale to measure global innovativeness,” *Journal of Applied Business Research*, Vol. 7, No. 2, pp. 89-97.

[10] Goldsmith, R. E. and C. F. Hofacker (1991). “Measuring consumer innovativeness,” *Journal of the Academy of Marketing Science*, Vol. 19, No. 3, pp. 209-221.

[11] Hurt, H. T., Joseph, K., and C. D. Cook (1977). “Scales for the measurement of innovativeness,” *Human Communication Research*, Vol. 4, No. 1, pp. 58-65.

[12] Kirton, M. J. (1976). “Adaptors and innovators: a description and measure”, *Journal of Applied Psychology*, 61(5), 622-629.

[13] Price, L. L., and N. M. Ridgway (1983). “Development of a scale to measure use innovativeness”, in R. P. Bagozzi & A. M. Tybout (Eds.) *Advances in Consumer Research*, Vol. 10 (pp. 679-684). Ann Arbor: Association for Consumer Research.

[14] Ragusa, G. (2011). “Engineering creativity and propensity for innovative thinking in undergraduate and graduate students,” *Proceedings of the 2011 ASEE Annual Conference & Exposition*, Vancouver, BC, June 2011.

[15] Jablokow, K. W. (2005). “The catalytic nature of science: Implications for scientific problem solving in the 21st century,” *Technology in Society*, 27(4), 531-549.

[16] Goldsmith, R. E., Freiden, J. B. and J. K. Eastman (1995). “The generality/specificity issue in consumer innovativeness research,” *Technovation*, Vol. 15, No. 10, pp. 601-612.

[17] Jackson, D. N. (1976). *Jackson personality inventory manual*. Goshen, New York: Research Psychologists Press, Inc.

[18] Goldsmith, R. E. (2001). “Using the domain specific innovativeness scale to identify innovative Internet consumers,” *Internet Research*, Vol. 11, No. 2, pp. 149-158.

[19] Flynn, L. R. and R. E. Goldsmith (1993). “A validation of the Goldsmith and Hofacker innovativeness scale,” *Educational and Psychological Measurement*, Vol. 53, pp. 1105-1116.

[20] See Jackson, D. N. (1976), p.10.

[21] Kirton, M. J. (2011). *Adaption-Innovation in the Context of Diversity and Change*. London, UK: Routledge.

[22] Leavitt, C. and J. R. Walton (1975). Development of a scale for innovativeness. In M. J. Schlinger (Ed.), *Advances in consumer research*, Vol. 2, Ann Arbor, MI: Association for Consumer Research, pp. 545-554.

[23] Leavitt, C. and J. R. Walton (1981). The open processing scale: A measure of innovative cognitive style. Working paper, College of Administrative Science, The Ohio State University.

[24] Fisher, E., Biviji, and I. Nair (2011). "New perspectives on teaching innovation to engineers: An exploration of mental models of innovation experts," *Proceedings of the 2011 ASEE Annual Conference and Exposition*, Vancouver, BC, June 2011.