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Identifying Key Factors of Engineering Innovativeness

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Dr. Kathryn Jablokow is an Associate Professor of Mechanical Engineering and Engineering Design at Penn State University. A graduate of Ohio State University (Ph.D., Electrical Engineering), Dr. Jablokow's teaching and research interests include problem solving, invention, and creativity in science and engineering, as well as robotics and computational dynamics. In addition to her membership in ASEE, she is a Senior Member of IEEE and a Fellow of ASME. Dr. Jablokow is the architect of a unique 4-course module focused on creativity and problem solving leadership and is currently developing a new methodology for cognition-based design. She is one of three instructors for Penn State's Massive Open Online Course (MOOC) on Creativity, Innovation, and Change, and she is the founding director of the Problem Solving Research Group, whose 50+ collaborating members include faculty and students from several universities, as well as industrial representatives, military leaders, and corporate consultants.

Dr. Senay Purzer, Purdue University, West Lafayette

enay Purzer is an Assistant Professor in the School of Engineering Education. She is the recipient of a 2012 NSF CAREER award, which examines how engineering students approach innovation. She serves on the editorial boards of Science Education and the Journal of Pre-College Engineering Education (JPEER). She received a B.S.E with distinction in Engineering in 2009 and a B.S. degree in Physics Education in 1999. Her M.A. and Ph.D. degrees are in Science Education from Arizona State University earned in 2002 and 2008, respectively.

Dr. Daniel Michael Ferguson, Purdue University, West Lafayette

Daniel M. Ferguson is the recipient of four NSF awards for research in engineering education and a research associate at Purdue University. Prior to coming to Purdue he was Assistant Professor of Entrepreneurship at Ohio Northern University. Before assuming that position he was Associate Director of the Inter-professional Studies Program and Senior Lecturer at Illinois Institute of Technology and involved in research in service learning, assessment processes and interventions aimed at improving learning objective attainment. Prior to his University assignments he was the Founder and CEO of The EDI Group, Ltd. and The EDI Group Canada, Ltd, independent professional services companies specializing in B2B electronic commerce and electronic data interchange. The EDI Group companies conducted syndicated market research, offered educational seminars and conferences and published The Journal of Electronic Commerce. He was also a Vice President at the First National Bank of Chicago, where he founded and managed the bank's market leading professional Cash Management Consulting Group, initiated the bank's non credit service product management organization and profit center profitability programs and was instrumental in the breakthrough EDI/EFT payment system implemented by General Motors. Dr. Ferguson is a graduate of Notre Dame, Stanford and Purdue Universities and a member of Tau Beta Pi.

Dr. Matthew W. Ohland, Purdue University and Central Queensland University

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 $14.5 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 Chair of the IEEE Curriculum and Pedagogy Committee and an ABET Program Evaluator for ASEE. He was the 2002–2006 President of Tau Beta Pi and is a Fellow of the ASEE and IEEE.

Ms. Jessica Menold Menold, Pennsylvania State University, University Park

Jessica Menold is a second year graduate student interested in entrepreneurship, the design process, and innovativeness of engineering graduates and professionals. She is currently working as a student mentor in the Lion Launch Pad program, where she works to support student entrepreneurs. Jessica is currently conducting her graduate research with Dr. Kathryn Jablokow on a project devoted to the development of a psychometric instrument that will measure the skills, behaviors, and traits of an innovative engineer. Her hope is that this awareness of individual innovativeness levels will enhance engineering professionals and student's innovative skillsets. Jessica is also interested in studying and teaching design thinking methods to students, and is currently working to spread design thinking through mini-workshops across Penn State.

Identifying and Assessing Key Factors of Engineering Innovativeness

Project Goals

This NSF REE project has four major goals: (1) to define the key characteristics of engineering innovativeness; (2) to place those key characteristics in the phases of the innovation process; (3) to develop, test, and collect initial validity evidence for tools to measure the characteristics of engineering innovativeness in student and practicing engineers; (4) to prepare for further validation studies that will include our research collaborators and to solicit collaborator participation in the future construction of a benchmark database on engineering innovativeness.

Major Activities

During the second year of this collaborative three-year project of Penn State University and Purdue University researchers, we engaged in five major activities. First, the project team conducted a large scale Delphi study, during which we engaged with over 150 engineering innovators in three Delphi rounds. Second, we recruited five additional academic and six additional corporate research collaborators. Third, in October 2014, we held our second project evaluation panel (PEP) meeting. Fourth, we developed drafts of our test instrument based on a year-long study of prior art and other relevant research. Fifth, we disseminated our findings to current and potential collaborators through presentations at three academic conferences; more presentations in 2015 are planned.

Specific Objectives

Our specific year two objectives were: 1) to identify the characteristics of engineering innovativeness in the phases of innovation through the completion of the Delphi Study; 2) to acquire additional academic and corporate collaborators to assist in instrument testing and validation; 3) to complete a literature and prior art review and construct our test instrument in forms appropriate to both engineering students and practicing engineers with the assistance of psychometric experts; and 4) to develop an instrument testing and validation plan appropriate to our research goals and contexts.

Significant Results

In this section, we summarize the following: 1) Delphi Study key findings; 2) results of collaborator recruitment efforts; 3) a summary of our instrument research, instrument construction process, and face validity study; and 4) the design of our unique testing and validation process.

The Delphi Study resulted in five key findings (Purdue team leading), as follows:

- ***Agreement on characteristics definitions was achieved.*** After incorporating round one survey participant comments into the revised characteristic definitions provided in the round two survey, 97% of the Delphi Study participants agreed with the revised definitions. After definition revisions, no new or additional characteristics were identified beyond the 20 original engineering innovator characteristics.

- ***All 20 identified characteristics are found in Engineering Innovators.*** In the Delphi Study characteristic selection and ranking process, every one of the 20 possible characteristics of an engineering innovator was selected in one of the three innovation stages (discovery, development, implementation) for a 1-7 ranking by 10% or more of the Delphi Study participants.

- ***Important characteristics differ significantly by phase of innovation.*** The highest selected and ranked characteristics are unique in the discovery, development, and implementation stages of the innovation process. For example, creativity and curiosity are among the highest ranked characteristics in the discovery stage and among the lowest ranked characteristics in the implementation stage.

- ***Engineering innovators possess unique combinations of the critical characteristics.*** The most important characteristics by ranking were selected by no more than 70% of the Delphi Study respondents, i.e., 30% of the respondents did not even select the highest ranked engineering innovator characteristic for a 1-7 ranking. This evidence, as well as other data, led us to conclude that engineering innovators have highly diverse sets of characteristics which aid them in being innovative.

- ***Delphi Study reached consensus on the most important characteristics by stage of the innovation process.*** The selection and ranking of characteristics by stage of the innovation process has a 97% correlation between the round two selection survey and the round three re-selection survey. Delphi Studies are usually judged to achieve consensus with a level of 50-60% agreement, and our results greatly exceed that threshold.

Collaborator Recruitment

Collaborators have agreed to support two testing phases in 2015, as well as validation studies in 2016-2018, each recruiting significant and representative samples of their engineering student or practicing engineer populations. These samples will be combined for testing purposes.

- Academic Collaborators include faculty and researchers at Carnegie Mellon, Georgia Tech University, Lawrence Technological University, Lehigh University, Penn State University, Purdue University, Rose-Hulman Institute of Technology, Saint Louis University, and Stanford University. Carnegie-Mellon, Georgia Tech and Stanford are new this year. Discussions are continuing with other academic collaborators.
- Corporate Collaborators include innovation and engineering managers at AECOM Technology Corporation, BASF Corporation, The Chrysler Group LLC, Corning Incorporated, Cummins Incorporated , Eaton Corporation, International Automotive Components Group, Kimberly-Clark Corporation, Little Diversified Architectural Consulting, Procter & Gamble and Walker Parking Consultants. All companies except Kimberly-Clark, Procter & Gamble and Walker Parking Consultants are new this year. Discussions are continuing with other corporate collaborators.
- Dissemination Partners include the *Journal of Engineering Entrepreneurship* [JEEN], The NSF sponsored Epicenter Project - The National Center for Engineering Pathways to Innovation at Stanford University and Venture Well, and ASEE's Entrepreneurship and Innovation Division.

Instrument Development Process (Penn State team leads)

- ***Instrument research.*** In 2013/2014, 39 validated instruments that measure constructs related to one or more of our 20 characteristics of engineering innovativeness were identified from the Entrepreneurship, Information Processing, and Motivation/Self Efficacy literature. The constructs underlying these instruments were critically reviewed in terms of the elements of cognitive function they assess and whether those constructs are considered to represent innate traits or learned skills/behaviors.
- ***Instrument construction process.*** An instrument development and validation process unique to our situation was constructed with guidance from psychometric experts. Up to ten behavioral descriptions of each engineering innovativeness characteristic were created from the knowledge base of prior art/research, our own engineering innovator interviews, and the Delphi Study results.
- ***Face validity study.*** A face validity test was used to reduce the behavioral item descriptions to five items per characteristic in preparation for testing and validation in both student and practicing engineer populations.

Design of Our Testing and Validation Process

- ***Classic Item Analysis:*** The purpose of classic item analysis is formative – i.e., we are trying to maximize reliability. The mean item score provides information on estimated classical reliability, while the corrected item-total correlation provides information on discrimination. We will use representative samples of both target populations (engineering students and engineering practitioners). The results of the classic item analysis will eliminate behavioral description items that are not performing well. Since we have 20 characteristics of engineering innovativeness, each currently with five items, we will treat each characteristic as a separate item test. Finally, we will look at each testing participant's overall score, and if there are items across testing participants that consistently do not contribute to their overall innovativeness score, then those items can be eliminated.

- ***Pilot Testing (leading to Factor Analysis):*** After our classic item analysis is complete, we will move to large scale pilot testing and apply full factor analysis. We will first conduct a confirmatory factor analysis to see which factors emerge in the optimized model. Because we have a theoretical framework (theory developed through content experts), we will start with confirmatory analysis. We expect to see 20 factors emerge, corresponding to the 20 characteristics of engineering innovativeness. A second order factor analysis may also be applied to see whether certain factors cluster together within each of the three stages of the innovation process and as dominant characteristics - i.e., testing the results of the Delphi study to determine which characteristics are most important in which (or across all three) stages of innovation.

- ***Collection of Validity Evidence:*** Validity evidence will be collected throughout the lifetime of the instrument, including the coming year. Validation is a "matter of argument" (as opposed to "standard forms of validity"); that is, our claims about the construct lead to hypotheses, and we design studies to test them, collect data, and generate proofs. These proofs accumulate over time to support the instrument and its use. There are many types of validity evidence (proofs), including data gathered from content validation, process validation, factor analysis (to investigate internal structure), correlational analyses, and the examination of intended and unintended consequences. We will collect validity evidence of each type over time.

Key Outcomes

The second year outcomes of the project were four-fold.

- First, the project includes a greater number of strong collaborators [three more schools and eight more corporations] who are helping recruit research participants, serving as project advisors, or are potential users of the products that will be produced.

- Second, the Delphi Study resulted in a set of distinct insights which are both unique to engineers and not found in existing literature.

- Third, we have received a detailed second year report from our Project Evaluation Panel (PEP members) that will help guide the next steps of the project. It strongly recommends that the project be continued beyond the current grant.
- Fourth, our development, testing, and validation processes are unique to our research but can also serve as a guide for others who may attempt similar work in the future.

Project Goals for 2015

1) Development, testing, and validation of the engineering innovativeness measurement instrument for both student and practicing engineer populations through the collaboration and support of ten universities and ten corporations in three phases:
    a. Classical item analysis and instrument testing.
    b. Pilot testing and factor analysis.
    c. Validation testing of instrument[s].
2) Planning for full evaluation studies in 2015-2018 of Engineering Innovativeness at all 20 collaborating academic and corporate institutions.
    a. Project plans for research studies to be conducted at the participating collaborating organizations completed by fourth quarter 2015.
    b. Research Summit with representatives of collaborating organizations in fourth quarter 2015
    c. Instrument training workshops and update sessions conducted at collaborating organizations.
3) Dissemination of research results through conference presentations and journal papers; training seminars; sharing results with study participants; and through dissemination of research results by our academic and corporate research collaborators and dissemination partners:
    a. Academic Collaborators include faculty and researchers at Carnegie Mellon, Georgia Tech University, Lawrence Technological University, Lehigh University, North Dakota State University, Purdue University, The Pennsylvania State University, Rose-Hulman Institute of Technology, Saint Louis University, and Stanford University.
    b. Corporate Collaborators include innovation and engineering managers at AECOM, Chrysler, Corning, Cummins, Eaton, Interactive Automotive Components, Kimberly-Clark, Little Diversified Architectural Consulting, Procter & Gamble and Walker Parking Consultants.
    c. Dissemination Partners include the *Journal of Engineering Entrepreneurship* [JEEN], The NSF sponsored Epicenter Project - The National Center for Engineering Pathways to Innovation at Stanford University and Venture Well, and ASEE's Entrepreneurship and Innovation Division.

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