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What is Engineering Innovativeness?*

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An innovation is the 'implementation of a new or significantly improved product (good or service), process, marketing method, or organizational method in business practices, workplace organization or external relations'. Acting as innovators and as the translators of new or existing technology into innovations that benefit society is the torch that engineers are expected to carry. Multiple vague and overlapping definitions of innovative behavior by engineers lead to much confusion in our society over the role that engineers play or can play in the innovation process. In this paper we explore the innovative behavior of engineers and the relationship of that innovative behavior with the creative, problem solving, design and entrepreneurial behavior of engineers. These different perspectives of defining the innovative behavior of engineers, or, as we call it, 'innovativeness' in engineers, illustrate the societal confusion over the definition of innovative behavior by engineers. The key question that we propose to answer is: 'What set of intrinsic abilities (skills, knowledge, personality traits, or attributes) when combined with domain knowledge, experience and other extrinsic factors enable and inspire engineers to create innovations that benefit society?'

Keywords: creativity; innovation, problem solving; engineering design education

1. Innovations: today's societal dream

> 'the science and engineering research enterprise . . . these are disciplines that lead to innovation across the spectrum of modern life' [1] pp. 90–91.

Innovation in products, processes and concepts is seen as a socioeconomic cure for many of the troubles of modern societies. Acting as the translators of new or existing technology into innovations that benefit society [2] is the Olympic torch that engineers are expected to carry. Yet the vague, overlapping, and multiple definitions of engineering innovativeness lead to much confusion in our society. The purpose of this research is to explore the definition of innovativeness in engineers. The initial research question is: 'What is engineering innovativeness?' and more specifically, 'What is that set of intrinsic abilities (skills, knowledge, personality traits, or attributes) combined with domain knowledge and experience and other extrinsic factors that enable and inspire engineers to create innovations that benefit society?' Given an accepted definition of innovativeness, we will use an engineering innovativeness measurement instrument to ask the critical questions for advancing engineering innovativeness:

> 'How innovative are engineering students and professional engineers?' and 'How do we increase engineering innovativeness?'

An innovation is understood as the 'implementation of a new or significantly improved product (good or service), or process, marketing method, or organisational method in business practices, workplace organisation or external relations' [3]. Innovation is measured as the output of a process or the result of a series of actions and decisions by an individual, team, company, group or nation that produces something innovative. To be innovative, an innovation must be new and provide benefits in the context where it is implemented. To be an innovator, you must bring forth ideas that are both novel and benefit the parties or organizations to which your ideas are successfully applied so that they accept, purchase, or implement those ideas. There are no boundaries as to who may benefit from your newly implemented idea. So, if you produce innovations then you are innovative, but that leaves us with a gap in understanding the skills, knowledge, personality traits, and attributes, or cognitive and societal processes that are used by engineers to produce an innovation.

2. Innovative engineers: the modern alchemists

Being called an innovator is a desired label and potential compliment for a successful designer, artist, businessman, teacher or musician, as well as an engineer. Yet consensus definitions of the possible sets of skills that represent the ability to be innovative as an engineer do not exist for professional or scientific engineering activity. Innovativeness is most often measured by the output of innovations, rather than the skills, knowledge, personality traits, or attributes that were necessary to produce those innovations. The term innovative is also used interchangeably or by overlapping

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definition in literature and conversation with the words creative [4], designer [5], problem solver [6], and entrepreneur [7] to describe a person's behavior, motivation or abilities and the results of that behavior: problem solutions and innovations.

To date, research on innovativeness and competency skills for engineers has focused on whether engineers are creative [8] and good problem solvers [9]. More recently there have been calls to also make sure engineers possess design [5] and entrepreneurial skills [7]. These four competency objectives are knowledge and process skill sets assumed to make engineers more competent and innovative. 'Technically competent and innovative' is the siren call made by the National Academy of Engineering in its 2005 report, Educating the Engineer of 2020 [10]. In entrepreneurship research, there is also a call to focus on how entrepreneurs do innovation, not just the economic evidence of what successful entrepreneurs produce, i.e., innovative businesses [11].

The theoretical framework for this research is interpretivist, because the possible skill sets for engineering innovativeness are not viewed as a single fixed solution but as a set of competencies (skills, knowledge, personality traits, or attributes) with many possible winning combinations. Interpretivist approaches are founded on the belief that reality is socially constructed and fluid [12]. Thus, interpretivism presumes that what we know is always negotiated within cultures, social settings, and relationships with other people. What is called an innovation or innovative behavior in one culture may be interpreted differently in another culture. In all cultures, the ability to be innovative in this research is defined as the individual being located in innovation space in a place or on a multidimensional ability surface where the individual utilizes their skills to produce innovations.

The paths that individuals take to become potentially innovative or the abilities that they exercise to be innovative may be unique to that individual or even the result of following a preferred path for acquiring those competencies within a domain. However these innovative abilities may be acquired or developed, they place the individual in a location in innovation space where their competencies can be exercised to conceive and implement innovative products, processes, or concepts. Figures 1 and 2 are provided as a conceptual representation of the innovation space, a place where innovators create innovations, each in their own way.

The purpose of Fig. 1 is to show apparent relationships between the concepts used in conjunction with or defined as a part of engineer innovativeness; creativity, problem solving, design thinking and entrepreneurial. Boxes and ellipses in Fig. 1 represent the collection of abilities or factors grouped under that concept or personal or social influence on engineer innovativeness. Arrows in Fig. 1 are hypothetical indications of relationships between factors or abilities where the direction of the arrow indicates a proposed direction for that influence. Figure 2 is a symbolic representation of the overlapping definitions and interconnected nature of all the concepts or factors that relate to, define or catalyze engineer innovativeness. Both Figs. 1 and 2 indicate our belief that engineer innovativeness is a multidimensional space with unique combinations of factors and abilities that define the innovative potential for an engineer.

Our method for achieving consensus on a definition of engineering innovativeness will be a multiple-round Delphi Study, a social-constructivist process for achieving a community definition. The expert participants in the Delphi study will be drawn from the domains of our society that study aspects of innovativeness or the engineering domains that produce innovations in products, processes, and concepts. The community definition of engineering innovativeness will then be incorporated into an existing or adapted innovativeness measurement instrument, continuing an interpretivist approach. Validation of the engineering innovativeness measurement instrument will be done through guided open-ended interviews with innovative engineers selected by criterion sampling, using a grounded theory approach. Finally, the instrument to measure the innovativeness of engineers will be administered to samples of student and professional engineers to begin an 'engineering innovativeness' benchmarking process and interventions evaluation process. The ability to measure innovativeness in student and practicing engineers or the potential to be innovative as an engineer has significant implications for engineering education, capital investment, policy formulation, management of corporate enterprises, the future socioeconomic well-being of our societies, and, of course, our search for 21st century alchemists.

3. Creativity by engineering alchemists

As humans work to solve their problems, they sometimes propose solutions that are judged to be new or novel, sometimes solutions that are so unique they are even called brilliant ideas and occasionally, most often after many long years of hard work and supported by a network or community [13, 14], they propose a solution or a change in a domain that is valued and adopted by that community or their culture. All three of these types of problem solutions are called 'creative' by society [4].

Creativity is understood as the 'ability to produce work that is both novel and appropriate' [3] while some see creativity as just the ability to see possibilities that others haven't noticed [15].

In this research, creativity is 'a cognitive process that results in an idea or solution that is novel and appropriate that people will purchase, adopt, use or appreciate' (i.e., a domain-changing idea) [4].

Researchers in creativity believe that 'creativity arises where there is a happy combination of factors such as personality traits, social influences, environmental conditions and cultural values but that there is no single recipe for making it happen' [16]. Sternberg maintains that there 'is not a single trait or type of creativity (process) but perhaps many different types of creativity with at least three different forms multiple creativities might take: creativities with respect to processes, domains, and styles. Multiple creativities exist if creativity is not only multidimensional, but multiple in nature. That is, it exists if there is no one thing that is truly creativity, but rather, multiple things that are' [17].

Other researchers believe that novelty or originality is rather easy to generate, regardless of the human traits that help explain how it happened, whereas ideas judged appropriate and adopted in a symbolic domain are very difficult to generate. Discovering new or creative ways of acting or thinking that change a domain almost always requires three critical and difficult inputs:

1. long arduous acquisition of knowledge about a domain of acting or thinking,
2. incremental gains in understanding of that domain acquired over long periods of time but with puzzles that remain, and
3. interaction with other experts who are gathering information about that same domain but bring their own unique and diverse insights and experiences to share with you, that is, you learn together and share experiments, thoughts, and ideas but from very different perspectives [4].

4. Similar alchemy formulas for creativity and problem solving

Learning how to solve life's myriad problems is a critical step that occurs in our development into adult humans. However, when we solve a problem in a way that is unique from what others have done previously, even a problem that others have solved, we are doing something that others will call different. If that new way of solving the problem is judged better in terms of its benefits to society, then we have done something which also may be judged as creative. If our new way of solving a problem, our problem solution, is accepted by others in our community, then our creative problem solving is a domain-changing solution or an innovation by our previous definition [18].

The patterns of thinking involved in the processes of problem solving and creative thinking are similar and involve the same cognitive processes. Problem solving today is generally defined as a process with six steps [19, 20] while Dewey defined it as a three step process of defining the problem, identifying alternatives and selecting the best alternatives [21]. For example, a description of a six-step problem solving process is:

1. Problem Definition: Document the problem; check that you answer the right problem.
2. Problem Analysis: Understand the current situation and why there is a problem.
3. Generating Possible Solutions: Generate several alternate solutions.
4. Analyzing the Solutions: Use criteria to evaluate solutions generated in previous step.
5. Selecting the Best Solution(s): Make a selection using the criteria from the previous step.
6. Implementation: Prepare and execute the plan for the selected solution[s].

Creativity has been defined as having four steps [22]:

1. Problem Analysis: Problem Finding and Problem Formulating to facilitate idea generation.
2. Ideation: Generating a variety of alternate solutions to the formulated problem.
3. Evaluation: Specifying criteria and evaluating the generated ideas against those criteria.
4. Implementation: Selecting the preferred solution(s) and preparing and executing an implementation plan.

A comparison between the problem-solving process definition and the creativity process steps show that they are similar cognitive processes and presumably require a similar set of abilities.

Many psychologists believe that our creativity stems from our need to make sense of our sensory input or surroundings. As we associate any new sensory input to previous sensory input, a constructivist model of learning, [23, 24] we come up with a new way of making sense of what we observe, that is, a novel idea. Thus, 'our creativity stems from our need to solve problems' [25]. Novel ideas arise when we come up with new associations between memories and sensory input and map our mental models and memories to what we currently perceive—a process much like children do in their imaginary play games. In this way 'creativity is seen as a subset if not entirely synonymous with problem solving' [26].

However, despite the similarity in the problem-solving and creativity processes, researchers attribute different characteristics to individuals behaving creatively compared to individuals problem solving. Skills needed for problem solving are defined as: (using) tools, defining, goal-identification, (using) heuristics, and reasoning [9]. Bloom and Perry further argue that the nature of the skills that we use in problem solving change as the nature of the problem changes from structured to unstructured problems and as our intellectual ability to think reflectively and critically change as we gain experience and expertise in problem solving and move from everything in our world being certain to everything in our world being relative and subjective [27].

On the other hand the critical attributes of human creativity are described as tolerance for ambiguity, willingness to surmount obstacles, willingness to grow, intrinsic motivation, risk-taking, desire for recognition, fluency, flexibility, originality, elaboration, curiosity, imagination, and independence [15, 17, 28].

Further different people use different cognitive strategies in solving problems [6] much as there are different types of creative strategies that people deploy [17]. Finally research has shown that people tend to have a particular style that they use in problem solving. A problem solving style can be open and innovative or closed and constrained but both styles of problem solving are effective, depending on the individual's capacity and on the context of the problem situation [29].

5. Creatively solving design problems supports engineering innovativeness

There are up to eleven different types of problems that engineers may be asked to solve, all requiring a process of generating and weighing alternatives and coming up with the best possible solution [28]. But the type of problem labeled a design problem is unique in that the problem is ill defined, that is, the problem lacks clear goals and evaluation criteria, is poorly structured, and there is no right or wrong answer, only better or worse answers. The pedagogical approach of problem based learning used in engineering design courses builds on this intellectual dilemma and present the engineer with real-world ill-structured problems, the highest level of problems defined in the Bloom and Perry cognitive thinking architecture [27].

Design problems challenge the engineer like no other problem because they require the engineer to provide the problem structure, solution alternatives, and evaluation criteria, and to remain open to changing the proposed problem solution as new information becomes available. Creative solutions gain special weight in solving design problems because they represent a potential solution to the nature of the problem as well as to the specific problem. Creativity in solving design problems is 'recognized as an essential part of the engineering design process in the concept generation and evaluation stages' [30].

Of greatest importance is the fact that most real world problems are ill structured and require the highest levels of problem solving skills and intellectual or cognitive abilities [27], that is, the ability to creatively design solutions that solve ill-structured, open-ended, never-have-enough information, always-changing-requirements, and hard-to-satisfy client problems.

A prototypical five-step design process is defined as:

1. Problem Scoping and Information Gathering: identifying criteria, constraints, and requirements; framing the problem goals or essential issues; gathering information; and stating assumptions about information gathered.
2. Project Realization: deciding among a set of alternatives and communicating elements of the final design through writing, sketching, creating instructions, and creating bills of materials.
3. Considering Alternative Solutions: thinking of potential solutions (or parts of potential solutions), experimenting with solution ideas, and thinking of ways to get around an impasse.
4. Total Design Time and Transitions: Over the course of the total time the designer devotes to design activities, a designer may frequently transition between the different design activities or devote longer periods of time to an activity before moving to the next task.
5. Solution Quality: Ultimately, at the end of the design session the designer may have an idea, a sketch, a prototype, a model or a set of plans and instructions; the final design can be assessed based on how well it meets design criteria or how 'creative' or 'innovative' it is. [31]

In summary we believe that the design process is a problem-solving process with the cognitive requirements of an elevated or mature set of problem solving attributes but not personal attributes or abilities distinct from creativity or problem solving abilities.

6. Entrepreneurial abilities complete engineering innovativeness

Entrepreneurs according to Peter Drucker 'create something new, something different, they change or transmute values' [32]. Drucker dismisses the start of small businesses (gas stations, fast food outlets, Starbucks stores), which merely replicate what has been done elsewhere, as not entrepreneurial in the game-changing sense that we are using in this research. This sentiment is echoed by founders of entrepreneurship programs in universities including Professor A. C. Cole who founded the Harvard Center for Entrepreneurship History in 1948 and is quoted by Professor Jonathan R.T. Hughes in 1983 [33]:

> 'The study of entrepreneurship is similar to the study of creativity in any field. It is creativity, originality, which should be the central focus of entrepreneurial studies. The entrepreneurial contribution is precisely that of original perception, new ideas, and new departures. The unexpected is made to happen.'

The key reason for including entrepreneurial behavior within the scope of engineering innovativeness is that societal expectations for engineers are that the innovations resulting from the practice of engineering innovativeness will be implemented to benefit society. Innovative engineers therefore need to be successful entrepreneurs themselves or be able to partner with entrepreneurs to implement their new useful domain changing products, processes, or concepts. We conclude that entrepreneurial attributes are required aspects of engineering innovativeness.

Seven attributes and three skills have been identified as needed for successful entrepreneurs [34]:

1. Need for achievement**.** Entrepreneurs strive for performance and compete. They build their company with their professional goals in mind and set high target levels and put in much effort to reach them.
2. Need for autonomy. Entrepreneurs desire the ability to resolve their problems and to bring activities to a successful end on their own.
3. Need for power. Power is the need to have control over others to influence their behavior. Successful entrepreneurs know what they want and how to influence others to achieve their own goals.
4. Social orientation. Entrepreneurs know that connections with others are required to realize their ideas. They make these connections easily and are driven by professional considerations in their social activities.
5. Self efficacy. Entrepreneurs are usually convinced that they can bring every activity to a successful end. Also, they feel that they can control their own success, which does not depend on others.
6. High degree of endurance. Successful entrepreneurs have an ability to persist, in spite of setbacks or objections.
7. Risk taking propensity. Entrepreneurs can deal with uncertainty and are willing to risk a loss.
8. Market awareness. The ability to sympathize with the needs of (potential) clients, link these needs to one's own business and appeal to the specific needs of a clearly defined target group of customers. Entrepreneurs have the ability to anticipate changes in the market based on their awareness of the needs and wants of customers and the activities of competitors.
9. Creativity. This is the ability to adopt views from different perspectives and to see and try new possibilities based on open observations of (changes in) the environment. Moreover, creativity reflects the capability to turn problems into new opportunities.
10. Flexibility. This is a measure of the ability to adapt and react to changes they observe in their environment, such as new needs of clients or new competitors in their market [34].

7. Additional insights into the alchemy of engineering innovativeness

Many researchers contend that entrepreneurial skills are crucial to generating innovations [7] and others insist that creativity and entrepreneurial skills are simply the most important of several innovation building blocks:

> 'Thus innovation represents a marriage of the vision to create a good idea and the perseverance and dedication to stick with the concept through its implementation. Successful entrepreneurs are able to blend imaginative, creative thinking with systematic, logical processing abilities; this combination is the key to their [innovation] success' [7].

Researchers analyzing the causes of innovative behavior by engineers and entrepreneurs potentially attribute engineer innovativeness or the level of engineer innovativeness to several different conditions or factors:

> First, education and the acquisition of domain expertise are seen as crucial innovation skill factors [35]. Second, self-efficacy, the desire and an individual's judgment of their ability to perform a task, strongly influences motivation and outcome expectancy during an engineering design process [36]. Third, an individual's mindset is a personality characteristic that influences creativity and innovation and the willingness to take risks [37]. Fourth, prior experience is also viewed as a key factor in innovativeness. Fifth, individuals who have created more than one new business (e.g., serial entrepreneurs) or who have

worked in an industry or process for a long enough time to have developed human capital in that domain are believed to be more likely to be innovative [38]. Sixth, community influence on the production of innovations is seen as key to the generation of innovations [39] and finally personality is believed to influence innovation creation [40].

In Fig. 1 the probable conceptual relationships between the major intrinsic factors and extrinsic factors of engineering innovativeness are shown in the concept map. In Fig. 2 the probable overlap in intrinsic factors and extrinsic factors among these innovativeness dimensions are shown by a concept diagram map.

Table 1 refers to content of literature references

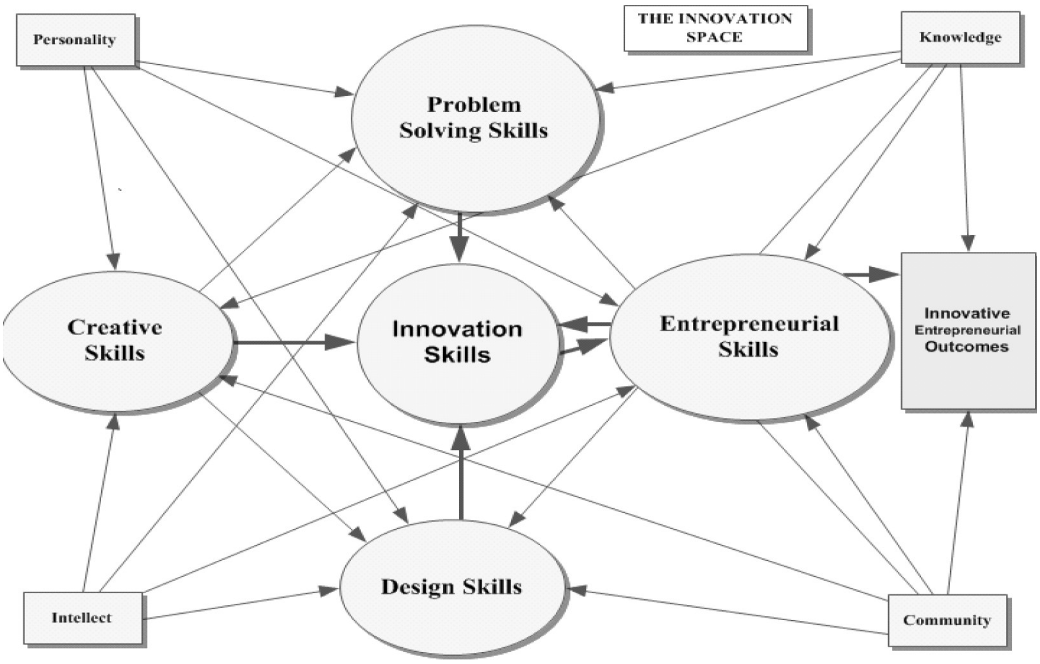

Fig. 1. The Conceptual Map of the Innovation space.

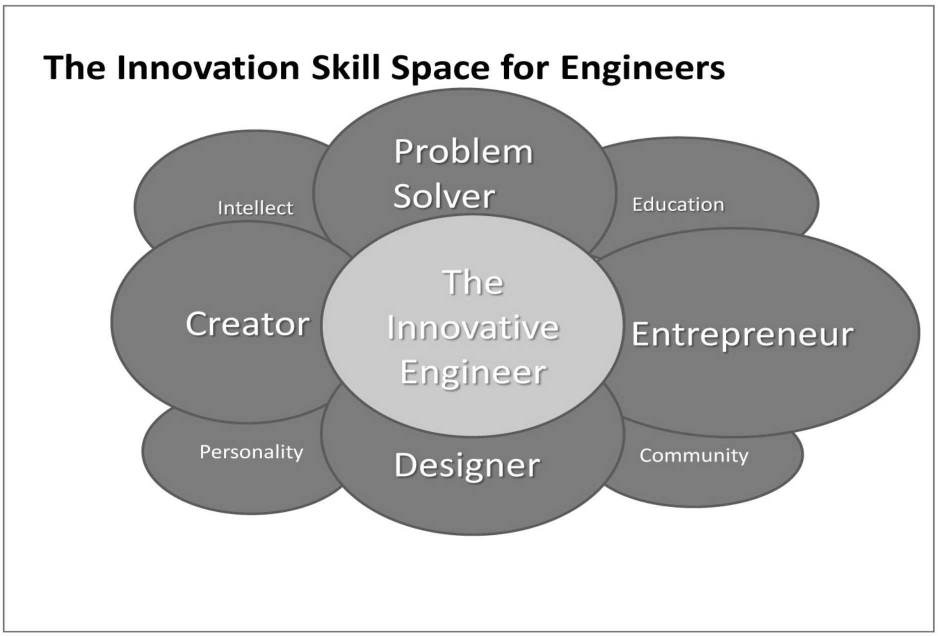

Fig. 2. A Diagram of Engineering Innovativeness.

Table 1. Partial Concept Mapping of Article Content vs. Intrinsic Behavior, Motivators or Attributes and Extrinsic Factors Potentially Contributing to Engineering Innovativeness

Intrinsic or Extrinsic Innovativeness Factors	Creativity	Problem Solving	Design Thinking	Entrepreneurial	Innovativeness
Market awareness	[2, 3]		[31]	[34]	[2, 3]
Domain expertise, Created more than one new businesses	[4, 13, 14]				[4, 13, 22, 38]
Personality	[17]				[40]
Education				[35]	[31]
Community influence Cultural values, Social awareness Social orientation, Environmental constraints	[4, 13, 14, 17]		[31]	[34]	[2, 3, 34]
Implemented	[4, 22]				[4, 22]
Generation of new ideas. Ideation, Creativity, Imagination, Originality, See possibilities that others haven't noticed	[2, 3, 18, 22, 41]	[28]	[30]	[34]	[4, 7, 22]
(using) Tools,		[9]			
Defining		[9, 28]			
Goal-identification, vision		[5, 9]	[5]	[5]	[5]
(using) Heuristics		[9]			
Reasoning, logical abilities		[6, 9]			
Problem analysis, Evaluation, Solution Quality, Considering Alternative Solutions, Problem Scoping and Information Gathering		[19]	[19, 31]		
Project Realization Implementation	[22, 41]	[19]	[31]		
Total design time/transitions			[31]		
Tolerance for ambiguity	[19]	[28]		[34]	
Need for achievement	[19]			[34]	
Need for autonomy	[19]			[34]	
Need for power				[34]	
Self efficacy			[36]	[34]	
High degree of endurance, Dedication	[4]			[5]	[7]
Risk taking propensity	[19]			[34]	[37]
Growth mindset					[37]
Elaboration	[19]				
Flexibility	[19]			[34]	
Fluency	[19]				
Motivation	[17]				
Problem solving style	[18]	[18, 29]			[18]

for this paper that identified intrinsic factors or extrinsic factors as supporting one of the four perspectives related to innovativeness and potentially factors included in engineering innovativeness. Rows describe conditions, actions, influences, skills, process steps or motivators claimed to be important to innovativeness. Rows are also combined when items appear similar. Columns segregate the rows by perspectives taken when discussing innovative behavior: creativity, problem solving, design thinking, entrepreneurial behavior, or the generation of innovations or the creation of new businesses that are domain-changing. As you can see from the mapping of the possible factors of innovativeness mapped with the perspectives often discussed along with innovativeness there is potential definition overlap and redundancy.

8. The alchemy of the Delphi process

The method proposed for achieving a community definition of engineering innovativeness is a Delphi study [42–46]. A Delphi study is a technique for gathering data from a group anonymously. The Delphi technique was developed by the Rand Corporation in the 1960s for forecasting technology innovation, and is a method of generating ideas and facilitating shared understanding among experts who have special knowledge to share but find it difficult or too expensive to meet in person for the extended conversations required to reach agreement.

To obtain a community definition of engineering innovativeness, a Delphi panel of innovation experts will be assembled and polled through anonymous surveys until a community definition of engineering innovativeness emerges. This definition may include mainstream and outlying aspects and will be used to develop an engineering innovativeness instrument that will be tested and validated. Both the community definition of engineering innovativeness and the validated engineering innovativeness measurement instrument will be widely disseminated.

A Delphi study is appropriate because there are many different definitions of innovativeness and therefore potential definitions of innovativeness in engineers. A Delphi study is a social constructivist approach to achieving agreement among the different experts each with their own perceptions of what is innovativeness in engineers.

9. Participants in the Delphi study

Participants in the Delphi study will be selected using a five-step Delphi Panel Formation process [42]. These steps are [47]:

1. Categorize the experts needed for the Delphi study to make sure no important class of experts is excluded;
2. Populate the list of possible experts with actual names drawn from the class disciplines, organizations, and including both practitioners and academics;
3. Ask contacts among our identified experts to nominate other experts;
4. Rank experts within each class of experts based upon their qualifications; and
5. Invite experts to participate in the Delphi process in rank order of their qualifications until we have obtained commitments from a sufficient number of participants to staff each panel required by the Delphi design and stop soliciting experts when we have reached an adequate Delphi panel size [42].

The disciplines identified for the engineering innovativeness Delphi Panel include individuals who are intellectual and innovation leaders in Aerospace Engineering, Biomedical Engineering, Chemical Engineering, Civil Engineering, Computer Engineering, Design, Electrical Engineering, Entrepreneurship, Environmental Engineering, Industrial Engineering and Mechanical Engineering. The panel should also include Psychologists who focus on learning skills and creativity, Psychologists/ Sociologists who study individual and group behavior related to creativity, Business Professors who teach innovation-related subjects and engineering educators who are innovating in engineering education practices. Other experts identified for the Innovativeness in Engineers Delphi Panel might include: editors of Journals who publish articles on innovation, authors who write about their experiences in being innovative, administrators who award grants to encourage innovation, entrepreneurs recognized for their innovativeness, corporate managers of product development, corporate managers from companies recognized for their innovations, engineers who have been recognized for their innovativeness, venture capitalists who give money to innovators, angel investors who give money to innovators and authors of books written on how to be creative, innovative and entrepreneurial. These 26 categories will be used to create a panel of 26–52 individuals who agree to participate in the multiple rounds of the Delphi process.

Assuming a maximum of four rounds to reach either consensus or stability in the responses and up to a maximum of 1–2½ hours required of each Delphi panel member per round, a Delphi panel member will be committing a minimum of 3–4 hours and a maximum of 7½–10 hours of time over the 4–6 month course of the Delphi process.

10. Rounds of Delphi engineer innovativeness survey

The first Delphi round is the distribution of a survey instrument that establishes a base set of definitions through both open-ended and close ended questions. Analysis of these responses leads to the development of a second round instrument, in which participants are asked to clarify and rank order survey items discussed in the first instrument. A third round of surveys, if necessary, further clarifies the responses received in the second round particularly for outliers. Experts in the Delphi process report that by the third round you often have achieved an equilbrium level where quantitative analysis of responses is meaningful. In any case, either in full survey rounds or in selected in-depth treatment, the panel organizer continues to poll panel participants until the desired level of consensus is achieved. A final report is then prepared and distributed to all panel members [47].

11. Summary of the alchemy formula for engineer innovativeness

We plan to conduct a Delphi survey among distinguished engineering innovators, innovation researchers and other distinguished investigators and educators in the innovation space to establish a community definition of engineering innovativeness. With this definition in hand we intend to develop or adapt and validate an engineering innovativeness measurement instrument. Given an acceptable measurement tool we then propose to benchmark engineering innovativeness to identify strategies and tools to increase engineering innovativeness.

References

1. National Academy of Engineering and Institute of Medecine, *Rising Above The Gathering Storm: Energizing and Employing America for A Brighter Economic Future*, National Academy of Sciences, Washington, D.C., 2007.
2. National Academy of Engineering, *The Engineer of 2020*, National Academy of Sciences, Washington D.C., 2004.
3. A. Ferrari, R. Cachia and Y. Punie, Innovation and Creativity in Education and Training in the EU Member States:

Fostering Creative Learning and Supporting Innovative Teaching, *European Commission Joint Research Centre*, 2009.
4. M. Csikszentmihalyi, *Creativity, Flow and the Psychology of Discovery and Invention*, Harper Perennial, New York, NY, 1996.
5. C. Bollfrass, Designing innovative engineers, *Hart's E&P,* **81**(10), 2008, pp. 94.
6. H. Simon, The Functional Equivalence of Problem Solving Skills, *Cognitive Psychology,* **7**, 1975, pp. 268–288.
7. M. Ames and M. A. Runco, Predicting Entrepreneurship From Ideation and Divergent Thinking, *Creativity & Innovation Management*, **14**, 2005, pp. 311–315.
8. N. Genco, An Experimental Investigation of the Innovation Capabilities of Engineering Students, *American Society of Engineering Education*, Austin, TX, 2010.
9. J. Welch, Problem-solving skills utilized by graduating engineers from a baccalaureate program to solve problems, Ed.D., Pepperdine University, United States—California, 2009.
10. National Academy of Engineering, *Educating the engineer of 2020: adapting engineering education to the new century*, National Academies Press, Washington, DC., 2005.
11. D. Dimov, Grappling with the unbearable elusiveness of entrepreneurial opportunities, *Entrepreneurship Theory and Practice*, **35**(1), 2011, pp. 57–83.
12. D. Cohen and B. Crabtree. *Qualitative Research Guidelines Project*, July 2006, Robert Wood Johnson Foundation.
13. A. Hargadon, *How Breakthroughs Happen*, Harvard Business School Press, Boston, MA., 2003.
14. S. Johnson, *Where Good Ideas Come From: The Natural History of Innovation*, Riverhead Books, New York, NY, 2010.
15. E. P. Torrance, The Beyonders in a Thirty Year Longitudinal Study of Creative Achievement, *Roeper Review*, **15**(3), 1993, pp. 131–135.
16. E. A. Edmonds, et al., The studio as laboratory: Combining creative practice and digital technology research, *International Journal of Human-Computer Studies,* **63**(4–5), 2005, pp. 452–481.
17. R. J. Sternberg, Creativity or creativities?, *International Journal of Human-Computer Studies,* **63**(4–5), 2005, pp. 370–382.
18. DeBono, Edward de Bono on creative thinking, ed: The DeBono Group LLC, 2006.
19. P. Heller, R. Keith and S. Anderson, Teaching Problem Solving through Cooperative Grouping: Group vs. Individual Problem Solving, *American Journal of Physics*, 1992, **60**(7).
20. K. Cherry, What is Problem Solving? [Online]. Available: http://psychology.about.com/od/problemsolving/f/problem-solving-steps.htm
21. J. Dewey, *How We Think?* Heath, Lexington, MA., 1933.
22. L. Zeng, R. W. Proctor and G. Salvendy, Can Traditional Divergent Thinking Tests be Trusted in Measuring and Predicting Real World Creativity, *Creativity Research Journal,* **23**(1), 2011, pp. 24–37.
23. H. P. Ginsburg and S. Opper, *Piaget's Theory of Intellectual Development*, Prentice Hall, New York, NY, 1988.
24. L. Vygotsky, *Thought and Language*, The MIT Press, London, UK, 1986.
25. M. Kirton, The Kirton Adaption-Innovation Inventory: a reply to Mulligan and Martin, *Psychological Reports*, **46**, 1980, pp. 950.
26. M. Kirton, Kirton Adaption-Innovation Inventory [1998 Edition], in *KAI*, L. L. Brown and R. Brown, Eds., ed. Highlands, Gravel Path, Berkhamsted, Hertfordshire HP4 2PQ, United Kingdom: Occupational Research Centre, 1976.
27. R. Irish, Engineering Thinking: Using Benjamin Bloom and William Perry to Design Assignments, *Journal of Engineering Thinking*, 1999, **3**(2), pp. 83–102.
28. D. H. Jonassen, Toward a design theory of problem solving, *Educational Technology Research and Development,* **48**(4), 2000, pp. 63–85.
29. M. Kirton, *Adaption-Innovation in the Context of Diversity and Change*, Routledge, New York, NY, 2003.
30. G. Thompson and M. Lordan, A review of creativity principles applied to engineering design, *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, **213**(1), 1999, pp. 17–31.
31. C. Atman, Engineering Design Processes: A Comparison of Students and Expert Practitioners, *Journal of Engineering Education*, October, 2007, pp. 359–379.
32. P. F. Drucker, *Innovation and Entrepreneurship: Practice and Principles* Harper Business, New York, NY, 1986.
33. G. D. Meyer, The Reinvention of Academic Entrepreneurship, *Journal of Small Business Management,* **49**(1), 2011, pp. 1–8.
34. H. Oosterbeek, The impact of entrepreneurship education on entrepreneurship skills and motivation, *European Economic Review*, **54**(3), 2010, pp. 442–454.
35. O. J. Andersen, A Bottom-Up Perspective on Innovations: Mobilizing Knowledge and Social Capital Through Innovative Processes of Bricolage, *Administration & Society*, **40**, 2008, pp. 57–78.
36. A. R. Carberry, Measuring engineering design self-efficacy, *Journal of Engineering Education,* **99**(1), 2010, pp. 71–79.
37. C. S. Dweck, *Mindset:The New Psychology of Success*, Ballentine Books, New York, 2006.
38. I. Peña, Intellectual capital and business start-up success, *Journal of Intellectual Capital,* **3**(2), 2002, pp. 180–198.
39. L. Rustam, Technology business incubators to help build an innovation-based economy, *Journal of Change Management,* **3**(2), 2001, pp. 167–176.
40. B. A. Willy and L. Kolvereid, Organizational Strategy, Individual Personality and Innovation Behavior, *Journal of Enterprising Culture,* **13**(1), 2005, pp. 7–19.
41. OECD, *New Zealand OECD Reviews of Innovation Policy OECD Reviews of Innovation Policy: 2007*.
42. C. Okoli and S. D. Pawlowski, The Delphi method as a research tool: an example, design considerations and applications, *Information and Management*, **42**, 2004, pp. 15–29.
43. G. J. Skulmoski, The Delphi Method for Graduate Research, *Journal of Information Technology Education*, **6**, 2007, pp. 1–21.
44. A. L. Delbecq, A. H. Van de Ven and D. H. Gustafson, *Group techniques for program planning a guide to nominal group and Delphi processes* Scott, Foresman, Glenview, Ill., 1975.
45. J. W. Murry, Jr., Delphi: A Versatile Methodology for Conducting Qualitative Research, *The review of Higher Education*, **18**(4), 2004, pp. 423–436.
46. R. A. Streveler, M. A. Nelson, B. M. Olds and R. L. Miller, *Using a Delphi Study to Identify the Most Difficult Concepts for Students to Master in Thermal and Transport Science*, Paper presented at the ASEE Annual Conference Proceedings, Nashville, Tn.
47. The State of Victoria. *Delphi Study*. 11 July 2007. Available: http://www.dpi.vic.gov.au/DSE/wcmn203.nsf/LinkView/D7B9E063A2B4FFAFCA25707E00248822EB-B2EB2F9035229BCA257091000BF7A6

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