AC 2012-3100: ENGINEERING INNOVATIVENESS

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ENGINEERING INNOVATIVENESS

Abstract

This paper explores engineering innovativeness. The data is drawn from a set of 8 interviews of experienced engineers and engineering educators. The research question is: “What set of intrinsic abilities, when combined with extrinsic factors, enable engineers to create innovations that benefit society? The six most important innovative behavior attributes of engineers suggested by the interviewees were: domain knowledge, opportunity recognition, teamwork skills, the willingness to listen to others strengthened by curiosity, risk taking or the willingness to risk failure, and persistence. Creativity was seen as essential to jump start the innovation process but clearly not sufficient for getting an idea successfully introduced into the marketplace. Entrepreneurial behavior was also seen as a critical component of the innovation process but not sufficient unto itself for creating a successful innovation. Innovation creation was seen as a process that can be taught, as knowledge that can be acquired or as skills that can be strengthened. On the other hand there was a strong belief that some aspects of innovativeness are based upon relatively fixed personality characteristics. Future plans include building on these interviews and creating and validating a new engineering innovativeness instrument based on community-derived factors to benchmark and assess the development of engineering innovativeness factors within engineering students and practicing engineers.

Introduction

Leonardo daVinci is celebrated as one of the most creative people of all time. Thomas Edison is credited with establishing entire industries. Steve Jobs is said to have revolutionized how we use computers with the introduction of the Apple computers, the iPhone and the iPad. Society's fascination with people who are innovative and make discoveries that improve our lives knows little bounds. Even Presidents make calls for the innovations that come from the work of such people.

"The first step in winning the future is encouraging American innovation."

President Barack Obama, January 25, 2011[1]

Our research question is: "What set of intrinsic abilities (skills, knowledge, personality traits, or attributes), when combined with extrinsic factors, enable engineers to create innovations that benefit society?"

This paper discusses a qualitative research study set in an interpretivist framework which explores engineering innovativeness. The data is drawn from a set of 8 interviews of experienced engineers and engineering educators, each with 30-40 years of industry, entrepreneurial, and academic experience. The interviews were conducted in the summer of 2011. This study employs a grounded theory approach to produce a description of engineering innovativeness, an ill-defined social construct, and those internal and external factors which encourage or inhibit innovative behavior by engineers.

The purpose of this exploratory study is to inform a process to develop or adapt a measurement instrument of engineering innovativeness or potential innovativeness so that innovativeness can be benchmarked in student and professional engineers. A benchmark of engineer innovativeness will enable tests of interventions that increase innovativeness attributes or skill sets in engineers, potentially benefiting society. If engineers become more innovative as a result of changes in their behavior or the environments in which they learn, work and live, society stands to benefit from an increase in their innovations. [2]

Theoretical perspective

"The theoretical framework for this research is interpretivist because the skill sets for engineering innovativeness are viewed 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 [3]. Thus, an interpretivist approach 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." [2] In all cultures innovativeness is defined as an ability where an individual utilizes their skills or competencies and produces something new or novel that has value in that culture and is adopted, purchased or used.

References to relevant literature are included along with the assertion statements as opposed to a separate literature section as the most logical place to include information which strengthens the assertions of the interviewees in this exploratory study.

Figures 1 is provided as a conceptual representation of the innovation space, a metaphorical place where individuals create innovations, each in their own way. The purpose of Figure 1 is to show potential relationships between the concepts (ovals) used in conjunction with or defined by the interviewees or in the literature as a part of engineer innovativeness: creative, problem solving, design, and entrepreneurial behavior. Boxes in Figure 1 represent factors of personal or social influence on engineer innovativeness. Arrows in Figure 1 are hypothetical indications of relationships between factors or concepts where the direction of the arrow indicates a proposed direction for influence between the innovativeness factors or concepts.[2]

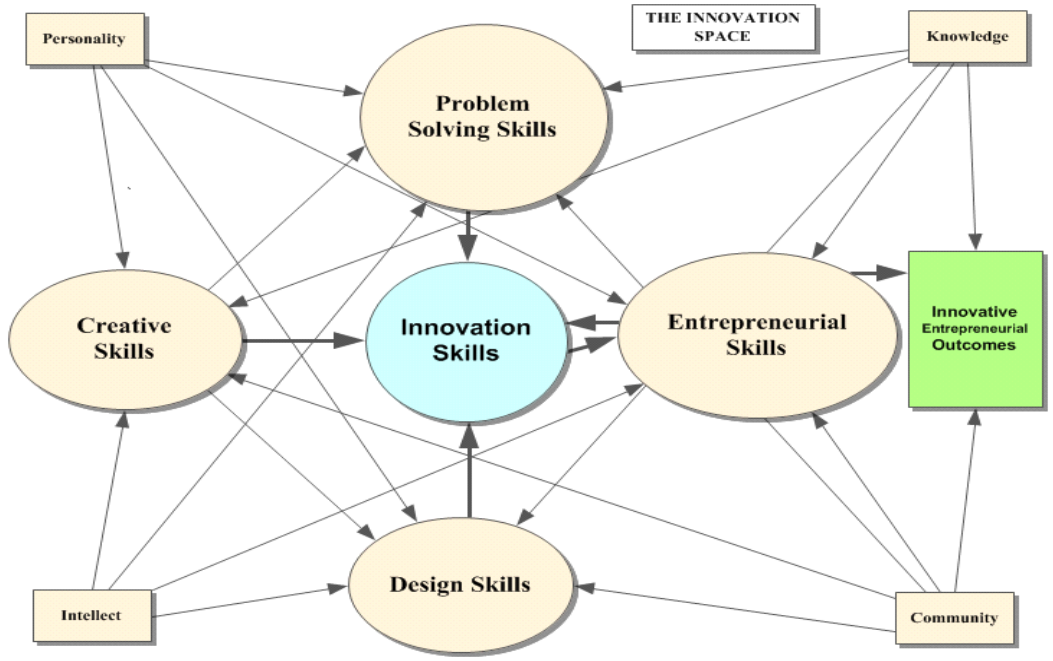

Figure 1: Map of the Innovation Space

Research Questions

This exploratory qualitative study examines the phenomena of how and why engineers create innovations that benefit society and is directed at answering two questions:

> What is an innovation?
>
> What are the intrinsic or extrinsic human or societal factors that enable engineering innovativeness or influence the ability of engineers to produce innovations?

Methodology

In this study structured interviews were conducted lasting 45-90 minutes. Open-ended questions were used in the interviews and these questions are listed in Table 1. The actual questions depended on the flow of the interview and covered the definition of an innovation, the identification of attributes of innovative behavior, the relationship of innovative behavior to other types of behavior potentially related to innovative behavior, and an assessment of the current state of engineering innovativeness.

Table 1.
Questions included in the guided interview on engineering innovativeness

1. What is your definition of innovation?
2. What do you consider innovative behavior?
3. What do you feel is the most important personal trait that leads to innovation or innovative behavior for an engineer?
4. How important do you feel creativity is to innovation ability?
5. How important do you feel design skills are to innovation ability?
6. What relationship do you see between problem solving skills and innovativeness?
7. Do you feel engineers are innovative? Why or why not?
8. Do you feel engineers can become more innovative?
9. How are innovative behavior and entrepreneurial behavior related?
10. Do you feel engineers can be/should be more entrepreneurial?

The interviews were open coded using an inductive analysis process that allows assertions, patterns, and ideas to emerge from the data [4]. The interview questions were used as the initial analysis structure for developing codes but the examination of the data resulted in data codes and themes emerging that were not based on the initial question structure. The coding process was recursive and it involved all members of the research team in multiple rounds of coding, coding reviews, strength testing, and the review of previous coding decisions. Within-interview analysis of interview data was done and then cross-interview analysis of data was done, resulting in a combining of data codes. Prototype assertions were tested based on strength of evidence and revised to reflect the strongest evidence.[5] The conventions used in quoting participants are as follows: Statements by interviewees are presented in italics with quotations followed by their pseudonym. Words in brackets were added by the researchers to clarify context.

Participants

Interviewees were identified as experts in innovation and entrepreneurship, selected as a convenience sample and chosen for these criteria [5]:

1. Over 20-30 years of combined innovation, academic, or entrepreneurial experience.

2. Available for up to 90 minute interviews at the June, 2011 ASEE annual conference in Vancouver, Canada or available for interviews in the Midwest in the summer or fall of 2011.

The sum of the total experience of the eight interviewees in the sample is over 250 years' experience. Seven of the interviewees were male and one was female. Six of the eight interviewees have PhD's, five in engineering disciplines, Seven of the eight have industry experience, six of the eight have been entrepreneurs, seven of the eight have academic experience in engineering colleges, and seven of the eight have engineering degrees. The engineering degree fields include Acoustical, Biomedical, Civil, Electrical, and Mechanical Engineering.

Data Sources

Pre-interview questions: A description of the purpose and process of the research and the overall research questions was emailed to each interviewee at least one week before the interview was conducted.

Structured interviews: Face-to-face interviews were recorded and conducted in semipublic places or in interviewee offices and the interview process was guided by the prepared questions about engineering innovativeness and its relationship to creativity, design, problem solving, and entrepreneurial behaviors. Five interviews were conducted in Vancouver, Canada, two in Detroit, Michigan and one in West Lafayette, Indiana. A second set of interviews with three of the interviewees was conducted by phone. Only the first seven interviews are included in this analysis and none of the phone interview data is included. All interviewee data is anonymous and pseudonyms are used in the display of data.

Transcripts of interviews: Transcripts of the interview were prepared, edited to remove identifying information and the edited interview transcript was shared with the interviewee for possible redaction of data.

Researcher notes: Notes were prepared by the interviewer during and after the interview and used to help interpret the transcribed recording.

Secondary interviews: Three of the interviewees were interviewed by phone a second time later in the summer of 2011 to discuss additional questions regarding the engineering innovation process that emerged from initial analysis of the data and other activities of the research team. This data is not included in this analysis.

Results and Findings

Assertion 1

There was universal agreement among the interviewees that an innovation is a product, process or concept that is new or novel, is valued, and is successfully introduced into a market or society. A market is defined as a community of people who use the innovation. There was clear understanding that an innovation is not a patent, that is, just a new idea even if it is truly unique and not obvious. There was also a clear mandate that an innovation must be brought to a market or community that accepts or uses it in order to qualify as a true innovation that benefits society. This definition of an innovation is consistent with those found in the literature.[6-8]

Among the research interviewees there was widespread agreement on the definition of an innovation**.** Alfred captured the main thread of the innovation definition with the words new and value:

> ***"****So, innovation is about new value. It's some sort of new improvement. Innovation can also meet a need. It creates value. It meets a need and it's measurable."-Alfred*

David emphasized the acceptance by the market as a key criterion of an innovation:

> *"My definition of innovation is something that's new and novel and ….very much along with the definition of a patent, the legal definition. But more importantly the new and novel aspect of something innovative being new and novel is that the market, in fact, determines if it's innovative or not." To develop something new and novel that's accepted by the market is my definition of innovation…it's not innovative by my definition if it's not brought to the market and the market accepts it."-David*

Bruce and Carl added reinforcement to the idea that an idea is developed and must be accepted by a customer (community) or market to actually become an innovation:

> *"I now use the term innovation to mean development of products and services, that's how we use innovation, on providing value to the customer by the development of this new product or service."-Bruce*

> ***"****But innovation has a level of something that has value to society, a value that can eventually be translated to something meaningful to society either to the handicapped, or to the third world, or to the market or whatever, some kind of added value."-Carl*

Frank clarified the definition of new, referring to the US Patent Office (US PTO), to mean that new means an idea that is not an obvious extension of an idea that already exists in a market:

> ***"****And non-obvious is I guess the US PTO's definition. The non-obvious one is sometimes hard to argue but once you see LED lighting mature, become inexpensive, become useful wave lengths, high intensity etc. replacing a flashlight incandescent bulb. A halogen light bulb with an LED may be new it may be useful but it's, in my opinion, obvious. If I had to pick two words that summarize innovation it's invention plus commercialization."-Frank*

Edward also reinforced the definition of an innovation and added that it includes concepts not just products and that innovation can be bringing together two or more ideas into something new and not obvious but the ultimate test for an innovation is that it ends up benefiting people:

> *"It's bringing two or more ideas together in a way that no one has thought about before or they're not obvious associations, the product of which (association) benefits people. It isn't necessarily a product. You could have an innovative film. You could have an innovative text book. You could have innovative products that benefit people. It isn't necessarily an invention. It's a new idea that didn't exist prior to that bringing together of two or more things. Well I want to make the distinction. It's different than an invention and so the thing that people miss is that it isn't an idea that is in my head. It ends up benefiting people. It has to get into the market place. "-Edward*

Assertion 2

Engineering innnovativeness includes multiple competencies, skills, and attributes. Innovativeness is used interchangeably with innovative behavior in our discussion. The six most important innovative behavior attributes of engineers identified by the interviewees were domain knowledge, opportunity recognition, teamwork skills, the willingness to listen to others strengthened by curiosity, risk taking or the willingness to risk failure, and persistence. Several of these same intrinsic characteristics are cited in the literature on creativity.[9, 10] Other engineering innovativeness attributes were mentioned in the interviews but not by more than two of the interviewees.

Domain knowledge is often the first identified engineering innovativeness trait and it is viewed as a precondition for innovativeness. Domain knowledge includes technical competence as well as market understanding. Domain knowledge is cited by many researchers as a precursor of innovative results. [11-13] Market awareness is also emphasized as critical to innovative behavior . [14, 15] Bruce makes such knowledge a starting point for innovative behavior:

> *"As a whole they (innovators) need a sound understanding of the technology, at least an appreciation of technology or a deep trusting relationship with those who do. The ones I deal with are really the ones with the knowledge base. Understanding the market, a focused market understanding, a profound understanding of your limited focus market and an appreciation for the power of the strategic use of intellectual property can give you in the commercialization of that technology."-Bruce*

Alfred makes technical knowledge a starting point and Edward gives examples of why technical knowledge is only the starting point for innovative behavior.

> *"He (the innovator) takes his technical competence and uses it to build relationships with people to help them solve problems."-Alfred*

> *"It's a mistake to set up a young person to think they can run a business when they graduate from school, as with a bachelors (degree), because they know nothing about*

supply-chain management, distribution networks, American Disabilities Act. And so you need to learn business. Would you like a young person to design a heart/lung machine to support life during open heart surgery as a new graduate? They can be smart, right? (but) you have to know a lot of things not just about the technology."-Edward

David feels that domain knowledge is a clear differentiator when identifying innovative potential in a person:

"I classify them as innovative even though they may not classify themselves (that way) because often they see the world differently. They are technically knowledgeable, market knowledgeable to the point where they can see what's being done and how to improve it."-David

Opportunity recognition is seen as a skill accompanying domain knowledge and as a key skill of an innovator. Alfred makes opportunity recognition a required innovativeness characteristic:

"There has to be a mindset that looks for opportunity and is willing to engage human beings in some setting whether it's a market place or government agency and this mindset is opportunity seeking not just problem solving."-Alfred

David and Frank see opportunity recognition as an ability to synthesize, see across domains and an attribute that only particular individuals possess:

"It's a synthesis. It's a skill or ability. It's (an) understanding that one event or one problem or one technology can in fact be applied across multiple opportunities and that mindset allows innovative people to bring things together to synthesize."-David

"There are those who synthesize, who are able to connect dots, to be able to see how this, this and this connects to the other to solve a problem that is an opportunity for them. A lot of people have an innate ability to see how things connect."-Frank

Edward makes the point that the opportunity connections made by the innovator can be to ideas which are completely new or new to the domain:

"I'm going to say (innovators need to have) empathy and compassion. They have to be able to see a need. (To see) something doesn't exist that could exist."-Edward

Frank sees it as a decision model where an innovator is continually mapping economic needs and economic investments to identify market opportunities:

"He just sees problems (and) is immediately trying to map the economic potential of solving that problem with the economic investment it would take at an estimated level to come up with a solution to that problem as to what he even works on."-Frank

Teamwork skills and building and supporting relationships with a team of people that support the innovative process is viewed as a necessary skill of an innovator and seen as contrary to the popular myth of the lone wolf inventor-genius. David sets out the teamwork requirement and maintains that, while some individual people take credit for innovations, innovation is almost always the result of a team effort:

> *"So what I tried to do is put it in this context of idea to market and you need to be both innovative and creative through all those processes. Often it's not an individual trait. It's a team trait because it's rather complex and it's hard. I like the whole idea of an innovative and creative team. What is the greatest opportunity for economic development? It's often done by a team, rarely done by individuals. Rarely, and in this context at this time and at this date, some people may take credit for it but it was hardly ever an individual. I call it the myth of the rugged individual. It's a total myth. It's folklore, everything from Thomas Edison to John Wayne. It's folklore."-David*

Frank adds that we tend as a society to popularize the myth of the lone innovator and not see the requirement for a team player:

> *"I think one that's often overlooked is a good innovator is a strong team player. I think we tend to stereotype and pigeon hole a lot of innovators as the few great war-story people that we know about, like a Steve Jobs or the Wright Brothers."-Frank*

Alfred explains that building a team to support innovation is a process involving everyone in the team that supports the innovator:

> *"And (the innovator) forms a team and that team is both vertical and horizontal and the team could be better called a network because it's a collection of people and resources. So there's human capital, organizational capital and cultural or civic capital. And this team is both vertically and horizontally integrated into these systems and it has this capital and it's combined with this reference on the marketplace creating value. (It's) opportunity seeking. So it's not just the sea level people. They cascade this mindset down all the way to the grass roots level of the organization. So their vision, their mission and their goals are clearly articulated. I mean everybody knows what it is that they do that works in the organization and they have a service mindset."-Alfred*

The willingness to listen to others strengthened by curiosity and share ideas are traits of innovativeness that stand out in an innovative engineer. Frank is very firm in his description of an innovative person - an innovative person is someone who listens to the ideas of others:

> ***"****I want someone (as an innovator) who's listening to what everyone else is saying and always asking 'How can I add value to that?' and above and beyond that 'How can I make it better?' 'How can I use the strengths in their ideas to improve the weaknesses in the ideas I was putting forward myself?' And that's a hard skill to teach. You can*

certainly encourage it. You can recognize it and you can tell people you want it but my experience has been people's natural behavior is one way or the other."-Frank

Carl is also strong in his description of the listening skills of innovative persons:

"They always listened to people and regardless of the rank. They didn't say "I'm going to listen only to my boss because he's my boss. They listened to anyone at all. They always took time to listen, always. There was no such thing like, 'I don't have time right now. The attitude was I want to listen to you because I can get some kind of value. They were less talker and more listener."-Carl

George maintains that inquisitiveness or curiosity is at the heart of the reason for listening to others:

"*I think a part of innovation is life's experiences, what someone has really done in their lifetime, what kinds of experiences they've had. (Innovation happens) if in fact their mind or their thinking is open to the point where they are inquisitive. They want to know. They want to know more. Or they've had a personal experience in their life that has been puzzling and they just don't have a solution for it and they want to be able to find it."-George*

Risk taking or the willingness to risk failure is an attribute of an innovative engineer but not an attribute that is found in abundance among practicing engineers. Frank makes the point that organizations tend to punish and not reward failure, decreasing the motivation of engineers to be innovative:

"A willingness to tolerate failure was another big one. A lot of practicing engineers have a tough time with this. If you fail in the auto industry and your parts get recalled, your career is like done. You're the guy that got labeled with the ball joint that fell apart because…. That's a great one. Where I'm coming from is engineers generally don't like failure at all so they're not comfortable (with risk). You're going to generate 100 ideas, 99 of which are going to be bad."-Frank

George describes a specific person whom he believes is innovative as someone who experiments and can tolerate failure:

He's a Russian scientist and he's done some very neat things in terms of invention. .He has many patents and is a highly innovative person. He tries. He does experiments. Some of these things fail. Some of these things succeed. He's a wonderful professional engineer. He has a passion for invention. -George

Edward suggests that innovative persons are not rule followers, status quo kind of people:

"They aren't rule followers. You can't be innovative and be a rule follower, because you're breaking the rules by definition. That doesn't mean you're not law-abiding. It doesn't mean that you don't use common sense or use formulas but you're not a status quo kind of person."-Edward

Persistence in the face of lack of support or failure is considered an essential characteristic of innovators. Edward explains the need to persevere in the face of people or organizational resistance to your idea and ties this attribute to personal courage:

"They have to have courage because when I worked in industry I was told by a general manager, "With your new product ideas you're going to have 10 executive vice-presidents give you 3 reasons each why your idea's not good. You know, because, the market doesn't need it, it's too expensive, we've tried that before, da da da da da da…You're going to have to just swim upstream and take the personal risk to push for your idea because if your idea was obvious someone would have already done it."-Edward

Carl suggests that taking ownership of the idea is an important part of being able to persist in pushing or promoting the idea:

"They (innovators) trust experts to a point but they (innovators) need to be convinced 100% so they become the experts. They have to be able to say 'I defend this idea because of 1, 2, 3 and 4, not because the expert told me. The expert can tell you anything they want but you are the decision maker and it's completely up to you. You are the boss. It's your signature is at the end of the day, not the expert's signature. You sign on everything and it's your responsibility."-Carl

Edward and Frank also connect persistence to the willingness to fail:

"I don't know how to describe that as a trait but there's a prescience, there's courage, there's persistence, a self- confidence that you don't fear failure."-Edward

"A willingness to tolerate failure was another big one."-Frank

Assertion 3

A social community supports and enables or inhibits innovative behavior. A team is one type of social community. There was strong agreement that the ability to work in and with teams was a necessary ingredient for successful innovative behavior. A social climate that suppresses innovation in the form of lack of tolerance of failure or willingness to take risks was also judged to be a significant factor in inhibiting innovative behavior. These observations are consistent with the research of Edward de Bono on how to facilitate team creativity.[16]

David asserts that a team or social community can support innovative behavior:

> *"Often, (innovative behavior), it's not an individual trait. It's a team trait because it's rather complex and it's hard. I like the whole idea of an innovative and creative team and, again, what is the greatest opportunity for economic development? It's often done by a team, rarely done by individuals. Rarely, and in this context at this time and at this date some people may take credit for it but it was hardly ever (done by) an individual. I call it the myth of the rugged individual. It's a total myth. It's folklore. Everything from Thomas Edison to John Wayne. it's folklore."-David*

Edward explains how individuals can inhibit rather than support innovative behavior:

> *"I've been in business units where the leader of the business unit typically has the arrogant lens and you can't be innovative, you cannot be innovative as an employee, you will not take a chance. You'll keep your head low."-Edward*

Carl describes innovators as positive individuals, who listen and who are supportive of ideas, which stimulates and supports their own innovative behavior:

> *"They (innovators) were, first of all, very open-minded. You can talk to them about anything, even if you criticize them, they don't care. They just listen to the criticism. They took the essence without hard feelings and tried to see what good can come out of it. They looked at the good part of everything. They looked at the world in a very positive way. Improvisation was part of them. Having fun was part of them. Thinking all the time was part of them. Taking risks is part of them. They treated people very well. They always listened to people. They listened to anyone at all. They always took time to listen. Always. They were less talker and more listener."-Carl*

Assertion 4

Innovative behavior involves both creative and entrepreneurial behaviors. Creativity is seen as essential to jump start the innovation process but clearly not enough to get an idea successfully introduced into the marketplace. Entrepreneurial behavior is also seen as a critical component of the innovation process but not sufficient unto itself for creating a successful innovation. Marrying creativity and entrepreneurial behavior in order to create innovations and new businesses is a theme found in entrepreneurship literature. [17]

Bruce positions creativity as a part of the innovation process:

> *"(Being) Innovative is developing new products and services. You can be creative in doing that. You can be creative in your approach to it. If innovation is developing new products and services, creativity is the process of how you get there."-Bruce*

Carl positions creativity as a necessary element to being innovative but states that being innovative adds value to society beyond being creative:

"Creativity itself has an element, maybe unfairly so, of a child drawing something or a child putting together something. It's unfair. It's an unfair treatment of creativity. But innovation has a level of something that has value to society, a value that can be translated to something meaningful to society either to the handicapped, or to the third world, or to the market or whatever, some kind of added value."-Carl

Edward clarifies the relationship of creativity to innovation suggesting that creativity is necessary to innovative behavior but that innovative behavior is more just than creative behavior or entrepreneurial behavior:

"So again (innovativeness) is creativity in some respects …I think (creativity) is probably a necessary attribute but it's not sufficient to be innovative and to be innovative it's necessary but not sufficient to be entrepreneurial."-Edward

Alfred differentiates entrepreneurial behavior from innovative behavior and argues that you can be entrepreneurial without actually being innovative and he argues that innovative engineers go beyond problem solving:

"Being entrepreneurial is more than being innovative, it's different than being innovative. You can be entrepreneurial and not be very innovative, create value and solve problems or fill unmet needs. It's more opportunity orientation than problem solving. See that's the cusp between an entrepreneurially minded engineer and an engineer. An engineer wants to solve a problem. An entrepreneurially innovative engineer is seeking opportunities to be innovative not (just) to solve a problem."-Alfred

George supports Alfred's position as he asserts that not all creative people (and given the context of the question, engineers) are innovative.

"I think creativity is a part of the innovation process but in some instances creative people are not always innovative, meaning they may create something that might not necessarily relate to improving or enhancing functionality."-George

Assertion 5

There was a belief that engineering innovativeness can be taught or developed. Innovation creation was seen by some interviewees as a process that can be taught, knowledge that can be acquired or skills that can be strengthened. Innovativeness was seen by some as a hill that a person can climb as they master the process, gain the knowledge and practice the skills of an innovative person. This belief is echoed in the innovation literature.[18]

George makes the case that innovative behavior can be taught because he believes it is a process that can be replicated:

"I think of innovation as being a process that can be easily replicated, that can be taught, that is a method of really thinking differently, looking at enhancing, improving or developing a different way of doing things, that in some way enhances the overall

functionality of a product or process. It really is, in a sense, a breakthrough that requires more of a structured approach of looking at problems."-George

Bruce explains that innovative behavior depends on understanding technology, customers and markets and that this type of knowledge can be taught:

"We can make anybody, let's talk about those that have the background in technology, better innovators. And I think the characteristics you're looking for are the ability to understand that the technology's not everything. Understanding that market, you understand that the reason someone buys my product is to solve their problems which would drive you, by the way, to understand (that) I've got to understand their problems. I've got to know more and anticipate more what their needs are than they do."-Bruce

Carl argues that being innovative can be taught to people who are initially less innovative:

"Let's say I measured you and you are the 99th percentile of being innovative, fantastic. But what about those who are (in the) 80th or 40th percentile of being innovative, what we can do about them? Is it possible to change? We believe it's possible to make people both more creative and more innovative. We do believe so."-Carl

Edward strongly asserts that both innovative and entrepreneurial behavior can be taught:

"Well, the common question is 'Nature or nurture?' Can you teach entrepreneurism? Absolutely. Can you make somebody more creative, innovative? Absolutely."-Edward

Assertion 6

There was a strong belief that some aspects of innovativeness are based upon personality characteristics which resulted in a belief that some engineers are more innovative while other engineers are less innovative. This belief is shared by other researchers. [19-21]

David sees engineers as two types of people, those who break the world into manageable chunks and those who synthesize and connect the dots to innovate and create opportunities:

"A lot of people that I deal with on a regular basis differentiate and I think the (engineering) world can be classified into those who see the world and try and break it down into manageable chunks and are happy understanding those manageable chunks or other parts of it. Then there are those who synthesize, who are able to connect dots, to be able to see how this, this and this connects to the other to solve a problem that is an opportunity for them."-David

Frank sees how engineers work within a team and with team members as the differentiating innovative behavior characteristic:

"When I watch engineers either practicing or in the classroom setting, to me, the most important emergent behavior is how they approach the team thought processes. If you

get somebody who's just 'Give me your tablet. I've got an idea. I'm going to cover it up while I sketch it and then here it is. This is as good as gold. What are you guys thinking over there, you're idiots. They may be very smart and they even do very well in the traditional academic environment of test taking and straight analysis. I don't want them on my team, innovating. I want someone who's listening to what everyone else is saying and always asking 'How can I add value to that?' and above and beyond that 'How can I make it better?' 'How can I use the strengths in their ideas to improve the weaknesses in the ideas I was putting forward myself?' And that's a hard skill to teach. You can certainly encourage it. You can recognize it and you can tell people you want it but my experience has been (that) people's natural behavior is one way or the other."-Frank

Edward differentiates innovators as rule breakers not rule followers:

"They aren't rule followers. You can't be innovative and be a rule follower, because you're breaking the rules by definition."-Edward

Summary of Assertions

There was universal agreement among the interviewees that an innovation is a product, process or concept that is new or novel, is valued, and is successfully introduced into a market or society. The six most important innovative behavior attributes of engineers identified by the interviewees were domain knowledge, opportunity recognition, teamwork skills, the willingness to listen to others strengthened by curiosity, risk taking or the willingness to risk failure, and persistence.

There was strong agreement that the ability to work in and with teams was a necessary ingredient for successful innovative behavior. A social climate that suppresses innovation due to lack of tolerance of failure or unwillingness to take risks was also judged to be a significant factor in inhibiting innovative behavior. Creativity was seen as essential to jump start the innovation process but clearly not sufficient for getting an idea successfully introduced into the marketplace. Entrepreneurial behavior was also seen as a critical component of the innovation process but not sufficient unto itself for creating a successful innovation.

Innovation creation was seen by some interviewees as a process that can be taught, knowledge that can be acquired or skills that can be strengthened. Innovativeness was seen by some as a hill that a person can climb as they master the process, gain the knowledge and practice the skills of an innovative person. On the other hand there was a strong belief that some aspects of innovativeness are based upon personality characteristics suggesting that some engineers are more innovative while other engineers are less innovative. Table 2 summarizes the assertion statements.

Table 2: List of Assertions

Assertion 1: An innovation is a product, process or concept that is new or novel, is valued, and is successfully introduced into a market or society.

Assertion 2: Engineering innnovativeness behavior includes multiple attributes, skills, and competencies.

Assertion 3: A social community supports and enables or inhibits innovative behavior. A team is one type of social community.

Assertion 4: Innovative behavior involves both creative and entrepreneurial behaviors.

Assertion 5: There was a belief that engineering innovativeness competencies can be taught or developed.

Assertion 6: Some engineers are more innovative while other engineers are less innovative.

Limitations of the data

This initial analysis of engineering innovativeness is limited due to potential interviewer bias (all interviewees were previously known to the interviewer) and the convenience construction of the sample. A larger sample may be more representative of the engineering population. No subgroup analysis was performed. No interviews were done outside of engineering professionals or experienced entrepreneurs for a comparator sample.

Future work

Future research will expand the scope of the sample and identify the key factors of engineering innovativeness. Additional interviews will be conducted including comparator interviews. Subgroups, including ethnic or gender groups or disciplines, will be examined to determine whether there are differences in the skills or attributes of innovativeness within those subgroups. These interviews will add to the weight of evidence that establishes the core set of innovative skills and help determine whether those skills vary in any significant way across the subgroups or across engineering disciplines.

We plan to create and validate a new instrument based on community-derived factors to assess the development of these factors within engineering students and practicing engineers. It is our premise that there is no single "ideal" profile of innovativeness that leads to success. Instead, we expect to find diverse profiles (i.e., different combinations and degrees of the key innovativeness factors) that vary by individual, by context, and by discipline – all of which can lead to success within the right environment.

With our new, validated instrument in hand, engineering educators will be able to give feedback to each student about his/her unique "brand" of innovative potential and manifest ability, and then guide students in the appropriate directions to gain the additional knowledge and skills they each need (uniquely) to succeed innovatively. With global competition reaching new heights, we cannot afford to marginalize the contributions of any individual within the

innovation process – making a better understanding of innovativeness, its diversity, and its development a critical need.

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