The Framework on Innovative Engineering

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Paula Gangopadhyay, The Henry Ford (museums)

Paula Gangopadhyay is the Chief Learning Officer for The Henry Ford which includes the Henry Ford Museum, Greenfield Village, Benson Ford Research Center, Ford Rouge Factory Tour, IMAX and Henry Ford Academy. She brings more than 19 years of experience in the cultural sector with education, policy and business leaders, to her position.

In her current role as one of the core members of The Henry Ford's senior management team, Gangopadhyay is responsible for providing leadership, strategic direction, concept, design and development of 'education' in a broad and comprehensive sense at The Henry Ford. She's responsible for a vast array of onsite, online and offsite student, educator, youth, family, adult and leadership programs, products and experiences for The Henry Ford's five sites, which in turn collectively attract over 1.5 million visitors a year, and has a mammoth collection of 26 million artifacts. She led the visioning of a dynamic education strategic plan as well as the conceptualization and development of many paradigm-shifting educational products and programs. She spearheaded and authored the development of compelling K-12 curricula, Innovation 101 and Be an Innovator series which are currently being enthusiastically adopted and implemented by teachers nationwide through the Henry Ford's Innovation Education Incubator project.

Prior to joining The Henry Ford, Gangopadhyay served as executive director for the Plymouth Community Arts Council, curator of education, public programs and visitor services at the Public Museum of Grand Rapids, executive director of the Great Lakes Center for Education, Research and Practice and executive director of the Commission for Lansing Schools Success (CLASS). Gangopadhyay is heavily involved in several professional organizations. She serves as a reviewer on state and federal grant panels as well as a thought-leader on several national forums. She has served as the Project Director of National Endowment for the Humanities (NEH) grants. Gangopadhyay has a master's degree in history, certification in archival, museum and editing studies and a fellowship in education policy.

President Barack Obama appointed Gangopadhyay as a member of the National Board of Museums and Libraries for a four-year term in 2012. She is the recipient of the 2012 American Alliance of Museums (AAM) EdCom Award for Excellence in Practice, 2013 Community Leader Award from the India League of America, the 2014 Michigan Informal Educator of the Year from the Science Teacher's Association and 2014 Faraday Communicator Award from the National Science Teacher's Association.

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Condoor teaches sustainability, product design, and entrepreneurship. His research interests are in the areas of design theory and methodology, technology entrepreneurship, and sustainability. He is spearheading Technology Entrepreneurship education at SLU via Innovation to Product (I2P), iChallenge, and entrepreneurship competitions and funded research. He is the Principal Investigator for the KEEN Entrepreneurship Program Development Grants to foster the spirit of innovation in all engineering students. Condoor authored several books. The titles include Innovative Conceptual Design, Engineering Statics, and Modeling with ProEngineer. He published several technical papers on topics focused on conceptual design, design principles, cognitive science as applied to design, and design education. VayuWind, a hubless wind turbine for urban environments, is one of his inventions. VayuWind deploys airfoils parallel to the rotational axis in such a way that, unlike other windmills, it rotates around a ring frame, leaving the central portion open for other uses. This enables VayuWind to extract wind power using existing structures such as commercial buildings and skywalks with minimal noise pollution.

Prof. Edward J. Coyle, Georgia Institute of Technology

Edward J. Coyle is the Arbutus Professor of Electrical and Computer Engineering, directs the Arbutus Center for the Integration of Research and Education, and is the founder of the Vertically-Integrated Projects (VIP) Program. He is a Georgia Research Alliance Eminent Scholar and was a co-recipient of the National Academy of Engineering's 2005 Bernard M. Gordon Award for Innovation in Engineering and Technology Education. Dr. Coyle is a Fellow of the IEEE and his research interests include engineering education, wireless networks, and digital signal processing.

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The Framework for Innovative Engineering

Abstract

Leaders in industry and government call today for the development of innovative or entrepreneurial behavior and skills in engineers (innovative is defined in this paper as including commercial execution and/or entrepreneurial behavior). Defining the critical characteristics of an innovative engineer in the different stages of the innovation process (or the Framework for Innovative Engineering, or Framework) was the goal of a team of 14 engineers, entrepreneurs and engineering faculty who participated in two focus group discussions on how successful innovative engineers behave during the innovative process. The first focus group discussion was held in October 2012 during the NSF sponsored Epicenter retreat at Stanford's Sierra Camp. The second focus group discussion was sponsored by the NCIIA and was held for two days in Atlanta, Georgia at Georgia Tech in June 2013 following the annual ASEE meeting,

The research question discussed at those two meetings was:

> What are the most important characteristics (knowledge, skills or attributes) of an innovative engineer in discovering, developing and implementing and sustaining an improvement-in, or a new or novel, product, process or concept?

The purpose of this paper is to document and share the processes used and the resulting definitions and identification of innovative engineering characteristics that were developed during those two Framework focus group discussions.

Introduction

The participants in the two focus group meetings described in this paper believe that an understanding of the knowledge, skills and attributes of innovative engineers is an important contribution to the ongoing discussions in our society about using innovation and entrepreneurship to improve our economy and address the major problems we face as a society. We feel that engineers have both a responsibility and a critical role to play in identifying and helping to resolve the challenges we face as a society in resource use, technology use or in socio-economic issues. Understanding how engineers contribute to innovations that address the problems or challenges of our society is, in our minds, an important task which is why we have participated in this journey. We are pleased to share our discussions with you and look for your support in continuing our research and entering into the dialogue with us.

Stanford Sierra Camp initial focus group discussion

The focus group discussion at the Stanford Sierra Camp (FGSSC) in October 2012 was scheduled for 90 minutes after a 60 minute brainstorming session designed to discover topics of interest. Our FGSSC discussion group defined this goal:

> Focus on [defining] a framework around which the education of engineers in the knowledge, skills and attributes (KSAs) of innovative engineering can be designed, delivered and assessed.

Participants in FGSSC are listed in Table 1. FGSSC participants also decided that our current and future deliverables included:

- A description of each innovative stage in the development of a new innovation and
- Identification and definition of the unique KSAs that an engineer needs to bring to each innovative stage.

Table 1 Participants in Sierra Camp Framework focus group

Participant	Affiliation	Subgroup
Wendy Newstetter	Georgia Tech	Team Leader
Marshall Brain	NCState	Develop
Richard Donnelly	George Washington	Deploy
Dan Ferguson	Purdue	Develop
Eden Fisher	Carnegie Mellon	Develop
Haneda, Kazumasa	Rotary	Deploy
David Nino	Rice	Discover
Gangopadhyay, Paula	The Henry Ford (Museums)	Discover
Angela Shartrand	NCIIA	Deploy
Ikhlaq Sidu	UCal Berkeley	Discover

FGSSC participants defined the stages of innovative engineering as discovery, development and deployment or three distinct stages or time segments in the development of a new product, process or concept.

The Discovery Stage was defined as the beginning of the innovative process and characterized as a time to execute global strategies and practical discovery methods. Four key global strategies and related practical discovery methods were identified and are illustrated in Figure 1.

Global Strategies	Recognize opportunity spaces in the market and:	Transplant working business models to new markets by	Empathize with users (feel their pain) and	Have Longer Term Vision
Practical Method	Exploit new technologies	Entering new geographies	Redesign products/processes to minimize pain	Do not focus on quick profits or quarterly results
Practical Method	Serve changing demographics	Adapting to cultural differences/preferences	Focus on the actual user need not product features	Plan for how to meet the market/user need 5 or 10 years out
Practical Method	Evaluate/exploit changes in laws or regulations	Serving new segments with modified products		

Figure 1 Global Strategies and Practical Methods to implement in the Discovery Stage

Four global strategies that innovative engineers should deploy in the discovery stage were described by Sierra Camp participants:

- Recognizing opportunity spaces in the market
- Transplanting working business models to new markets
- Empathizing with users/customers to discover values, meaning and user pain
- Having a longer term vision about how markets or user needs will change over time

Practical methods for implementing global strategies were also discussed and are also presented in Figure 1. The global strategies and practical methods included in Figure 1 are meant to be examples to capture the essence of the discovery strategy not an exhaustive list of discovery strategies or methods.

The development stage of innovative engineering was described by the FGSSC participants as 'The Valley of Death' for innovative engineering (Ford, Kousky, & Spiwak, 2007). The Valley of Death was characterized by the following conditions:

- No customers
- No product
- Resources exhausted
- Team leaves

- Regulators stall
- Technology fails

The strategies that an innovative engineer should use to bridge The Valley of Death were identified as:

- Define the needs or pain to be addressed by the venture.
- Adapt/pivot to changing market conditions and customer needs.
- Find/Conserve resources needed to operate business and design, make, deliver and service product.
- Obtain and direct the people resources necessary to grow and sustain the business.
- Influence-external partners, regulators and customers to buy or support product or service.
- Make the product or service with enough quality and service support to generate the resources to grow and sustain the venture

The critical characteristics of successful innovative engineers were identified as + when positive and – when negative. The symbol +/- means the KSAs were perceived for engineers to include both conditions. These characteristics were:

+ trained to define problems
+/- look for alternate solutions [but jump too quickly to solutions]
+ know about technology
+/- narrowly focus on their own technology
+ manage systems to optimize performance
+ know about laws/limits of current science of technology

FGSSC participants also observed that the weaknesses of innovative engineers in bridging the Valley of Death were:

- being enamored of technology
-not empathizing well
- becoming technical problem solvers, not leaders
- not always being open to other disciplines/approaches

The Deploy and Sustain stage represents the completion of the innovation and signals the delivery and maintenance and growth of the innovation over a longer period of time. The subgroup on Deploy and Sustain at the Sierra Camp only had time to identify some strategies and actions appropriate to this stage of the innovation process. Characteristics of innovative engineers were not included in their brief discussions.

Strategies	Business Model creation and testing	Evaluate and continuously improve prototypes	Recognize whether solution is scalable and how to serve product/ market.	Secure funds/ resources for deployment	Do market analysis and assessment of product use and competition	Create distribution, marketing and sales strategies and execute strategy
Actions	Define and hire team members with needed skill sets	Start manufacturing and roll out of product while adapting product to specific product/ markets	Establish customer support program and manager of customer relations	Develop and implement strategies for growth and managing change.	Knowhow and why customers use and buy the product or service.	Put the sales, distribution and customer support system in place.

Figure 2 the Deploy and Sustain Strategies and Actions

Georgia Tech focus group discussion

As a second step in developing the Framework, a group of 11 engineers, entrepreneurs, engineering educators and researchers met in June 2013 at Georgia Tech to further develop and refine the definitions, characteristics and process descriptions that were initiated during the Sierra Camp discussions. The participants in these Georgia Tech focus group discussions are shown in Table 2 and the agenda for the focus group meeting is displayed in Table 3.

Table 2 Participants in the Georgia Tech focus group discussions

Participant	Affiliation
Wendy Newstetter, Team Leader, PI	Georgia Tech
James Cawthorne,	Purdue
Sridhar Condoor,	St Louis
Ed Coyle	Georgia Tech
Dan Ferguson, Project Manager	Purdue
Eden Fisher	Carnegie Mellon
Paula Gangopadhyay,	The Henry Ford (Museums)
Cornelia Huellstrunk	Princeton University
David Nino	Rice
Angela Shartrand	NCIIA
Donald Wroblewski	UCal Berkeley

Table 3 Agenda for the Georgia Tech focus group discussions

FRAMEWORK RETREAT	SCHEDULE OVERVIEW
Wed, June 26	
6:00pm-	Evening reception -Bioengineering faculty terrace
7:00pm- 9:00pm	informal dinner- invited talk on innovation
Thursday, June 27	
9:00 -11:30am	presentations on relevant prior research by attendees
1:00-3:00pm-	sub-group breakouts to work on identifying and defining the knowledge, skills and attributes of engineers for the stages of innovative engineering
3:30-5:00pm-	reporting of sub-group results to whole group
6:00pm	-reception Bioengineering faculty terrace
7:00pm- 9:00pm	informal dinner adjourn to Georgia Tech hotel
Friday, June 28	
9:00 -11:30am-	voting and achieving consensus on deliberations of retreat participants
1:00-3:00pm	Framework subgroup, designing retreat report and initiating planning for Delphi confirming study

Literature Search preceding the Georgia Tech focus group discussion

One of the challenges in bringing together a diverse group of individuals to discuss a topic such as innovative engineering is that everyone enters the conversation at different points in understanding the phenomena. These differences exist in vocabulary as well as the context of understanding innovative engineering. A common set of readings was provided to all participants in this retreat in an attempt to provide a baseline for conversation. Table 4 illustrates the various perspectives that the articles about innovative engineering provided the Georgia Tech focus group participants. Each participant was tasked with summarizing and presenting the key findings from the articles they were assigned to read and synthesize. We are summarizing only 3 of these 15 articles in this paper as they were among the most influential literature that guided the subsequent discussions of the focus group. These three articles were Engineering Innovativeness by Ferguson et.al (D. M. Ferguson, Cawthorne, Ahn, & Ohland, 2013); Mapping the Behaviors, Motives and Professional Competencies of Entrepreneurially Minded Engineers (EME) in Theory and Practice by Pistrui et.al. (Pistrui, Layer, & Dietrich, 2013) and The impact of entrepreneurship education on entrepreneurship skills and motivation.by Oosterbeck et.al.. All three of these papers and the other reviewed material gave us lists of researched characteristics to prime our focus group discussions on identifying the characteristics of innovative engineers in the stages of innovation.

Engineering Innovativeness

This paper by Ferguson et al. explored engineering innovativeness (D. M. Ferguson, et al., 2013). The data was drawn in 2011 from a set of 8 interviews of experienced engineers and engineering educators. The research question was: "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 (Flanagan, 1954).

Mapping the Behaviors, Motives and Professional Competencies of Entrepreneurially Minded Engineers in Theory and Practice

Pistrui et al. studied 313 entrepreneurially minded practicing engineers (EME) in 2011 to identify characteristics of these practicing engineers to incorporate in engineering pedagogy at the collegiate level in order to improve their entrepreneurial/innovation mindset (Pistrui, et al., 2013). The characteristics chosen for the EME analysis were drawn from personal and professional assessment factors obtained from validated surveys provided by Target Training International and identified in entrepreneurial literature. This Structural Equation Modeling analysis study was implemented though an online survey with a hypothesized 33 manifest behavior, motivation or skills variables. These 33 hypothesized variables were reduced to the 19 manifest variables shown in Figure 3 below through statistical tests of the survey responses. The acronyms definitions are defined in Table 4 below.

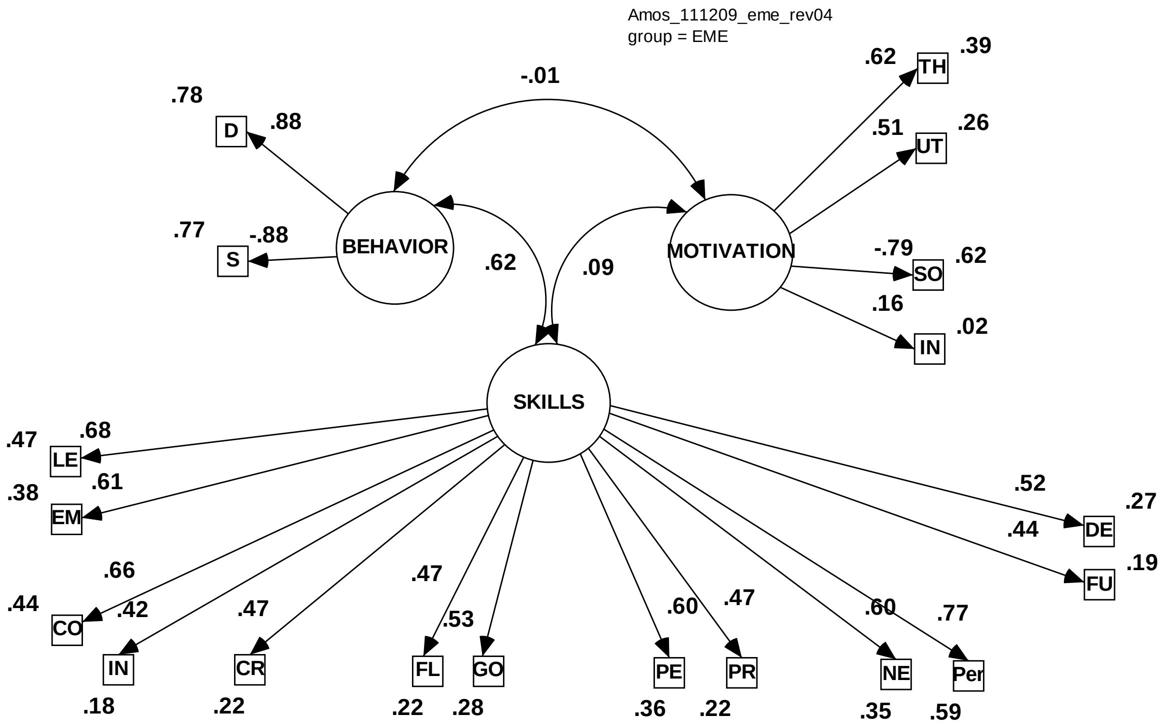

Figure 3 Entrepreneurially Minded Engineers Structural Equation Model (Pistrui, et al., 2013)

"The EME SEM, Figure 3 is the graphical representation of the model's estimated standardized path regression weights and variable squared multiple correlations. All path coefficients were statistically significant (p = .02). The 19 variable Cronbach alpha's yielded a standardized α = 0.761 which is close to the desired reliability of α = 0.8, therefore providing an acceptably reliable dataset." (Pistrui, et al., 2013)   Table 4 defines the EME Manifest Variable Acronyms.

Table 4 SEM Manifest Variable Acronym Definitions (Pistrui, et al., 2013)

Skill Competency	**Code**
Analytical Problem Solving	(AN)
*Conflict Management	(CO)
Continuous Learning	(CL)
**Creativity/Innovation	(CR)
Customer Service	(CU)
*Decision Making	(DE)
Diplomacy	(DI)
Empathy	(EP)
*Employee Development	(EM)
**Flexibility	(FL)
**Futuristic Thinking	(FU)
**Goal Orientation	(GO)
**Interpersonal Skills	(IN)
**Leadership	(LE)
Management	(MA)
*Negotiation	(NE)
**Personal Effectiveness	(PE)
**Persuasion	(Per)
**Steadiness	(S)
Compliance	(C)
Planning/Organizing	(PL)
**Presenting	(PR)
Self-Management	(SE)
Teamwork	(TE)
Written Communication	(WR)
Motivation	
*Theoretical	(TH)
Aesthetic	(AE)
Traditional	(TR)
**Individualistic	(IN)
*Social	(SO)
*Utilitarian	(UT)
Behavior	
*Dominance	(D)
Influence	(I)

* indicates the trait was one of the 19 remaining manifest variable in the SEM model.

** indicates the trait intuitively maps onto the engineering innovator/entrepreneur characteristics

The impact of entrepreneurship education on entrepreneurship skills and motivation.

Oosterbeek et al. used a Dutch test for entrepreneurial competencies, ESCAN. in research conducted on students involved in entrepreneurship curricula (D. Ferguson & Ohland, 2012; Oosterbeek, 2010). ESCAN measures seven competencies and three skills required for successful entrepreneurs and are widely used in the Netherlands by banks and educational institutions to help manage entrepreneur loan programs or assess entrepreneur educational programs. ESCAN's entrepreneurial competencies are intuitively mapped to engineering innovator characteristics identified in this study.

Table 5 Innovator/Entrepreneur Characteristics (Oosterbeek, 2010).

Entrepreneur Characteristics	**Intuitive Mapping of Engineer Innovator Characteristics**
Need for achievement. Entrepreneurs strive for performance and compete	Self-Reliant
Need for autonomy. Entrepreneurs desire the ability to resolve their problems and to bring activities to a successful end on their own	Self-Reliant, Persistent
Need for power. Power is the need to have control over others to influence their behavior.	Team Manager/Leader
Social orientation. know that connections with others are required to realize their ideas.	Networker/Team Player Team Manager/Leader
Self-efficacy. Entrepreneurs are usually convinced that they can bring every activity to a successful end.	
High degree of endurance. Successful entrepreneurs have an ability to persist, in spite of setbacks or objections.	Persistent Alternatives Seeker
Risk taking propensity. Able to deal with uncertainty and are willing to risk a loss.	Risk Taker, Experimenter, Developer

Table 6 The conceptual content of the background papers that informed the Georgia Tech focus group discussions.

	Type of Paper			Primary Context		Aspect(s) of the Innovative Engineer Addressed						
Article Authors	**R**	**C**	**D**	**I**	**E**	**ED**	**ES**	**EP**	**B**	**S**	**M**	**K**
(Bilen, 2005)	**X**		**X**		**X**			**X**	**X**	**X**	**X**	
(Bygrave & Hofer, 1991)		**X**			**X**	**X**	**X**					
(Duval-Couetil, 2010)			**X**		**X**				**X**	**X**	**X**	**X**
Erikson, T. (2003)		**X**			**X**				**X**	**X**		**X**
(Flanagan, 1954)	**X**			**X**					**X**	**X**		**X**
(Fisher, Biviji, & Nair, 2011)		**X**		**X**					**X**	**X**		**X**
(Ford, et al., 2007)		**X**					**X**					
Hsu, C. C. (2013)	**X**				**X**	**X**			**X**			
Kriewall, T. J. (2010)			**X**		**X**	**X**		**X**	**X**	**X**	**X**	**X**
Man T.W.Y. (2002)		**X**			**X**				**X**	**X**		**X**
(Mitchelmore & Rowley, 2010)		**X**			**X**				**X**	**X**		**X**
(Oosterbeek, 2010)			**X**		**X**				**X**	**X**	**X**	**X**
(Pistrui, et al., 2013)	**X**				**X**				**X**	**X**	**X**	
(Ragusa, 2011)	**X**		**X**	**X**					**X**	**X**	**X**	**X**
Siddiquie,Z. (2012)		**X**		**X**					**X**	**X**	**X**	**X**

Table 6 Key
R = Research; C = Conceptual; D = Descriptive
I = Innovation; E = Entrepreneur
ED = Entrepreneurship definition
ES = Entrepreneurship stages; EP= Entrepreneurship Program
B = Behavior; M = Motivation; S = Skills; K = Knowledge

The articles referenced in Table 6 discuss innovative engineers through the lens of a descriptive, conceptual, or research approach. Descriptive (D) papers were written to describe the process of specific/ programs or the development of assessment tools. Conceptual (C) papers try to develop a model, or some complex understanding using additional literature and research sources, explaining a component or aspect of innovative engineering. Finally, these research (R) papers provided quantitative or qualitative data supporting the claims made in this paper. All papers addressed innovative engineering; however, some papers were completely situated in entrepreneurial engineering contexts (E), while others were sublimated in papers about innovation (I).

In summary the articles referenced in Table 6 discussed the definition of entrepreneurship (ED), the existence of various stages of entrepreneurship (ES), and students' experiences in various entrepreneurship programs (EP). Almost all papers resulted in a discussion of the characteristics, or competencies, associated in developing innovative behaviors (B), skills (S), knowledge (K), and/or motivations (M) in engineers.

Findings from the Georgia Tech focus group discussions

As a result of the preparation, discussions and debates at the Georgia Tech focus group meeting several outcomes were obtained. First, the stages of innovative engineering were defined and are shown in Table 7. Second, concept definitions for KSAs and innovative engineering were developed and are shown in Table 8. Third, the characteristics of an innovative engineer were identified and then ranked by the focus group in a collaborative voting process. As the definitions of all the ranked characteristics were developed they were intuitively combined into a smaller set of uniquely defined characteristics shown in Table 9. The actual voting matrix from the Georgia Tech meeting is shown in Appendix A.

For the stages of the innovative process the focus group looked to the work of Ford who described the innovative process and called the middle stage the Valley of Death from an economist's point of view. Ford viewed the process as a linear process as depicted by Johnson and Gold from whom Ford et al. drew their contextual model (Ford, et al., 2007) as shown in Figure 4.

Figure 4 Johnson and Gold's Innovation Sequence

As depicted in Table 7 the Georgia Tech focus group defined the innovative process as having three stages: Discover, Develop and Deploy and Sustain equivalent to the stages depicted by Johnson and Gold and adopted by Ford et al. In common parlance it is the beginning, middle and end or completion of the innovative process. There are many different models for describing the innovative process and Denning et al. capture several different innovative process models in their book, *The Innovators Way(Denning & Dunham, 2010)*. However, guided by the Sierra Camp focus group decisions, the Georgia Tech focus group adopted a three stage linear model for their engineering innovator/entrepreneur characteristic discussions.

Table 7 Stage definitions developed by the Georgia Tech focus group

Stages of innovative/ entrepreneurial engineering	There are three stages of innovative engineering: discover, develop and deploy/sustain.
Discover	Identify a significant need or opportunity that engineering tools, processes or concepts can address.
Develop	Define and generate/establish an economically viable product, process or system that addresses the discovered need.
Deploy and Sustain	Launch and stabilize a scalable and sustainable solution to the developed need.

In Table 8 the working definitions for the characteristic discussions are displayed. Knowledge and skills are individual characteristics that we believed could be strengthened, nurtured or developed through education and experience. Attributes are characteristics that we felt were defined more by personality or character and while they are no less important could be enhanced or enabled in an individual engineer/innovator. These definitions guided our discussions of innovative characteristics and the organization of our findings as shown in Table 9 and Appendix A.

Table 8 Concept definitions developed by the Georgia Tech focus group

Knowledge	What you understand from education or experience
Skills	What you can do or tasks you are able to perform
Attributes	What you bring or how you need to act
Innovative Engineering	The discovery, design, development and implementation of a sustainable solution that creates value.

Table 9 is the map of the end result of our two focus group discussions and the organization of our conversations into a more coherent list of the innovative characteristics that we set out to identify. In our voting process we assigned values to the importance of the characteristics and each of us at Georgia Tech had 5 votes (ranging from 5 to1 with 5 high) for each stage which we could apply to any characteristic in each stage. The number after the name is the total weighted votes each characteristic received from the voters on Friday morning. Also note that Appendix A shows a larger number of characteristics that were given votes as Table 9 combines similarly defined characteristics into one characteristic (pain recognition and opportunity recognition are an example of two characteristics that were combined into recognizes opportunities). Figure 4 maps a set of even further combined characteristics to show how these characteristics change across the stages of the innovative process.

Table 9 Characteristics identified for the innovative engineer during the stages of the innovative process

Characteristics/Stages	Discover	Develop	Deploy and Sustain
Knowledge			
	Domain knowledge-7*	Technical knowledge-11*	Business acumen=33*
		Business acumen-13	
Skills			
	Recognizes opportunities-23	Market focused-33	Human resource manager-18
	Idea generator-21	Alternatives seeker-17	Engages stakeholders-15
	Keen observer-18	Engages stakeholders-9	Team manager-14
	Recognizes value-13		Strategic thinker-14
Attributes			
	Empathy-28	User centered-19	Adaptable-25
	Curiosity-21	Failure tolerant-17	Tenacious-16
	Dissatisfied with status quo-14	Persistent-16	Organized-14
	Flexible-8	Adaptable-13	

*Note: the number in the cell is the number of votes received by the KSAs at the Georgia Tech focus group meeting.

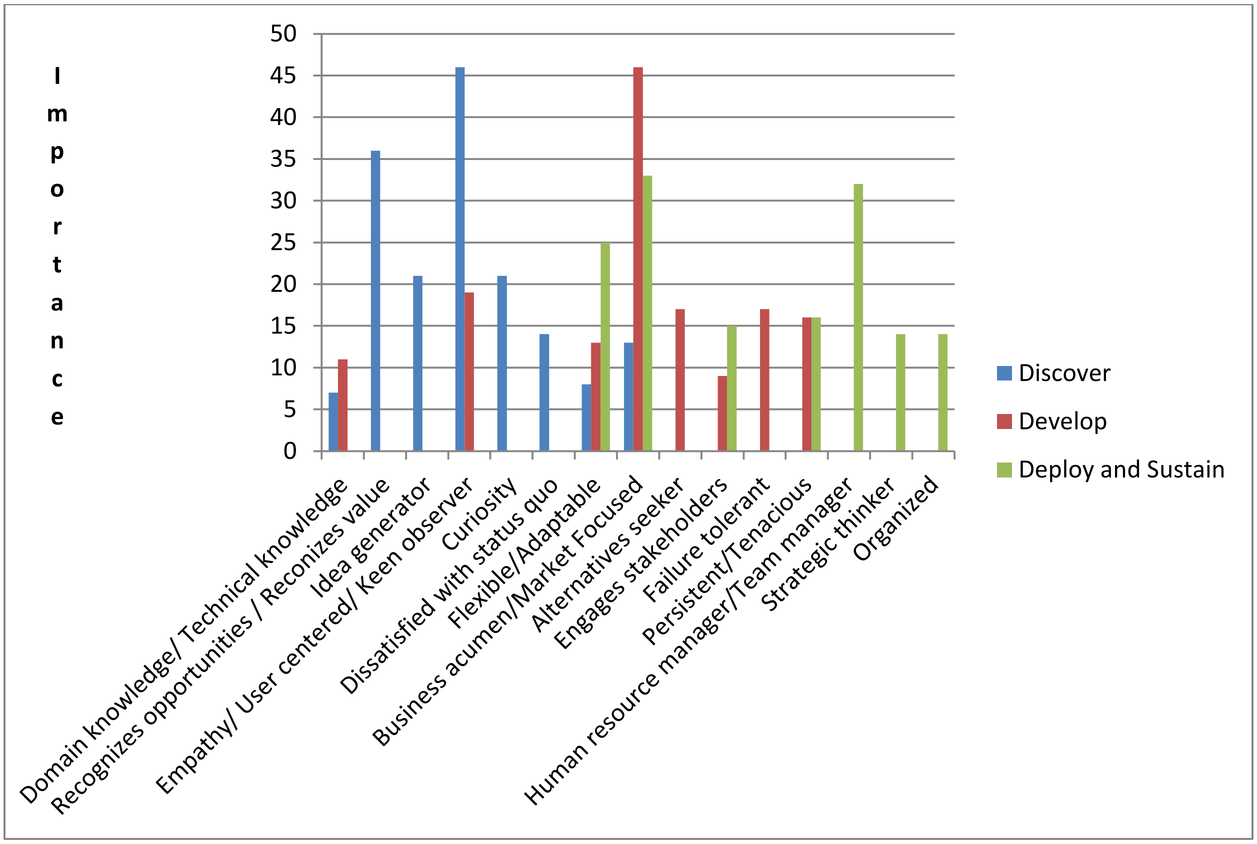

Figure 4: Plot of importance attached to specific engineering innovator characteristics in the stages of the innovative process

Discussion

Figure 4 summarizes our focus group work and presents two key findings:

1. There are specific innovator/entrepreneur engineer characteristics important to each stage of the innovation process.
2. The characteristics or strengths of an engineer in one stage of the innovation process are not necessarily the same characteristics required in a different stage of the innovation process (Caldicott, 2013; Griffin, Price, & Vojak, 2012). This finding has implications for hiring, job placement/selection, team management, professional development and self-assessment of engineering professionals and their education and life-long learning.

Conclusions

Insights into the critical characteristics of an innovative engineer will aid student and practicing engineers as well as engineering faculty in self-reflection, instruction and team management. These findings will also help establish learning objectives for innovative engineering curriculum and inform corporate hiring, staffing and team management decisions involving innovative engineers.

Future Work

A working group selected from the Georgia Tech participants has planned and is executing a Delphi Study involving up to 100 innovative engineers in order to confirm and refine the work of the two focus groups. The Delphi Study is described in Appendix B. Defining relationships among the identified innovative engineer characteristics and confirming our findings are viewed as the critical tasks going forward in this research.

Acknowledgments

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Appendix A: Voting on the innovative characteristics

Results of voting and intuitive aggregation			
Discover			
KSA	**Rating**	**KSA**	**Rating**
Empathy	19+	**Empathy**	28
Customer focus	9=		
Pain recognition	6+	**Recognizes opportunities**	23
Opportunity recognition	17=		
Curiosity	20+	**Curiosity**	21
Tolerance of ambiguity	1=		
Idea generation	9+	**Idea generator**	21
Imagination	10+		
Vision/creation	2=		
Fresh set of eyes	9+	**Keen observer**	18
Keen observer	9=		
Anti-establishment	8+	**Dissatisfied with status quo**	14
Dissatisfaction with status quo	6=		
Value recognition	8+	**Recognizes value**	13
Understanding of societal problems	5=		
Flexibility-fluidity	8	**Flexible**	8
Domain knowledge	7	**Domain knowledge**	7

Results of Atlanta voting and intuitive aggregation		**New name for combined categories**	**Aggregation/total ranking**
Develop			
KSA	**Rating**	**KSA**	**Rating**
Adaptable model	15+		
Developing unique value in relationship to other alternatives/customers	11+	**Market focused**	33
Market focused design	7=		
User centered	3+		
Design knowledge and skills	13+	**User centered**	19
Understanding feature/benefits of relationship	3=		
Failure tolerant	17	**Failure tolerant**	17
Prototyping	9+	**Alternatives seeker**	17
Minimum viable product	7+		
Filter, chose and prioritize	1=		
Persistence	11+	**Persistent**	16
Tolerance for ambiguity	5=		
Adaptability	13	**Adaptable**	13
Business acumen	4+		
Risk calculation	9=	**Business acumen**	13
Technical knowledge	11	**Technical knowledge**	11
Stakeholder engagement	9	**Engages stakeholders**	9
Leadership	4	**Not included**	
System thinking	3	**Not included**	

Results of voting and intuitive aggregation		**New name for combined categories**	**Aggregation/total ranking**
Deploy and Sustain			
KSA	**Rating**	**KSA**	**Rating**
Business acumen	24+	**Business acumen**	26
Sales knowledge/skills	1+		
Selling and delivering product in line with the business proposition	1=		
Scaling and reacting to environment to make change in value proposition [continuous improvement model]	25	**Adaptable**	25
Hiring a team skills	10+		
Human resource management	8=	**Human resource manager**	18
Tenacity	16	**Tenacious**	16
Stakeholder engagement	9+	**Engages stakeholders**	15
Finding business partners	6=		
Team management	7+		
Delegation	1+	**Team manager**	14
Interpersonal skills	6=		
Strategic thinking	14	**Strategic thinker**	14
Organized	2+	**Organized**	14
Organization skills	7+		
Detailed focus	5=		
	5		

Appendix B: Description of the Delphi Study

Leaders in industry and government call today for the development of entrepreneurial behavior and skills in engineers. Defining the critical characteristics of an entrepreneurial engineer in the different stages of the entrepreneurial process is the goal of this Delphi Study. A Delphi Study is a collaboration of several experts who develop, through a series of 2-4 rounds of anonymous information exchange, a consensus answer or potential solution to a question or problem.

The research questions guiding this Delphi Study are:

- What are the critical characteristics of an entrepreneurial engineer in the stages of the discovery, development and deployment of an improvement in or new or novel product, process or concept?
- What are the most important characteristics of an entrepreneurial engineer in each stage of the entrepreneurial process (discovery, development, deployment)?
- How are these characteristics of an entrepreneurial engineer related or combined?

What commitment is required of Delphi Study participants?

We anticipate three rounds of managed information exchange in this Delphi Study; each round requiring 30-75 minutes of interaction with an online survey; which will be preceded by 15-30 minutes of reading background material. The three rounds of information exchange are:

- Reviewing and agreeing on entrepreneurial engineer characteristic definitions.
- Ranking characteristics in each stage of the entrepreneurial process and defining relationships between entrepreneurial engineer characteristics.
- Commenting on or revising the rankings and relationship definitions.

What do Delphi Study participants receive?

- Delphi Study participants will receive a copy of the research results.
- Delphi Study participants will have insights into being an entrepreneurial engineer that will aid them in self-reflection, team management and hiring and staffing decisions.

How will results of the Delphi Study be disseminated?

- The FRAMEWORK project team will distribute the Delphi Study results through Delphi Study participants and in conference workshops and presentations, web talks and published papers with assistance from the NCIIA and Stanford's Epicenter project for undergraduate entrepreneurship education and other interested parties such as the Kern Family Foundation's Kern Engineering Entrepreneurship Network (KEEN) Engineering Schools and the Journal of Entrepreneurial Engineering.

When will the Delphi Study be conducted?

- The three Delphi Study rounds will take place between 1/15/13 to 6/15/14.