Do Engineering Creativity/innovation Courses Impact Engineering Innovativeness?

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Abstract

Through five years of previous NSF-sponsored research working with engineering education programs and major U.S. Corporations, we have identified the most important characteristics of engineering innovators (across and in each phase of the innovation process) and validated a new instrument (ABAKAS = Assessment of Behaviors, Attitudes, Knowledge, Attributes, and Skills) to assess them. In our context, an innovation is a product, process, or concept that has been discovered, developed, and implemented in a sustainable manner in a community. The innovation process is therefore defined to have a beginning (discovery), a middle (development) and a completion phase (implementation).Claims on how to create innovations or be more innovative are as popular as diet plans, but these claims are not connected by evidence to engineering student learning experiences and outcomes. Courses with titles like 'Innovation and Creativity for Engineers' have not provided assessment evidence that these courses positively impact or enable the characteristics that we now know comprise engineering innovativeness.

Our key research question is: *What is the impact of Creativity/Innovation courses and their ilk (individually or as a sequence) on the engineering innovativeness characteristics of engineering students?*

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I. Introduction

Training engineers to become more innovative is a national priority, as evidenced by a recent publication of the National Academy of Engineering and the University of Illinois – Educate to Innovate: Factors That Influence Innovation [1] – in which C.D. Mote, President of the National Academy of Engineering, notes that "Innovation capability should be a new indicator of US workforce readiness to compete successfully in the global economy**".**

In the business realm, the organizational management guru, Peter Drucker, said this about the importance of innovativeness [2]: "Every organization – not just businesses – needs one core competence: innovation. And every organization needs a way to record and appraise its innovative performance."

We believe that every engineer needs to understand their innovative capabilities, to assess their need to exercise those capabilities in the contexts in which they work and live, and to grow their innovative capabilities over time relative to the needs of the communities they serve [3,4]. Accordingly, our initial research question was:[5].

"What are the characteristics or knowledge, skills, and attributes that enable engineers to translate their creative ideas into innovations that benefit society?"

II. Grounded Theory Study

While there is prior research on innovativeness characteristics, almost none of the research has focused on engineers [6-8]. Instead, research on innovativeness for engineers tends to focus on whether engineers are creative [9,10], good problem solvers [7], and/or whether they possess design skills [8] and entrepreneurial skills [1,11-13]. Both the engineering research community and society link innovativeness with creativity and entrepreneurial behavior, often joining the terms, but not providing a clear definition of innovative engineering behavior [1,14].

Our research to define engineering innovativeness began over 5 years ago by interviewing over 50 peer-identified master/expert engineering innovators. We analyzed that interview data and their views about innovative behaviors using a grounded theory approach [15,16]. Results of that initial qualitative work are combined with two further studies and the resulting data is summarized in Table 1.

III. Delphi Study and Focus Group Study

We conducted two additional studies to support our grounded theory work; first we conducted a focus group of experts from engineering education and entrepreneurial engineers who identified engineering innovativeness characteristics most important in the phases of the innovation process [17] and second we conducted a three-phase Delphi study involving 150 engineers nominated for their innovation achievements[18]. Delphi Study participants clarified the characteristic definitions and ranked engineering innovativeness characteristics most important to each phase of the innovation process. Table 1 displays the 20 engineering innovativeness characteristics and their *in vivo* definitions in *alphabetical* order as derived from our Grounded Theory and Delphi Studies [18,19].

Table 1: Combined Grounded Theory and Delphi Studies: Engineering Innovator Characteristic Definitions [19]

Characteristic	*In vivo* Definitions Based on the Grounded Theory and Delphi Studies
Alternatives Seeker	Actively searches for multiple choices or solutions or new non-obvious options to make something better.
Analytical	Separates something into component parts or constituent elements.
Associative Thinker	Joins or connects together ideas or facts from different domains or experiences.
Challenger	Questions the current state of things.
Collaborator	Actively networks with people in or supporting the project.
Communicator	Explains the idea, the concept, and the opportunity by speaking, writing, gestures or use of pictures or diagrams.
Creative	Invents a new product, process or concept that has value to a community.
Curious	Actively challenges themselves to learn or know more about something.
Developer	Enables self and others by breaking down barriers and obtaining sufficient resources to move something ahead.
Experimenter	Performs a series of actions and carefully observes their effects in order to learn about something.
Implementer	Takes an idea from development into an end product.
Knowledgeable	Possesses information, understanding, or skill that spans a significant number of different subject areas.
Market/ Business Savvy	Possesses practical understanding or knowledge of [business or market] and able to use this knowledge to identify unmet needs.
Passionate	Expresses strong emotions or beliefs about something.
Persistent	Continues to do something even though it is difficult or other people want you to stop.
Risk Taker	Doesn’t think failure is bad, but that failure provides for learning.
Self-Reliant	Confident in own abilities and able to do things for yourself.
Leader	Inspires other individuals and facilitates achieving a key result or a group of aligned results.
User Empathetic	Understands the feelings, thoughts or experiences of another person/group
Visionary	Has ideas about what could/should happen or be done in the future based on an understanding of user needs.

IV. Instrument Development

Using this set of three-times-verified engineering innovativeness characteristics we then conducted a 3 year instrument development project to develop, test and validate an instrument that measures engineering innovativeness characteristics.

In an extensive search of the literature we found 27 validated instruments that had constructs that measured one of more of our characteristics in three major categories: (1) entrepreneurship, (2) information processing, and (3) motivation/self-efficacy. In total, 84 constructs from these 27 instruments were related to one or more of the 20 characteristics. Seven of the 27 instruments fell in the entrepreneurship category, eleven were categorized as measures of information processing, and nine were categorized as measures of motivation and/or self-efficacy [20]. Twelve additional sources were used to construct our test items.

Next we constructed a 200 item instrument, selecting 10 items for each characteristic from the 84 constructs and additional instruments. This 200 item draft instrument we submitted to a Face Validity test using 25 experienced engineers and ranked each of the 10 items per characteristic as to whether the item was consistent with the definition (as seen in Table 1). As a result of the Face Validity test we ended up with an instrument with 105 items due to some ties in rankings. We made duplicate instrument copies for both engineering students and professional engineers as we were unsure of whether these two populations would respond similarly to the instrument.

Item analysis was our next validation step. We recruited 200+ students from 7 engineering schools and 200+ professional engineers from 7 companies. Each participant completed the 105 randomly presented items survey. We then calculated the Chronbach Alpha score for each group of items associated with a characteristic. In the student test instrument 6 items were eliminated due to low Chronbach Alpha scores and 8 items were eliminated in the professional engineer version. Only 3 identical eliminated items were taken out of both test instruments.

Our final validation test was a large scale factor analysis study for student and professional engineering populations using the revised instrument created after item analysis changes to the instruments. After data cleaning the engineering student factor analysis sample, obtained from 4 schools, was 943 participants and the corporate sample, obtained from the engineering staffs of 7 companies, was 1086 professional engineer participants.

We conducted factor analysis using traditional statistical methods and also Bayesian probabilistic analysis methods [21]. For the professional engineer sample, traditional factor analysis using an Eigenvalue of 1.0, identified 21 factors that explain about 60% of the variance in the factor test sample data (see figure 1). For the professional sample, using the Bayesian factor analysis approach and examining Dendograms, and Contingency Table Fit data we determined that 21 factors explained over 70% of the variance in the survey data (see figure 2). One of the reasons for this improvement in the factor analysis association results appears to be the non-linear relationships that exist between some of our variables. We also determined during our analysis work that the Bayesian factor solutions gave us better variance explanation results for the student factor data than we could get using the student data alone or the student data in combination with the professional data. We decided therefore to only use one instrument, the professional factor version, in further use of the instrument with both students and professionals.

As a result of the factor testing and a Markov Blanket analysis of the items [22] we were able to reduce the instrument's total items to 81 items. However the resulting number of factors increased to 24 factors and one of the original characteristics, self-reliant, was eliminated. The five new factors are titled Overcomes, Empathizes. Empowers, Plans and Solves Problems; making a total of 24 factors in the ABAKAS instrument now being used.

Eigenvalues

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	22.7514	23.699		23.699
2	5.0201	5.229		28.929
3	3.4595	3.604		32.532
4	2.7431	2.857		35.390
5	2.4348	2.536		37.926
6	2.2917	2.387		40.313
7	1.7831	1.857		42.171
8	1.6067	1.674		43.844
9	1.5426	1.607		45.451
10	1.4920	1.554		47.005
11	1.4458	1.506		48.511
12	1.3535	1.410		49.921
13	1.2877	1.341		51.262
14	1.2008	1.251		52.513
15	1.1715	1.220		53.734
16	1.0904	1.136		54.869
17	1.0472	1.091		55.960
18	1.0218	1.064		57.025
19	0.9879	1.029		58.054
20	0.9525	0.992		59.046
21	0.9411	0.980		60.026

Figure 1 # Factors vs. % of variance explained

Our qualitative and Delphi Student research and the subsequent instrument development and validation work provided the ABAKAS instrument that is the focus of this research project.

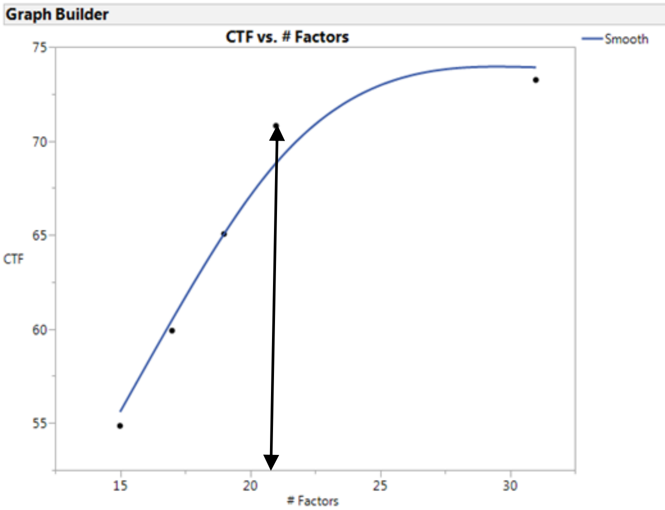

Figure 2 Contingency Table Fit vs. # Factors

V. *Research Methods*

A. Research Population

The ABAKAS Instrument was administered at Georgia Tech (GT) in Spring 2017 to 40 students in a Capstone Design Course (Mechanical Engineering/ Industrial Design). Pretest, midterm and end of term data from the GT capstone were collected. At Detroit-Mercy (UDM) the ABAKAS instrument was administered to 9 students in a Master's in Product Development Program at the beginning of the Spring 2017 Term and to 8 of the same students again at end of term.

B. Data Collection

A Qualtrics web-based survey is being used to voluntarily collect data anonymously. Each respondent is asked to rate themselves on the 81 randomly presented items: "Please indicate how well each item describes you consistently over time and across all aspects of your life. A person who...."

Innovation or innovativeness is not mentioned in the ABAKAS Instrument or in its administration. A red herring question randomly presented in the survey eliminated about 1-3% of students who started the survey. About 15% of the students across all samples did not finish their responses and all partial surveys were discarded. Any respondent with a standard response deviation less than 0.15 was also removed.

VI. *Findings*

In the Georgia Tech sample the greatest absolute changes in self-assessment means between the assessment at the beginning of the term, time 1, [29 participants] and the midterm assessment, time 2, [15 participants] occurred in the means of five innovativeness characteristics: Alternatives Seeker, Asks Questions, Curious, Implements and Passionate. However, in the final self-assessment, time 3, [8 participants] there was only 1 characteristic, Collaborates, that showed significant differences using 2 sample T tests by characteristic: time 3 - time 1, T-test = 0.038. The change in the Collaborates characteristic distribution occurred time 2 to time 1 and was substantially unchanged time 3 to time 2: The time 2 – time 1 mean change = +0.30 and time 3 – time 1 mean change was = +0.27; meaning the respondents perceived they had significantly changed their behavior in this innovativeness competency but this change occurred [potentially] due to course interventions at the beginning of the course. At UDM there were no significant statistical mean changes in innovativeness characteristics between the beginning of term pretest and the midterm self-assessment test.

VII. *Conclusions*

We conclude that these courses potentially impact a relatively narrow set of innovativeness characteristics and that the effects on innovativeness self-assessment, as with most learning, occur close to the learning experience.

VIII. *Further Research*

We have collected data and continue to gather ABAKAS data from professional engineers and intend to test a preselected innovator sample to identify archetypes if they exist. We also intend further course and cohort intervention and longitudinal studies.

IX. *Limitations*

Our sample sizes are currently small, intervention tests are few and data acquisition is incomplete.

X. *Acknowledgments*

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