Integrating Innovation Curriculum: Measuring Student Innovation to Assess Course and Program Effectiveness

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Abstract

The USA is falling behind other nations in innovation, creating serious threat to the health, stability, and influence of our country. Industry is desperate to hire engineers able to innovate, and universities are developing programs to instill the innovative mindset required to improve global competitiveness [1].

Innovation requires collaboration between engineering, business, and creativity to realistically prepare students to be innovators. Researchers at the University of Arkansas's College of Engineering and Sam M. Walton College of Business collaborate to understand major challenges of introducing and integrating innovation into engineering curriculum and pedagogy. They are researching topics, approaches, and specific learning environments that result in student proficiency.

Innovativeness is multifaceted and unfolds over time. Assessing the current and evolving environment and ecosystem (courses and programs) allows researchers to understand what factors cause or affect improvements. This could significantly improve the development and practice of the innovative mindset in students and provide basic insights into developing effective teaching strategies and training methods to cultivate innovative faculty.

Based on theoretical grounding, the researchers compiled a comprehensive set of measures designed to quantify student participants’ individual differences in innovative capacity and behavior. Drawing from seminal works on creativity and contemporary innovation inventories, the intent of the survey is to capture pre- and post-intervention levels of student innovation. In concert with quantitative measures that have demonstrated good validity and reliability, the survey includes qualitative measures aimed at understanding students’ idiosyncratic conceptualization of innovation, and its relationship to their career aspirations.

The survey was administered to undergraduate students. Three potential innovation styles (as an outcome, a process, and a mindset) are tested before and after program intervention and compared with the control group. Baseline survey results are presented in the paper. Data collection will continue in late Spring 2020, and the data will be analyzed and presented at the conference. The intention for this study is twofold: 1) investigation of potential program impacts on students’ innovative capacity and behavior, and 2) evaluation of the associations between students’ perceived innovation and academic performance and the differences between groups.

This paper presents the need for developing engineering innovators, literature supporting the survey developed, information on the survey, results, and analyses.
**Introduction**

An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process). [2]

Innovation – or practical creativity – is mainly about **making** new ideas useful. As an innovator, you can solve old problems with new ideas, or you can solve new problems with old ideas used in radically different ways. As a practical problem-solver, it helps to understand more about how to succeed with innovation and how to make innovation succeed. [3]

Four years ago, the University of Arkansas College of Engineering (CoE) began offering a pilot course for First-Year Engineering students: the First-Year Engineering + Business Honors Innovation Experience. The Sam M. Walton College of Business (WCOB) students, while planned from the beginning, were added in Year three. “The origin of the program stems from the CoE Engineering Dean’s Advisory Council observing, over time, that recently graduated engineers, newly hired by their companies, seemingly struggled with developing new ideas, new ways to approach problems, or being able to solve problems they had not seen before. It was almost as if the creativity, innovation, enthusiasm and ‘out of the box’ thinking they brought with them into engineering programs was being (unintentionally) trained out of them by the prescribed approach focused on formulaic methods and ‘toolkits.’” [4]

With increasing interest and focus on innovation and innovativeness in the United States (and worldwide, for that matter), the National Science Foundation (NSF) has declaring stimulating innovation as one of its three strategic goals: “…challenges require strategies that promote convergence: the merging of ideas, approaches, tools, and technologies from widely diverse fields of knowledge to accelerate innovation and discovery.” [5]

To develop an innovation-based ecosystem, the U.S. must produce more STEM graduates capable of driving innovation. Student innovation can come by way of innovation-based or innovation-enhanced courses, pedagogy and experiences designed to create a spark or to fan an existing spark into flame. This includes mentoring initiatives and professional skill building, all supporting a central innovation-development theme.

Much has been written about the need to assess entrepreneurship and innovation competencies in students, but few tools exist. To help fill this gap, the authors created the presented assessment tool from validated inventories that is focused specifically on innovation inclination, innovation capability, tolerance for risk and ambiguity, and, over time, changes in those characteristics for students. In order to know whether or not innovation-based courses, projects, programs, or initiatives have a positive effect – or, even any effect – it is necessary to create a baseline, follow the participants through their courses and through their academic studies.

Creating a methodology, assessment protocol, and assessment process and implementing it through an entire cohort (and those following) for the multi-college, interdisciplinary innovation courses, program, and initiative is a start in identifying the effects, making iterative and/or
successive improvements, and measuring the results of those improvements from an innovativeness and proclivity for innovation and creativity.

To this end, the University of Arkansas innovation team has created a survey to measure individual differences in innovative behavior and capacity, examine which factors significantly influence a student’s innovativeness, study how academic innovation strategies may influence students’ innovation development over time, predict which student attributes may help them become successful innovators in the future, and possibly predict students’ academic performance.

**Background**

The researchers desired to design a comprehensive set of measures based on theoretical grounding and devised to quantify student participants’ individual differences in innovative behavior and capacity. To identify relevant measures, the authors did preliminary literature review in the fields of psychology [6], [7], education [8], and management [9], [10] for measures of “creativity” and “innovativeness.” Additionally, literature reviews were conducted for nomological constructs including risk aversion [11], mindfulness [6], and trait empathy [12]. After reviewing existing scales, the researchers collaborated to select several measures that have both demonstrated previous validity and reliability and represent both seminal works on creativity (e.g. divergent [13] and convergent thinking [14]) and more contemporary research on innovation (e.g., imaginativeness [10] and innovative behavior facet measures [9]). For example, *Guilford’s Alternative Uses Task* [13] was employed to measure divergent creativity. Kier and McMullen developed the *Imaginativeness Scale* [10] as a measure of three cognitive skills that are key in problem-solving: creative, social, and practical imaginativeness. This measure has been shown to predict both quantity and quality of idea generation and selection in new value creation [10]. In sum, the quantitative portion of the survey captures both a broad understanding of innovation and its interrelated nomological neighbors, as well as represents both key seminal and current research.

In concert with the quantitative measures, the researchers wanted the survey to include qualitative measures aimed at understanding students’ idiosyncratic conceptualization of innovation. The researchers challenged participants to define innovation, identify obstacles that would hold them back from being innovative. Collecting this data enables researchers to systematically code the data to identify key trends and conceptualizations shared among students. In addition to both measures aimed at capturing student participants’ varying innovative behavior and capacity plus qualitative measures, the demographic information is also important for making comparisons between matched sets.

**Method**

**Participants & Procedures**

The survey was administered to undergraduate students. Three potential innovation styles (as an outcome, a process, and a mindset) were tested before and after program intervention and compared with the control group. The intervention group is students who enrolled to the pilot course of the Engineering and Business Innovation Experience. In contrast, the control group is those who had neither took this course before nor had any prior experiences with similar courses.
The innovation team began to collect the Wave 1 data in Fall 2019 and plans to collect Wave 2 data in late Spring 2020. In addition, students will be surveyed each semester as they progress through their studies, and each year new cohorts will join the study. Since only the first wave data is available, the following findings help establish the baseline of this study.

Initially, there were 450 responses collected by the Qualtrics online survey system. After removing participants either without complete data or with systematical responses, 191 students [115 (60.2%) male and 76 (39.8%) female] remained and approximately 84% of them were freshmen. Specifically, the intervention group had 76 students [61 (80.3%) male and 15 (19.7%) female] and the control group had 115 participants [87 (75.7%) male and 28 (24.3%) female]. Other demographic characteristics, such as race and class standing, are shown in Table 1.

Table 1. Demographic Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Intervention Group (N = 43)</th>
<th>Control Group (N = 148)</th>
<th>Total (N = 191)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
<td>34.9</td>
<td>61</td>
</tr>
<tr>
<td>Male</td>
<td>28</td>
<td>65.1</td>
<td>87</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>White/Caucasian</td>
<td>27</td>
<td>62.8</td>
<td>102</td>
</tr>
<tr>
<td>Black/African American</td>
<td>6</td>
<td>14.0</td>
<td>3</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>3</td>
<td>7.0</td>
<td>13</td>
</tr>
<tr>
<td>Asian/Asian American</td>
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<td>7.0</td>
<td>6</td>
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<td>Native Hawaiian/Pacific Islander</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Other/More Than Two Race</td>
<td>4</td>
<td>9.3</td>
<td>23</td>
</tr>
<tr>
<td>Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>22</td>
<td>51.2</td>
<td>139</td>
</tr>
<tr>
<td>Sophomore</td>
<td>3</td>
<td>7.0</td>
<td>3</td>
</tr>
<tr>
<td>Junior</td>
<td>12</td>
<td>27.9</td>
<td>1</td>
</tr>
<tr>
<td>Senior</td>
<td>6</td>
<td>14.0</td>
<td>5</td>
</tr>
</tbody>
</table>

Survey Instrument

The innovation team developed and adapted a survey based on multiple validated inventories intended to measure individual level attributes and trait for innovation, such as innovative behavior, imaginativeness, mindfulness, trait empathy, core self-evaluations, convergent and divergent thinking, well-being, and risk tolerance. Although 10 scales are included in this survey, only the primary 5 scales were used for the preliminary analyses. All study protocols were reviewed and approved by the Institutional Review Board (IRB) Human Subjects Committee.
**Demographics**

To help learn about different groups, demographic information was collected, such as:

- Birth month and year
- Biological sex
- Current gender identity
- Ethnicity
- Native language
- Highest level of education that parent(s)/guardian(s) completed
- Full-time vs. part-time student status
- Cohort
- Classification (first-year, sophomore, etc.)
- Anticipated graduation date
- Major(s), concentration(s), minor(s), previous major(s)
- Standing on the MacArthur Scale of Subjective Social Status “social ladder” [15]

The social ladder provides a way for participants to represent pictorially where they feel they stand at a given time in our society. The MacArthur Scale of Subjective Social Status [15] provides a means to graphically represent social status in terms of traditional socioeconomic indicators and status related to a person’s community.

![MacArthur Scale: Socioeconomic ladder](image)

Using the wording from the MacArthur Scale, participants are told, “Think of this ladder as representing where people stand in the United States. At the top of the ladder are the people who are the best off – those who have the most money, the most education and the most respected jobs. At the bottom are the people who are the worst off – who have the least money, least education, and the least respected jobs or no job. The higher you are on this ladder, the closer you are to the people at the very top; the lower you are, the closer you are to the people at the very bottom. Where would you place yourself on this ladder?” [15] The innovation survey asked participants which rung on the socioeconomic ladder they currently stand, and which rung best represents where their family stood on the ladder during childhood.

**Innovative Behavior Inventory**

This questionnaire was developed by Lukes & Stephan [9] and is intended to measure innovation behavior. This inventory has 23 items and proposed a latent construct with 7 factors, included Idea generation, Idea search, Idea communication, Implementation starting activities, involving others,
Overcoming obstacles, and Innovation outputs. Participants marked responses on a 5-point Likert-type scale to indicate how descriptive the item was of their behavior from fully agree (coded = 5) to fully disagree (coded = 1).

More specifically, the innovative behavior inventory [9] asks questions about such things as an employee’s ideas generation, search and communication; implementation starting activities; involving others; overcoming obstacles; and innovation outputs. The innovation team adapted this scale, which is geared toward people in the workplace, to be used for students. Since many students have not had work experience, participants were told, “If you do not have job experiences, you will encounter the term "at work" or "In the workplace" in taking the following survey. Please think about "at school work" or any previous experience you've had as a student in a group setting - either on a class project, in a student club, or in a team-setting - where you have had responsibility to fulfill a certain role as a part of a larger goal.” Although modification in this way does not allow a direct comparison to the validated results of the Lukes & Stephan inventory [9], it does adapt for the undergraduate student population and provides baseline results that will then need to be validated in the future.

The questions in this section solicit information on the level at which students like to try new ways of doing things, find new solutions to problems, try out new ideas and persuade others, develop opportunities for new ideas, involve others in implementation of new ideas, be persistent in overcoming obstacles, and are successful with new ideas.

**Imaginativeness Scale**

This survey section utilized the Kier & McMullen inventory [10] to measure how imaginative participants are relative to such things as self-creativity (creative imaginativeness), socially understanding other’s emotional state and other’s points of view (social imaginativeness), and their ability to navigate new problems scenarios (practical imaginativeness). Using an 18-item 7-point (i.e., 1 = strongly disagree to 7 = strongly agree) Likert-type scale, a respondent is asked to reflect on his or her creative, social, and practical imaginativeness. [10]

**Mindfulness**

The mindfulness section measured students’ frequency of experiences such as being distracted, having trouble focusing, repressing emotions, “running on automatic,” and not being “in the moment” that was developed by Brown & Ryan. [6] This scale described mindfulness by using a 15-item scale. Based on the incremental 6-point Likert type scale (i.e., almost always, very frequently, somewhat frequently, somewhat infrequently, very infrequently, almost never), this scale reflects participants’ awareness of their mindfulness with higher scores indicated they are less mindfulness in the daily life events.

**Core Self-Evaluations**

Judge, Erez, Bono & Thoresen stated, “core self-evaluations is a basic, fundamental appraisal of one’s worthiness, effectiveness, and capability as a person.” [7] There are four traits that make up the core self-evaluations: self-esteem, generalized self-efficacy, neuroticism, and locus of control.
These traits can be measured to predict people’s satisfaction with their job, job performance and life situation. In addition, this inventory was validated using both corporate employees and university students. It asks participants how strongly they agree or disagree with statements related to getting deserved success in life, feelings of depression, doubting competence, being in control of career success, coping with problems, and outlook for the future. Using 12 items, participants marked responses on a 5-point Likert-type scale (1 = strongly disagree to 5 = strongly agree) to indicate how descriptive the item was of their subconscious. Six items were negatively worded and were reverse-scored before the overall score was computed.

**Utrecht Work Engagement Scale (UWES)**

This Utrecht Work Engagement Scale, Student Version, was developed by Schaufeli & Bakker. Questions include topics related to how often students are energetic when involved in studies, how often they are enthusiastic about their studies, how often they are happy when intensely studying, and how often they are immersed in their studies. This inventory can provide an insight into students’ willingness to invest effort, to persist when obstacles are in their path, and their mental resilience, all of which are factors related to innovative behaviors.

The three aspects of work engagement (vigor, dedication, and absorption) are assessed by the UWES. It included 9 items on a 7-point Likert type scale. The ratings of this scale are unique, and the instruction is “If you have never had this feeling, cross the ‘0’ (zero) in the space after the statement. If you have had this feeling, indicate how often you feel it by crossing the number (from 1 to 6) that best describes how frequently you feel that way.”

**Statistical Analyses**

Several statistical analyses will be used to analyze the data after collecting Wave 2 data in late Spring 2020. First, all scales will be examined by using latent confirmatory factor analysis (CFA) to evaluate and compare with the original proposed validities. Second, the repeated measure will be conducted to evaluate the treatment and control group differences in each scale. Third, using all perception and personality scales mentioned in the method section, the innovation team researchers intend to build a regression model to predict participants’ academic performance in both Fall 2019 and Spring 2020.

For Wave 1, only the baseline data has been acquired. Therefore, descriptive analysis was conducted to describe the distributions of both the innovation and the control group. In addition, Shapiro-Wilk tests were conducted to examine the normality assumption for each composite scale score for each group. If the data violated this assumption, the nonparametric analysis, the Mann-Whitney U test, was used to compare the ranked differences between both groups. If the data met the normality assumption, then the traditional independent t-test was used and the effect size ($\eta^2$) was calculated to present the proportion of variance of the scale scores that are related to the factor (i.e., group membership). Data were analyzed using SPSS 25 (IBM, 2019) and SAS 9.4 (SAS, 2016).
Results

The descriptive results are presented in Table 2. Skewness and Kurtosis involve and display the tails of distribution which provide relative information about data distribution. However, both are very dependent on the sample size. Since the sample sizes on both groups are relatively small, the Shapiro-Wilk test was relied on to evaluate the normality assumption. The Shapiro-Wilk test indicated that three scales (i.e., Innovative behavior inventory, Imaginativeness, and Utrecht work engagement) had significant results which means the sample did demonstrate a significant departure from normality. Therefore, the Mann-Whitney U tests were conducted to evaluate the hypothesis that the innovation group would score, on average, similar to the control group in Wave 1. Similarly, the independent t-tests were used to evaluate the differences between groups in the other two scales (i.e., Mindfulness and Core self-evaluations).

Table 2. Descriptive Statistics (N = 191)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Intervention Group (N = 43)</th>
<th>Control Group (N = 148)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Innovative behavior inventory*</td>
<td>96.60</td>
<td>11.21</td>
</tr>
<tr>
<td>Imaginativeness *</td>
<td>98.63</td>
<td>12.38</td>
</tr>
<tr>
<td>Mindfulness</td>
<td>47.77</td>
<td>12.71</td>
</tr>
<tr>
<td>Core self-evaluations</td>
<td>43.21</td>
<td>8.14</td>
</tr>
<tr>
<td>Utrecht work engagement*</td>
<td>42.53</td>
<td>9.39</td>
</tr>
</tbody>
</table>

Note: *indicated the violation of normality through Shapiro-Wilk test

The results of the Mann-Whitney U tests were nonsignificant, which meet with our expectation, for Imaginativeness scale and UWES, z = -.616, p = .538, and z = -.588, p = .557, respectively. However, the Innovative Behavior Inventory was statistically significant, z = -2.167, p = .030, which indicated the intervention and control group were different in the baseline semester. In terms of the results of the independent t-test, the mindfulness scale did not have significant difference between groups, t(189) = .595, p = .552, and the effect size of η² .002 indicated a very small effect. Again, the Core Self-Evaluations scale did show a significant result, t(189) = -2.451, p = .015, which indicated both groups had differences in the baseline semester. However, the effect size of η² .031 also indicated a small effect. Therefore, the effect of unbalance and small sample size might be a matter of consideration for this measure.

Conclusions and Future Plans

Multi- and inter-disciplinary environments have also been shown to be effective in building creative thought. As defined by the National Academies of Science, Engineering, and Medicine, ‘multi-disciplinarily’ draws on knowledge from different disciplines but stays within their boundaries, whereas “interdisciplinary” analyzes, synthesizes, and harmonizes links between disciplines into a coordinated and coherent whole. [18] Numerous innovation education programs have incorporated a multi-disciplinary component, providing students with diverse perspectives that can drive creative thought, while also expanding student exposure to all areas of product
development. [17], [19] Through this approach to measuring student innovation to assess course and program effectiveness, the innovation team will not only be able to define a baseline on a significant population but will also be able to measure and assess the effects of changes to determine if they are actually iterative improvements. And, conversely, it may be possible to determine when negative impacts relative to effectiveness result from changes.

Baseline data showed no significant difference between the Intervention and Control groups for the Imaginativeness and the Mindfulness scales. However, there was a significant difference for the Innovative Behavior Inventory. There was a small but significant difference relative to the Core Self-Evaluations Scale, however that effect might be due to an unbalanced and small sample size. Data collection will continue in late Spring 2020 and the data will be analyzed and presented at the conference. Although the data collection is still ongoing, the intention for this study is twofold. First, an investigation will reveal whether or not the program made any impact on students’ innovative capacity and behavior which was reflected by using those scales. Then, an evaluation of the associations between students’ perceived innovation and academic performance in their 2019-2020 academic year as well as a comparison of the differences between groups.

Based on response and completion rates, the survey will need to be shortened. Analysis of this initial data will help determine which sections are most important and to reduce redundancy.

**Lessons Learned and Final Thoughts**

Based on the first offering (pilot) of the survey, and the responses and abandonments, the innovation team is making iterative improvements in the survey for the second deployment late Spring 2020. It is essential to keep the survey to an optimal length (to be determined) while ensuring the capture of all the information needed. And, it is important to change several of the exercises to ensure they are “fresh” each time the survey is taken.

The researchers look forward to following the students through their academic career and using this as a basis for iterative improvement of courses, program, and initiatives.
References


