The Nexus of Entrepreneurship and Innovation: A new approach to looking at the creative contributions of engineering graduates

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The Nexus of Entrepreneurship and Innovation–a new construct for looking at the creative contributions of engineering graduates

ABSTRACT

Engineers are called upon to possess strong analytical and communication skills, exhibit practical ingenuity, and be creative thinkers, all the while upholding high ethical standards. In more recent times they are also expected to be innovative and entrepreneurial. We see this in large companies working to incentivize their engineers to contribute to product innovation through, for example, involvement in makerspaces, hackathons, and design sprints. We see it in universities in their offering stand-alone courses on product innovation and entrepreneurship for their engineering students, integrating innovative and entrepreneurial ideas into existing technical courses, and creating a variety of extra-curricular activities to put those ideas into play. At the same time, the concepts of innovation and entrepreneurship are generally treated and explored as distinct areas of research; as such, distinct and separate measures of an individual's self-efficacy and associated behaviors have been developed.

In this work we take a different tack, wanting to identify the nexus, or common ground, of Innovative and Entrepreneurial self-efficacies, and Innovative and Entrepreneurial behaviors. Thinking about common ground is a useful lens with which to look at the intentional or focused creativity of engineers, whether they are working in new or existing enterprises. First, we show the development of this intersectional/nexus concept (which we call *Embracing New Ideas*, ENI) in terms of measures of self-efficacy (ENI-SE; consisting of six items, with a Cronbach's Alpha of .85) and behavior (ENI-B; consisting of five items, with a Cronbach's Alpha of .80). Then based on Social Cognitive Career Theory (SCCT), we model ENI-B (our dependent variable) as a function of ENI-SE and a variety of workplace and work-assignment features, as well as demographics. Our data for developing these new Self-Efficacy and Behavior Constructs, and creating a descriptive model comes from a sample of over 700 engineering alumni working in a variety of roles and job functions. Results from linear regression models show that over 55 percent of the variability in ENI-B is explained by a combination of self-efficacy and contextual or workplace factors. These results begin to establish a solid foundation for subsequent work that explores educational experiences that contribute to engineering students developing self-efficacy in Embracing New Ideas, and workplace settings that truly enable behaviors related to Embracing New Ideas.

1. Introduction

Today's technological environment is expanding rapidly in a manner that is accompanied by a large degree of uncertainty. As digitalization leads to larger societal changes, entrepreneurial and innovation-related skills have proven to be an essential part of the general skill sets needed to succeed in today's dynamic modern occupations [1]. These skills include abilities such as identifying market opportunities and generating new product or service ideas that solve current problems, fulfilling customers' unmet needs, or improving existing products and processes ([2] - [7]).

Due to the significant impact of innovation and entrepreneurship on economic development, there is an increased emphasis on entrepreneurial and innovative thinking and acting in the workplace [8]. For this reason, the question of how individuals think and act innovatively and entrepreneurially, whether undertaken within an existing organization or as part of creating a new organization, has turned into an essential question for researchers, educators, organizations, and policymakers (e.g. [9]). To delve deeper into this context, research has mainly studied independent business founders/entrepreneurs (e.g., [10]) and individuals engaging in intrapreneurship in established organizations (e.g., [11]). Noteworthy are more recent activities (and research) on organizations of all sizes taking up educating their engineers to think and act more innovatively, if not entrepreneurially (e.g., [12]).

Since economic wealth development in the modern economies is not only created by corporate CEOs and Wall Street financiers but also by the engineers who develop marketable innovations that are grounded in technology ([13]), increased attention is being directed towards promoting innovation and entrepreneurship among engineering students. Many universities have initiated campus-level centers, such as Lean Launch Pad and Epicenter (National Center for Engineering Pathways to Innovation) at Stanford University, as well as UnternehmerTUM (the Center for Innovation and Business Creation in Munich, Germany); such centers provide a range of educational programming, facilities and resources to promote innovation and entrepreneurship among their students ([14], [15]). The question being undertaken by a growing number of universities and colleges is: *How can we motivate and further support engineering students to engage in generating innovative ideas and materializing them in terms of new products, services and enterprises?* (e.g. [16] - [22]).

While many elements of innovative and entrepreneurial-associated skills are distinct from one another, there is considerable overlap that captures the essence of the entrepreneurial mindset within a technological innovation context. Both skillsets include generating, through various means, potentially useful new, unique, or novel ideas. It is this aspect of being innovative and entrepreneurial that we focus on in this paper, looking at workplace practices that promote engineering graduates going out into the world and generating these new ideas. We call this overlap or nexus between innovation and entrepreneurship the “Embracing New Ideas” (ENI) space and identify self-efficacy and behavioral measures that capture its essence. We also consider how to promote these associated behaviors in the workplace, situating our model in the framework of Social Cognitive Career Theory. Our associated research questions are:

- RQ1: How can Embracing New Ideas (ENI) be operationalized into measures of self-efficacy and behaviors?
- RQ2: What workplace, self-efficacy and personal factors relate to these behaviors in a variety of organizations?

For organizations that employ engineers, we identify workplace and job assignment features that challenge and enable engineers to be innovators. In companion work we present how to build engineering students’ confidence in ENI, identifying pedagogical approaches with the potential of helping engineering students to become “problem identifiers,” as well as “problem solvers” who are address the problem (the classical descriptor of engineers; [23]).

2. Literature Review

Our work considers how engineers are situated professionally to embrace new ideas (ENI). Our concept of ENI builds directly on individuals' innovation and entrepreneurial self-efficacies and behaviors, by focusing on the commonalities between innovation and entrepreneurship. The link between the concept of self-efficacy and behaviors or actions is described by the Social Cognitive Career Theory.

2.1 Social Cognitive Career Theory

As our study's focus is on individuals, and workplace environments that promote their becoming and being innovative and/or entrepreneurial, we adopted the Social Cognitive Career Theory (SCCT) as our framework (see Figure 2.1). SCCT was developed by [24] and later adapted by [25] with the aim of conceptualizing the evolution of academic and career-related choices and outcomes with their influencing factors (Lent et al.,1994; Lent & Brown, 2006). SCCT, as a framework, describes how learning experiences (both formal and informal) can lead to enhanced domain-specific confidence and outcome expectations. This then can lead to establishing associated goals and action taking.

In our current study we focus on Choice Actions (the actual behavior or actions of the individual), that result from Self-efficacy and Contextual Influences. We consider innovation and entrepreneurial self-efficacy measures (as well as our new measure at the intersection of innovation and entrepreneurship). In the next section we describe some of the key points in the literature related to innovation and entrepreneurial self-efficacies and behaviors.

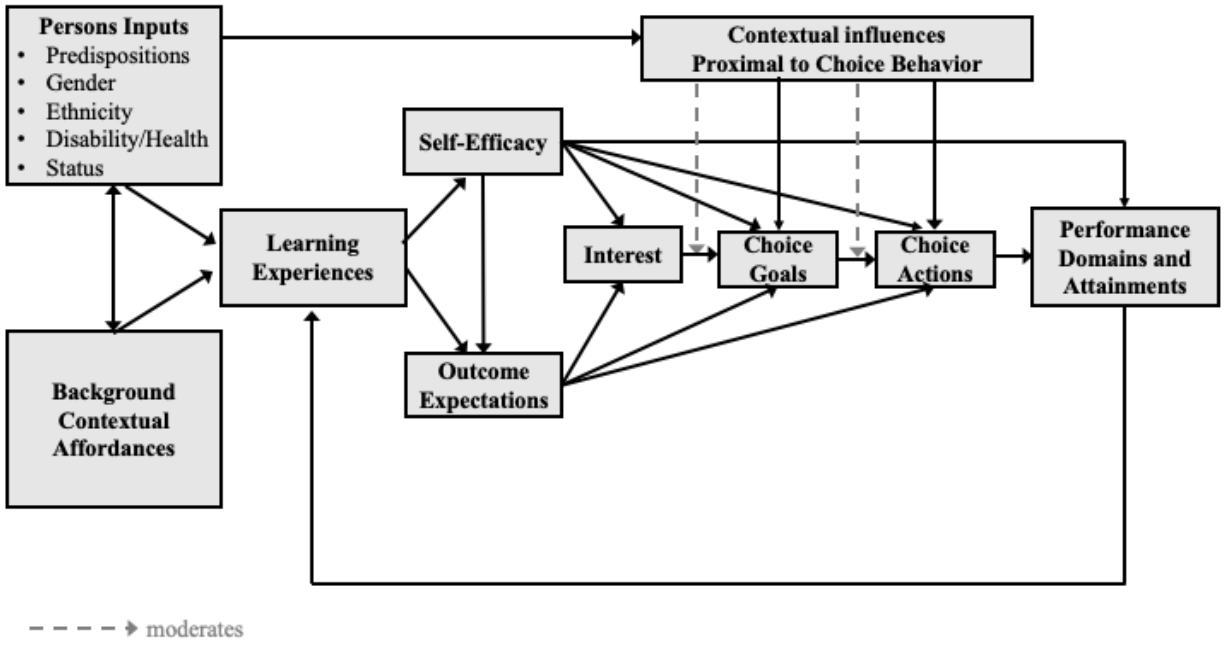

Figure 2.1 Conceptual Model of Social Cognitive Career Theory (SCCT) (source: adapted from [24], p.93)

2.1.1 Innovation and Entrepreneurial Self-Efficacies

Self-efficacy has a profoundly foundational impact on human behavior; it has gained significant attention in research and was initially introduced by [26] to the vocational research field. In the context of this study, self-efficacy should be interpreted considering the individual's perceptions about their own innovative and entrepreneurial skills, such as their abilities to develop opportunities and cultivate creative ideas rather than, for example, relate to how confident an individual is in his or her capabilities to solve a complex mathematical problem [27].

Several self-efficacy measures have been developed in the innovation and entrepreneurship research fields and tailored to the specific tasks that are assessed in this context (e.g., [28] - [32]). Innovation Self-Efficacy (ISE) refers to the individuals' confidence in their ability to innovate and engage in specific behaviors that characterize innovative people ([14], [31]), whereas Entrepreneurial Self-Efficacy (ESE) is the belief and confidence individuals have in their own capabilities to execute tasks aimed at entrepreneurial outcomes and pursuing new venture opportunities ([28], [29]). ESE and ISE have become essential cognitive psychological constructs in the innovation and entrepreneurship research fields, since it has been proven that they have a great impact on innovative and entrepreneurial intention, behavior choice and performance ([8], [28], [33]).

The Innovation and Entrepreneurial self-efficacy items considered by [14] and [29], respectively, are listed in Appendix Table A1. These items will play a role in our development of the new ENI self-efficacy construct.

2.1.2 Innovation and Entrepreneurial Behaviors (or Actions)

It is important to shed light on the individual's innovative and entrepreneurial behaviors since there would not be any innovations or entrepreneurial ventures without the innovators or the entrepreneurs behind them. In other words, the very actions undertaken by individuals that are building the innovative or the entrepreneurial venture, are the drivers of innovation or entrepreneurship [34]. Since innovative and entrepreneurial outcomes arise from actions executed by individuals, it is important to gain a general understanding of how these individuals behave and act.

Individual innovative behavior is characterized as all actions performed by an individual that are aimed at generating, developing and or implementing beneficial novelty as part of the innovation process ([4], [7], [35]). For example, [36] identified ten discovery and delivery skills (which we will also interpret as being behaviors) key to being innovative, namely: *Analyzing, Associational Thinking, Challenging the Status Quo, Experimenting, Networking, Observing, Planning, Questioning, Self-disciplined Executing,* and *Taking Risks*. More recently [37] conducted a Delphi Study to identify 20 Innovator Characteristics, 11 of which mapped directly to Dyer's discovery and delivery skills [36].

Individual entrepreneurial behavior includes all activities undertaken by a person that are associated with the creation of a new business [38]. McCelland et al. [39] identified 30 common skills/competences, deemed to be crucial for their success. These 30 can be grouped into 10 Personal Entrepreneurial Competencies (PECs), namely: *Opportunity Seeking and Initiative, Risk Taking, Demand for Efficiency and Quality, Persistence, Commitment to the Work Contract,*

Information Seeking, Goal Setting, Systematic Planning and Monitoring, Persuasion and Networking, and *Independence and Self-confidence*. The underlying behaviors of several of these Competencies speak to behaviors focused directly on creating something new, namely: *Opportunity Seeking and Initiative* (acts to extend the business into new areas, products or services, seizes unusual opportunities to start a new business, obtain financing, equipment, land work space, or assistance), and *Demand for Efficiency and Quality* (finds ways to do things better, faster, or cheaper).

The Innovation and Entrepreneurial Behavior Items associated with the work of [29] and [36], respectively, are listed in Appendix Table A2. These items will play a role in our developing the embracing new ideas Behavior construct.

2.2 The Innovation-Entrepreneurship Nexus (or common ground)

As described above, there are largely distinct literatures and research fields on self-efficacy and behaviors of innovators and entrepreneurs, though some scholars have brought them together in comparative studies (e.g., how are entrepreneurs different from or similar to innovators) (e.g., [43], [44]). Even recent education-related writing is based on a difference-model [45] argue for greater demarcation between entrepreneurship and innovation. Their perspective is framed around formal education related to learning to be entrepreneurial or innovative, arguing that universities and colleges are "missing the boat" if they only focus on or prioritize entrepreneurial education (which according to these authors depends on strong innovative ideas, so therefore should follow more intense education on developing strong technical and innovation skills); in this sense, their reasoning is in line with organizational process models that show innovative activities preceding entrepreneurial activities ([46]). The 2-circle Venn diagrams that [45] present to illustrate the relationships between entrepreneurship and innovations were intended to show a parallel relationship between management and leadership education with entrepreneurship and innovation education, respectively [52].

However, for us, their Venn diagrams inspired us to not focus our research on entrepreneurial and innovative self-efficacies and behaviors among engineers as separate and totally distinct measures, but rather to center our study on exploring the intersection or nexus of entrepreneurial and innovative attributes, particularly for those engaged in fields demanding strong technical skills. The idea of possible "common" elements of entrepreneurship and innovation (where the circles overlap) made us revisit their seemingly distinctive attributes and characteristics in more detail. We began to identify that they both rely on "the ability to conceptualize what has yet to become reality" [47]. This ability may depend on the integration of several attributes, including an individual's curiosity about and observation of the world, a tendency/drive to question (or even push against) the status-quo, in-depth knowledge in at least one domain [48], and creativity and imagination skills. We call this overarching/combined ability "to conceptualize what has yet to become reality" one of "embracing new (and perhaps useful) ideas," or Embracing New Ideas (ENI), for short.

Our work to identify and explore ENI measures was also influenced by the interview study conducted by [49] and [50] who investigated how project-based learning contributes to engineering graduates being able go out into the world and conceive and implement new ideas in a variety of domains/industries. As related to both entrepreneurs and intrapreneurs, [49] studied

their professional and academic learning experiences that enhanced their Embracing New Ideas-Self Efficacy, and identified a common set of educational take-aways for these individuals that enabled them to be "idea catalysts." The interview protocol developed by [49] focused on the "common ground" between entrepreneurship and innovation and inspired us to do the same, except with a quantitative approach.

In our research study, described below, we continue to develop this nexus or common ground as a concept related to both self-efficacy and behavior, as positioned in the SCCT model (Figure 2.1). We then go on to use this concept to consider what workplace situations promote the associated behaviors (our dependent variable), as promoted by self-efficacy and contextual factors (our independent variables).

3. Methods

Below we describe the survey instrument that forms the basis of our exploration of the intersection of innovation and entrepreneurship. This is followed by a presentation of how our survey responses were prepared for analysis, and the basic demographics of the resulting dataset. Finally, we lay out our approach to statistical modeling.

3.1 Description of Survey and Items on Self-efficacy and Behaviors

The data for our exploration of the common ground between entrepreneurship and innovation comes from survey data of 25 years of engineering graduates who had all participated in one of two immersive project-based learning experiences during their graduate studies at Stanford University. The surveys were deployed in the Summer of 2020 (for Course1: ME310-Global Engineering Design Thinking, Innovation, and Entrepreneurship) and in the Summer of 2021 (for Course2: ME218-Smart Product Design Fundamentals, Applications & Practice). Each survey deployment contained items related to the particular Course, as well as a common set of items related to demographics, first-job-out-of-school, current employment, future plans, and self-efficacy and behavior measures. It is those common items that form the basis of this paper. The overall response rate from the two deployments was 36 percent. Further details on survey design, participant recruitment and course descriptions can be found in [50], [51], [53] [54], [55].

3.1.1 Self-Efficacy Measures, Including Engineering Task and Design Thinking Self-Efficacies

The self-efficacy related items listed in Appendix Table A1 regarding innovation and entrepreneurship present an emerging focus on measures of self-efficacy which were contained in our survey. We note that there are items beyond the items in Table A1 that could have been included in the survey that were not. For example, Schar [14] explored 21 innovation-related self-efficacy items (based on Dyer's [41] 19 behaviors) as part of coming up with his five-item measure of self-efficacy.

Furthermore, there are twelve additional entrepreneurial self-efficacy items (beyond the ten listed in Table A1) that were developed by DeNoble et al. [29]. Since length was a critical factor to consider during our survey design, the survey only deployed two sub-dimensions of the original six sub-dimensional Entrepreneurial Self-Efficacy measure developed by [29] (i.e., 10 items instead of 22 items). Another reason why a reduced set of Entrepreneurial Self-Efficacy items

was utilized refers back to the fact that the intention of this survey is to focus on the Entrepreneurial Self-Efficacy sub-dimensions that are relevant for the majority of the Course1 and Course2 participants, and that were aligned with the survey research questions and objective. Therefore, the survey only included the two the Entrepreneurial Self-Efficacy sub-dimensions related to identifying opportunities as well as dealing with ambiguity and unexpected challenges. A final argument for the choice of these two sub-dimensions is that the mean scores of both show the highest statistical difference between entrepreneurship and non-entrepreneurship students in the original study of this measurement [29].

Our research also brings in the measures of Engineering Task Self-Efficacy (ETSE) and Design Thinking Self-Efficacy (DTSE), as described in Appendix Table A3, as part of modeling the relationships between self-efficacy and behavior depicted in the SCCT Model. Engineering Task Self-Efficacy [55], which consists of five items related carrying out engineering, is particularly relevant to our study population that consists of engineering graduates (though as we will see, not all are currently working as engineers). In addition, the paradigm of Design Thinking [56], which also consists of five items that capture key elements of engaging in design thinking, is found in many of the engineering courses at Stanford University, so may also have influence on behaviors.

3.1.2 Behavior Items in the Survey

The behavior-related items listed in Appendix Tables A2 regarding innovation and entrepreneurship are the focus of us exploring a new common ground behavior measure and were contained in our survey. Note that the six Innovation Behavior items in [29] are a subset of the longer list of 19 items; this reduction was made because of survey length limitations and were the ones that paralleled the innovation items developed by [14].

Since innovators could be employees in startups, small- or medium-sized enterprises or large corporations, it was important to follow a decisive criterion to distinguish these innovators (who may also be called intrapreneurs) from other "regular" employees. For this reason, the survey contained the three items that originated from the Engineering Task Self-Efficacy measure. The rationale behind this is that if an employee frequently exerts entrepreneurial activities in his or her current job (i.e., (i) discovering new ways to improve existing products; (ii) seeing new market opportunities for new products and services; and (iii) creating products that fulfill customers' unmet needs), it implies that this individual falls under the innovator/intrapreneur category performing these three entrepreneurial activities frequently.

As listed in Appendix Table A4, our survey also contains two related engineering task behavior measures, and eight more general workplace measures, as described in [55].

3.1.3 Other Survey Items to be Considered

Our survey also contained questions about industry sectors and roles related to their first job-out of school, their current (or most recent job), and some basic demographics. Survey takers were also asked about the influence of Course1 or Course2 on their career choices and direction, as well as professional performance.

3.2 The Dataset

3.2.1 Data Cleaning

While an expansive sample of survey responses offers a valuable opportunity to gain unique insights into a heterogeneous sample of engineering graduates, it also comes at a cost as the raw survey data requires rigorous cleaning.

The deployed surveys to Course1 and Course2 alumni collected 301 and 503 responses respectively (also accounting for 30 alumni who had taken both courses and subsequently completed both surveys). Once the datasets were generated, we created unique variables to represent the possible answer options for each question item, in addition to developing a codebook to guide dataset cleaning and creating a unified representation for an ideal, merged dataset.

After removal of "speeders" (survey takers who consistently gave the same quantitative answer for questions on self-efficacy) and those missing more than three answers from the self-efficacy items, we imputed missing values using the MICE (Multivariate Imputation by Chained Equations) Algorithm (the advantage of MICE is that it takes multivariate correlations into account and, thus, yields a more accurate imputation than simpler methods, such as imputing by simple mean or median). The resulting dataset for analysis consisted of 719 observations of which 459 came from the Course2 survey and 260 responses came from the Course1 survey.

3.2.2 Descriptive Statistics and Plots

Here we present descriptive statistics of the dataset. Several of the associated factors end up being important in the regression modeling presented in the Findings (Section 4). Furthermore, some factors illustrate the diversity of career paths that graduates in our dataset have taken; this allows us to explore how these pathways might influence engagement in embracing new ideas.

There are 719 graduates in our final combined Course1 + Course2 dataset, cleaned according to the process described in Section 3.2.1. There is a good distribution of these 719 graduates by class year, as illustrated in Figure 3.1. This is important in considering how engagement in new ideas might change with more workplace experience.

Some 20.31 percent of the survey respondents identified as female, 79.28 percent as male, and 0.42 percent selected "prefer not answer." Over half of the identified as white respondents (57.02%), followed by Asian or Asian American (33.38%). A fair number of graduates completed their undergraduate degree at institutions outside of the United States.

As a means of contextualizing the work and career situations of the respondents we note that nearly 67.04 percent considered their work at the time of taking the survey as "engineering work" (markedly down from 87.48% of them who identified their "first job out of school" as being engineering work). As shown in Table 3.1, more than half of them told us that they were involved in Research and Development (63.70%), followed closely by Design (56.47%). Project Management was identified by 39.22 percent as one of their job functions.

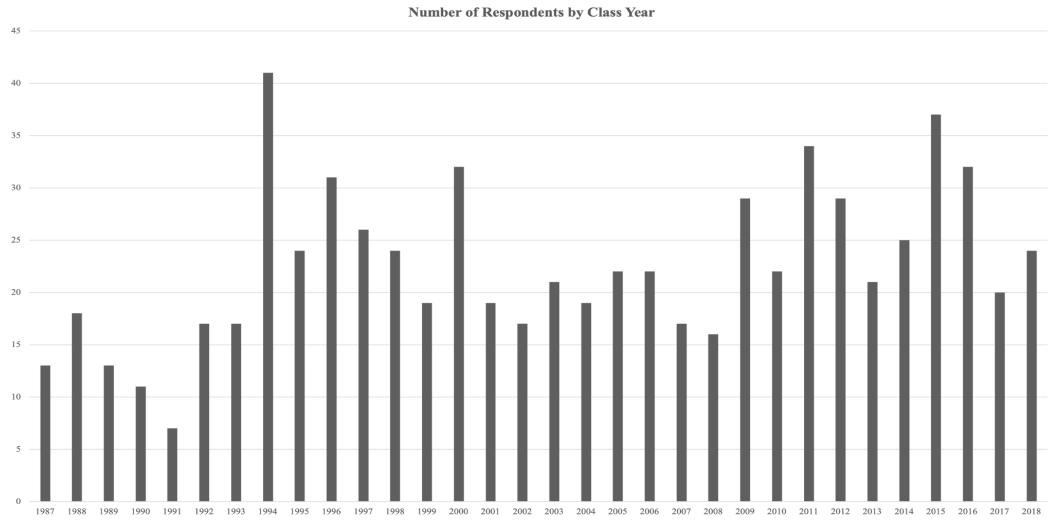

Figure 3.1 Distribution of Survey Respondents by Year They Took Course1 or Course2 (N_{survey}=719)

Table 3.1 Function or Business Unit of Current or Most Recent Job Identified by Survey Takers (Respondents could mark "all that apply")

Function or Business Unit of Current or Most Recent Job (*Select all that apply*)	Alumni survey respondents (N=719)	
	Respondents	Percentage
Research and development	458	63.70%
Design	406	56.47%
Project management	282	39.22%
Production/manufacturing	212	29.49%
Functional management	135	18.78%
Quality/testing	134	18.64%
Teaching/educational outreach	62	8.62%
IT	56	7.79%
Sales	50	6.95%
Marketing/public relations	48	6.68%
Support	41	5.70%
Finance	33	4.59%
Human resources	23	3.20%
Legal	17	2.36%
Security	12	1.67%
Other function/business unit	57	7.93%

When we look at the combination of R&D, Design and Production/Manufacturing (arguably the three areas most directly aligned with "engineering") in Figure 3.2 we see that 81 percent (581/719) are involved in one or more of these three engineering-centric functions (with some 19.6% (141/719) involved in all three). This means that 1 out of 5 of the survey respondents have

their primary function(s) outside of R&D, Design and Production/Manufacturing, suggesting there is a diversity in the types of work that these graduates are involved in.

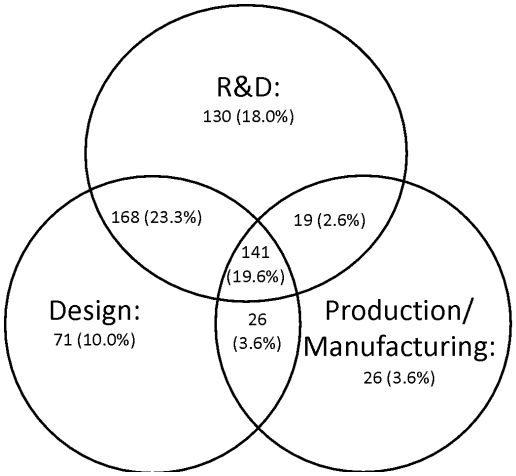

Figure 3.2 Percentage of Design, R&D and/or Production/Manufacturing Functions/Business Units Identified by Survey Takers (considering multiple answer options).

Finally, we present the organizational roles of our survey takers; some 44.65 percent of them were working at a medium or large size business at the time they filled out the survey, and another 21 percent are at a small business or start-up (Table 3.2). A healthy 12.52 percent identify their current role as a founder or co-founder of their own for-profit organization, and some 5.84 percent are faculty members or educational professionals at a college or university.

Table 3.2 Organizational Role Best Aligned with Current or Most Recent Job

Organization Role (current or most recent job)	Alumni Survey Respondents (N=719)	
	Respondents	Percentage
Employee for a medium- or large-size business	321	44.65%
Employee for a small business or startup company	151	21.00%
Founder/co-founder of your own for-profit organization	90	12.52%
Faculty member or educational professional in a college or university	42	5.84%
Employee for the government, military, or public agency (excluding a school or college/university)	23	3.20%
Employee for a non-profit organization (excluding a school or college/university)	12	1.67%
Founder/co-founder of your own non-profit organization	2	0.28%
Teacher or educational professional in a K-12 school	2	0.28%
Missing	76	10.57%
Total	719	100.00%

Note: The 76 "missing" answers to this question come from Course1 respondents whose first and current job were the same; survey branching mistakenly had them miss being presented with this question.

3.3 Statistical Details in Developing Embracing New Ideas Self-Efficacy and Behavior Measures

Based on the 719 survey responses we looked at correlation factors across the survey items related to innovation self-efficacy (ISE) and entrepreneurial self-efficacy (ESE) (as listed in Table A1); as a starting point a correlation factor of 0.4 or greater was used to flag candidate "common ground" items. This correlation was chosen, based on those recommended for factor

analysis (a different but aligned statistic process), as described in [56]. From this we noted five of the six ISE items as potentially being related to five of the ESE items, as listed in Table 3.3. Noteworthy is that the ISE item not included is *Asking a Lot of Questions*, and the five ESE items not flagged are *Tolerating Surprise Changes*, *Bringing a Product to Market, Production Under Stress, Determining a Business Plan,* and *Persisting Under Adversity.*

Table 3.3 Strong correlations between Innovation-related and Entrepreneurial-related items exhibited. (Items crossed-out in the table below did not show any correlations greater than 0.4 between Innovation and Entrepreneurial Self-Efficacy items.)

(a) Innovation-related Self-Efficacy Items [14] *How confident are you in your ability to do each of the following at this time?*
~~● Ask a lot of questions (ISE_AQ)~~
● Generate new ideas by observing the world (ISE_GNI)
● Experiment as a way to understand how things work (ISE_EXP_UND)
● Actively search for new ideas through experimenting (ISE_EXP_SEARCH)
● Build a large network of contacts with whom you can interact to get ideas for new products or services (ISE_NETWORK)
● Connect concepts and ideas that appear, at first glance, to be unconnected (ISE_CON_CONCPT)
(b) Entrepreneurial-related Self-Efficacy Items [29] *How confident are you in your ability to do each of the following at this time?*
● See new market opportunities for new products and services (ESE_MKT_OPP)
● Design products that solve current problems (ESE_DES_PROD)
● Discover new ways to improve existing products (ESE_IMPRV_PROD)
● Create products that fulfill customers' unmet needs (ESE_CRT_PROD)
● Identify new areas for potential growth (ESE_IDNT_GRWTH)
~~● Tolerate unexpected changes in business conditions (ESE_TLRT_CHNG)~~
~~● Bring product concepts to market in a timely manner (ESE_CPT_MKT)~~
~~● Work productively under continuous stress, pressure and conflict (ESE_WORK)~~
~~● Determine what the business will look like (ESE_BUSI)~~
~~● Persist in the face of adversity (ESE_PERS)~~

When we look at the "common ground" items (those with correlations greater than 0.4), they are all, in some form, about new ideas–either identifying gaps or market opportunities, connecting existing ideas (or products or service) in novel ways, or seeing new ways to improve existing products or services. They are centrally about identifying or generating new (and perhaps valuable) ideas, and all skew towards the fuzzy frontend of design and venture creation, though arguably with more intentionality than the ISE item of "Asking a lot of questions." We also see that the ESE items not included either reflect personality traits (e.g., persist under adversity) or moving an idea beyond its initial stages into a full-fledged business plan.

From the ten items (five from ESE and five related to ISE) we identified six to bring together as our new Embracing New Ideas Self-Efficacy (ENI-SE) measure, as will be presented in the Findings Section.

As a complement to the ENI-SE construct, we created a companion construct around Embracing New Ideas-Behaviors (ENI-B) based on existing behavior survey items (see Table A2). After this we explored the workplace factors in our survey that seemed to be present for those who are highly engaged in this type of behavior through regression modeling. Our regression modeling started with a series of stepwise regressions where we explored possible independent variables (beyond ENI-SE and other measures of self-efficacy contained in the survey) that might explain ENI-B (our dependent variable). This led to our final multiple regression, ordinary least square model, that is presented in Findings.

4. Findings

The first section below addresses our first research question; namely:

- RQ1: How can ENI Embracing New Ideas (ENI) be operationalized into measures of self-efficacy and behaviors?

This is followed by a regression model that begins to answer our second research question:

- RQ2: What workplace, self-efficacy and personal factors relate to these behaviors in a variety of organizations?

4.1 Development of an Exploratory ENI-SE and Its "Partner" Construct ENI-B

Our first research question focuses on operationalizing the nexus or common ground of innovation and entrepreneurial self-efficacies. As detailed in Section 3.3, we accomplished this by using our survey data to identify self-efficacy related items from ISE (six items) and ESE (ten items) which were moderately correlated with one another, recognizing that these items all focused on the fuzzy front-end of product development, where idea generation is at a premium. From a subset of these correlated items a new self-efficacy construct was created and called Embracing New (and potentially valuable) Ideas Self-Efficacy (Cronbach's Alpha, 0.85), as described in Table 4.1(a). Companion behavioral survey items were then identified, and from these a new behavioral construct was created – Embracing New (and potentially valuable) Ideas Behaviors (Cronbach Alpha, 0.80), as shown in Table 4.1(b).

Table 4.1 The Two Embracing New Ideas (ENI) Constructs, N_{survey}=719

a. **ENI-Self-Efficacy** (scale of 0-4, from *Not Confident* to *Extremely Confident)*
b. **ENI-Behaviors** (scale of 0-4, from *Never* to *Very Often*)

(a) Embracing New Ideas Self-Efficacy Items (0-4 Scale on Confidence)	Mean (SD)
Overall	2.78 (0.72)
Survey Items	
● Generate new ideas by observing the world (ISE_GNI)	3.03 (0.90)
● Actively search for new ideas through experimenting (ISE_EXP_SEARCH)	2.96 (0.90)
● See new market opportunities for new products and services (ESE_MKT_OPP)	2.22 (1.12)

● Create products that fulfill customers' unmet needs (ESE_CRT_PROD)	2.62 (1.00)
● Discover new ways to improve existing products (ESE_IMPRV_PROD)	2.92 (0.90)
● Connect concepts and ideas that appear, at first glance, to be unconnected (ISE_CON_CONCPT)	2.92 (0.85)
(b) Embracing New Ideas-Behavioral Items (0-4 Scale on Confidence)	Mean (SD)
Overall	2.63 (0.83)
Survey Items	
● Generating Creative Ideas#	3.18 (0.86)
● Searching out new technologies, processes, techniques, and/or product ideas#	2.95 (1.00)
● Seeing new market opportunities for new products and servicesˆ	1.90 (1.31)
● Creating products that fulfill customer's unmet needsˆ	2.52 (1.21)
● Discovering new ways to improve existing productsˆ	2.60 (1.12)

Notes: The first five items in the ENI-SE measure are complements, item-for-item with the first five items in the ENI-B measure.
From Innovative Behavior construct described in Table 2.2 [58]
^ From items related to entrepreneurial behaviors [29]

4.2 Workplace Consideration of Generating Ideas

Our multiple regression model of Embracing New Ideas-Behavior (ENI-B) allows us to address RQ2, namely *what workplace, self-efficacy and personal factors relate to these behaviors in a variety of organizations?* The model included independent variables related to demographics, self-efficacies and job features, and exhibited a reasonable R^2 with the model explaining 55.8 percent (54.9% adjusted R^2) of the variation, as shown in Table 4.2.
We found that "Demographic variables" of gender showed no explanatory power. On the other hand, whether the participant considers their current job an engineering job showed modest (and positive) explanatory power ($b=0.07$, $p<.01$), suggesting that those who see their work as engineering may be slightly more likely to exhibit ENI-behaviors. In contrast, working for a medium- or large-size business showed modest (and negative) explanatory power ($b=-0.04$, $p<.05$), suggesting that those employed in the alternatives (e.g., small business or start-up, academic institution, etc) may be slightly more likely to exhibit ENI-behaviors.

The model also contained two binary self-reported independent variables that connect directly back to the [COURSE]: *Did the survey respondents feel that the [COURSE] had been influential on their career or professional performance?* Neither were significant explainers. This is consistent with the SCCT model (see Figure 2.1) that depicts the connection between learning experiences and actions/behaviors to be indirect (mitigated by other factors).

We do see that the number of years out since graduation has some explanatory power ($b=0.06$, $p<.01$), with those who have been out longer exhibiting more ENI-behavior. This is consistent with the idea of experience enabling new opportunities to be creative (though we see that the effect is not particularly strong).

Table 4.2 Regression Model of Embracing New Ideas-Behavior (ENI-B) for the 719 Survey Participants

Predictors	Overall Estimates
(intercept)	0.00
Self-Efficacy	
Embracing New Ideas (ENI_SE)	0.29***
Engineering Task (ETSE)	-0.13***
Design Thinking (DTSE)	0.06*
Demographics	
Gender	0.04
What organizational role and type best align with your current or most recent job? — employee for a medium- or large- business	-0.04*
Would you describe your current or most recent job as engineering?	0.07**
In your current role, how often have your assignments involved:	
—cross-functional collaboration	0.06*
—working on something that generates interest and feedback from others in your organization	0.14***
—leading or directing others	0.09***
Current or most recent job function or business unit	
—Design	0.01
In your current role, how often have your assignments involved:	
—Designing a new product or project to meet specified requirements	0.44***
[COURSE] aspects	
—Years since ME218/310 graduation (normalized)	0.06**
—How would you rate the influence you [COURSE] experience had on your career choices & directions?	0.02
—How would you rate the influence you [COURSE] experience had on your professional performance?	0.01
Observations	719
R^2/R^2 adjusted	0.558 /0.559

Note: * p<.05, **p<.01, ***p<.001

Based on the SCCT model we would expect a relationship between self-efficacy and ENI-behavior. This was the case with our new Embracing New Ideas Self-efficacy (ENI-SE) measure, with a significant and positive relationship with ENI-B showing up (b=0.29, p<.001). The other two self-efficacy measures included in the model are related to processes, namely the engineering tasks (ET) and design thinking (DT) self-efficacy measures (see Table A3). While ETSE was a predictor of ENI-B, it was a *negative* predictor (b=-0.13, p<.001). In contrast DTSE was a positive (though weak) predictor (b=0.05, p<.05). That these two self-efficacy measures act in oppositive directions suggests:

- Even though both design thinking (DTSE) and engineering task (ETSE) are based on prescribed ways of solving/approaching problems, it may be that the process described by the ETSE construct that includes *developing and integrating sub-systems to build a complete system*, and *analyzing the operation of a complete system*, when taken as a whole, results in a more constrained or convergent process (particularly when compared with DTSE). We speculate that this more constrained approach to problem solving might limit how "outside of the box" and "questioning of the status quo" and consequently, one's confidence in Engineering Task behavioral measures.
- While some of the items within the DTSE construct seem aligned with the greater awareness of human needs (which, by extension, could be thought of as new markets and products), when combined with other aspects of the DTSE (e.g., *accepting feedback on your work and making changes)*, the outcome is a self-efficacy measure that is less aligned with the behaviors captured in ENI-B, which are directly focused on generating new ideas.

Finally, we note that several components of the job and environment have power in explaining ENI-B, particularly the frequency of activities that the current job involves: *Working on something that generates interest and feedback from others in your organization* (b=0.14, p<.001); *Leading or directing others* (b=0.09, p<.001); and *Cross-functional collaboration (working with different business units, etc.)*(b=0.06, p<.01). Interestingly, all three of these activities involve interacting with other groups and people in an organization and underscore the social nature of creative work.

While reporting that one of your functions or business units involved design had insignificant explanatory power, the frequency with which one is involved in *Designing a new product* or *project to meet specified requirements* was the most powerful predictor in our whole model (b=0.44, p<.001). This underscores the importance of designing something new in creative work.

5. Discussion

5.1 Interpreting the Statistical Model

Our regression modeling focused on factors that explained behaviors associated with embracing new ideas in the graduates' current work settings. Recall that key features of this behavior are generating, searching out, creating, and discovering new market opportunities and new products.

We see that the associated self-efficacy, Embracing New Ideas is a strong and positive explainer of Embracing New Ideas Behavior (ENI-B), suggesting that there are qualities of being entrepreneurial as well as innovative that support driving change, whether in a start-up or in an existing organization.

That we see frequency of *Working on something that generates interest and feedback from others in your organization* and *Cross-functional collaboration (working with different business units, etc.)* being positive predictors of ENI-B is consistent with the literature on corporate entrepreneurship (i.e., intrapreneurship), where studies have shown that management recognition (e.g., [59], [60]) and interdisciplinary collaboration (e.g., [61]) are organizational factors/strategies that contribute to innovative behaviors.

We were surprised to find the engineering task self-efficacy (ETSE) is a negative explainer of ENI-B. This suggests becoming expert in carrying out engineering in a prescribed manner (as suggested by the ETSE items, as contained in Appendix Table A3) may, in some circumstances, in fact limit and even negatively impact questioning the status quo in generating new ideas. Even considering the acknowledged value of technical knowledge in creating new ideas [48], this finding brings up the question of "the expert blind spot" [62], and suggests the value of "adaptive design expertise" ([63], [64]).

Our results show the importance of being involved in design as contributing to ENI-B. It is not only it being a component part, but it also seems that the frequency of design engagement is important. This does bring in questions about the relationships between design and creating new ideas. We are certainly not the first to suggest that design can play a critical role in generating new ideas, and in innovation endeavors more generally. In their 2018 analysis of design-innovation literature, Hernández, et al. [65] concluded that "*An organization's definition of design and what it can do will often affect the role design plays in innovation—creative idea generation or product design refinement, for instance—and the contributions those roles make to innovation processes and outputs.*" (pg. 254) and concluded that many of the papers they reviewed "*make claims about design being a fundamental component of a successful innovation process, but there are few explicit descriptions or quantifiable analyses of how design actually contributes."* (pg. 255).

Finally, our results based on the mechanical engineering population of Course1 and Course2 graduates show that some factors may be less important (and perhaps unimportant) in spurring individuals to the behaviors associated with generating new ideas; these include gender. We are particularly cautious in interpreting this gender finding as women remain a minoritized population in engineering, making up only 14.5 percent of the U.S. engineering workforce [66] and 15 percent of technology entrepreneurs in the United States [67].

5.2 Reflection on These First-Generation ENI-SE and ENI-B Constructs

We consider the measures of Embracing New Ideas self-efficacy and behaviors proposed in this paper as a start in exploring the common ground between innovation and entrepreneurship. First, more sophisticated statistical means could be employed to look at this common ground (we also mention this in Section 6 on future work).

Second, our regression model results suggest the important roles of design and creativity in idea generation. Design came up in interesting and inconsistent ways in our predictions of Embracing New Ideas-Behavior (ENI-B):

- Engineering Task Self Efficacy (ETSE) (which has a specific item on Design that reads "design a new product or project to meet specified requirements) came up as a negative predictor, even though that item's behavioral counterpart came up as a powerful and significant predictor; and
- Design Thinking Self Efficacy (DTSE) with its item on generating a wide variety of ideas, showed a weak relation to ENI-B, even though it can be argued that at its core Design Thinking is a process to encourage expanding the design frame.

While our work did not explicitly explore the role of creativity in promoting idea generation (both self-efficacy and behavior), literature talks about their close relationship (e.g., [68], [69], [70]), and by extension creativity's possible relationship to ENI-B. This leads us to speculate that some of the specific DTSE items that seem akin to creativity might play a role in promoting ENI-B.

All of this suggests new analyses related to the development of a second-generation ENI-SE measure that considers other items beyond innovation and entrepreneurship, by bringing in the survey items from ETSE and DTSE.

6. Conclusions, Limitations, and Future Research

In this study we explored the intersection of innovation and entrepreneurship, homing in on the shared "ability to conceptualize what has yet to become reality" [47]. Our working shorthand for this is "Embracing New (and potentially useful/valuable) Ideas (ENI)," as considered to be part of the fuzzy and essential front end of entrepreneurial and/or innovative endeavors. Operational definitions/measures of ENI in terms of self-efficacy and actions were created. Using a quantitative approach, ENI was looked at from a workplace behavior perspective.

What is particularly noteworthy about our workplace-related findings is that the frequency of ENI types of behaviors (e.g., generating creative ideas, searching out new technologies, and discovering new ways to improve existing products) was only weakly dependent on the type of organization one was at – large-sized, small-sized, start-up, etc. This suggests that elements of ENI-B can happen in all sorts of organizations, where individuals are given feedback and attention from others in their organization and interact with other business units and have the confidence in being entrepreneurial. (We speculate that organizational investment in training (its) engineers to be more entrepreneurial could be a sound/worthwhile investment with regards to new idea creation.)

The generalizability of this first study of ENI is both promising and limited, as it was based exclusively on a U.S. sample of 25 years of Stanford University engineering graduate alumni. This suggests several avenues of future research to consider:

1) **Sample populations beyond Course1 and Course2**, Silicon Valley and engineering to explore if the same workplace variables describing ENI behavior still hold up. This would start to address generalizability of the proposed relationships between ENI behavior and workplace and personal factors. Furthermore, some 40 percent of the variance remains unexplained by this study's model; *what other independent variables are relevant? What other demographic variables might come into play?*

2) **The robustness of the proposed ENI self-efficacy and behavior measures,** including what other items may be relevant to the idea of a "common ground" between innovation and entrepreneurship. For example, *does creative confidence or domain-specific confidence come into play?* Furthermore, *how might more sophisticated statistical approaches to creating self-efficacy and behavioral measures produce new insights into what "hangs" together in terms of new idea creation?*

3) **Innovation and entrepreneurship, beyond the idea generation stage.** Efforts beyond idea generation are needed to move to realized innovations, whether this be in start-ups or existing organizations. This suggests that there are needed skills and organizational resources to move ideas from the Discovery & Seed stages to Access & Commitment, Restructuring & Anchoring, and finally to Routinize [70]-[71]. This brings up questions about other key areas of self-efficacy (and associated skills and behaviors) that are needed by individuals (and by extension, organizations) to be successfully involved in *idea realization*.

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Appendix Table A1. Items in Self-Efficacy Measures for Innovation and Entrepreneurship
(on a scale of 0-4, from *Not Confident* to *Extremely Confident*)

(a) **Innovation-related Self-Efficacy Items** [14] *How confident are you in your ability to do each of the following at this time?*
● Ask a lot of questions (ISE_AQ)
● Generate new ideas by observing the world (ISE_GNI)
● Experiment as a way to understand how things work (ISE_EXP_UND)
● Actively search for new ideas through experimenting (ISE_EXP_SEARCH)
● Build a large network of contacts with whom you can interact to get ideas for new products or services (ISE_NETWORK)
● Connect concepts and ideas that appear, at first glance, to be unconnected (ISE_CON_CONCPT)
(b) **Entrepreneurial-related Self-Efficacy Items** [29] *How confident are you in your ability to do each of the following at this time?*
● See new market opportunities for new products and services (ESE_MKT_OPP)
● Design products that solve current problems (ESE_DES_PROD)
● Discover new ways to improve existing products (ESE_IMPRV_PROD)
● Create products that fulfill customers' unmet needs (ESE_CRT_PROD)
● Identify new areas for potential growth (ESE_IDNT_GRWTH)
● Tolerate unexpected changes in business conditions (ESE_TLRT_CHNG)
● Bring product concepts to market in a timely manner (ESE_CPT_MKT)
● Work productively under continuous stress, pressure and conflict (ESE_WORK)
● Determine what the business will look like (ESE_BUSI)
● Persist in the face of adversity (ESE_PERS)

NOTE: The 10 Entrepreneurial-related items make up two of the six sub-dimensions created by [29], namely "developing new product and market opportunities" and "coping with unexpected challenges."

Appendix Table A2. Items in the Behavior Measures related to Innovation and Entrepreneurship Asking about "Current or Most Recent Job" (on a scale of 0-4, from *Never* to *Very Often*)

(a) Innovation-related Behavior Items [36], [41], [42] *How often are you engaged in the following activities?*
● Searching out new technologies, processes, techniques and/or product ideas
● Generating creative ideas
● Promoting and championing ideas to others
● Investigating and secreting resources needed to implement new ideas
● Developing adequate plans for schedules for the implementation of new ideas
● Selling a product of service in the marketplace
(b) Entrepreneurial-related Behavior-related Items [29] *How often are you engaged in the following activities?*
● Discovering new ways to improve existing products
● Seeing new market opportunities for new products and services
● Creating products that fulfill customers' unmet needs

Appendix Table A3. Other Self-efficacy Measures Contained in the Survey

(a) Engineering Task Self-Efficacy (ETSE) Items ([55]): *How confident are you in your ability to do each of the following at this time?* (scale of 0-4, from *Not Confident* to *Extremely Confident)*
● Design a new product or project to meet specified requirements
● Conduct experiment, build prototypes, or construct mathematical models to develop or evaluate a design
● Develop and integrate component sub-systems to build a complete system or product
● Analyze the operation or functional performance of a complete system
● Troubleshoot a failure of a technical component or system.
(b) Design Thinking Self-Efficacy (DTSE) ([56]): *At this point in time, how confident are you in your ability to?* (sliding bar scale from 0-100)
● Sense how another person feels and who they might be thinking
● Look at problems in the world from different angles
● Generate a wide variety of ideas
● Build a prototype solution that satisfies user needs
● Accept feedback on your work and make changes
● Enhance the lives of people by finding a better way to do things

Appendix Table A4. Other Behavioral Measures Contained in the Survey, Asking about "Current or Most Recent Job" (on a scale of 0-4, from *Never* to *Very Often* (or *NA* for not applicable)

(a) **Engineering Task Behaviors** [55]: *How often are you engaged in the following activities?*
● Designing a new product or project to meet specified requirements
● Analyzing the operation or functional performance of a complete system
(b) **Other Workplace Behaviors** [55]: *How often are you engaged in the following activities?*
● Presenting your work to senior managers and leaders
● Working on something that generates interest and feedback from others in your organization
● Working in areas or domains that are unfamiliar to you
● Cross-functional collaboration (working with different business units, etc.)
● An ambiguous ill-defined problem
● Leading or directing others
● Documentation
● Ethical questions or considerations