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Measuring the Innovation Self-Efficacy of Engineers*

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Innovation is critical to our economic and social prosperity. Faculty and administrators have undertaken resource-intensive efforts to foster innovation in engineering education, yet we inadequately understand the impact these interventions have on individuals' judgment of their own innovation ability. This exploratory study developed a comprehensive instrument to measure an individual's self-efficacy toward innovation. Creation of the instrument began with a literature review and expert interviews with practitioners and academics specializing in engineering innovation. Subsequent tests with experts (n = 22) and students in engineering innovation (n = 681) were used to provide validity and reliability evidence for an initial set of items. The resulting Innovation Self-Efficacy Measure (ISE) consists of 29-items within 9 clusters: creativity, exploration, iteration, implementation, communication, resourcefulness, synthesis, and vision. Factor loadings revealed through exploratory factor analysis ranged between 0.715–0.899 with reliabilities ranging between a Cronbach's Alpha of 0.743–0.864. Implications for evaluation within engineering education are discussed.

Keywords: innovation; self-efficacy; instrument development; assessment

1. Introduction

Effective engineering education programs not only foster requisite skills for graduates, but also confidence in their ability to utilize those skills [1]. Students lacking confidence toward a skill are less likely to attempt to apply the skill [2, 3]. One recognized skill that has yet to be isolated and operationalized in a way that can be reliably measured is the ability to innovate.

Innovation is defined as the intentional implementation of novel and useful processes, products, or procedures to a new domain that are designed to benefit society [4] or the creation of new or significantly improved products or processes [5]. To innovate is to understand what is technically possible, desirable, and viable in the market place [6]. Innovators must develop, modify, and implement ideas, while navigating ambiguous problem contexts, overcoming setbacks, and persisting through uncertainty [7]. The decision to undertake such challenges is highly influenced by an individual's self-efficacy. Persistent cycles of innovation can therefore be especially challenging as poor results can negatively affect perceptions of efficacy.

Successful students should understand what it means to innovate and be confident in their ability to do so. Despite the obvious benefits of innovation and resource-intensive efforts to foster innovation within engineering education, we inadequately understand how to measure the impact of these interventions on individuals' judgment of their own innovation ability. Scholars have called for further refinement of the construct in innovation contexts (e.g., [8, 9]). Longitudinal explorations looking at lasting impact of interventions for innovation would provide in-depth insights, but such an approach is time intensive for fast-paced and time constrained engineering courses. These factors provide the impetus for this mixed methods examination of innovation self-efficacy and the subsequent development of a comprehensive measure that allows engineering educators to better understand how they are impacting student innovation self-efficacy.

In this paper, we discuss the process used to develop the Innovation Self-Efficacy (ISE) Measure, which includes a literature review, expert interactions, and student testing.

2. What is self-efficacy?

Self-efficacy is a facet of social cognitive theory that addresses an individual's judgment of their capability to organize and execute courses of action for a given task [2]. The theory claims that self-efficacy beliefs influence the way people live, work, and play; therefore, it is a pre-condition for productivity and discovery of new knowledge. Being efficacious toward a task is an important factor in an individual's ability to attempt and subsequently perform the task successfully. Individuals who are *efficacious* toward a given task persist until they achieve success, express a willingness to persevere in the face of obstacles and failure, possess intrinsic motivation, or motivation driven by internal rewards, for the task, engage in task specific behaviors, and display the ability to pursue certain challenges [2]. An individual's incentive to act can be limited by low self-efficacy even if they have the knowledge to

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complete the task because they don't believe they can produce the desired outcome [2].

An individual's self-efficacy is malleable and influenced by four sources (in descending order of impact): mastery experiences, vicarious experiences, social persuasion, and physiological states [2]. The primary influence on self-efficacy are mastery experiences. Mastery experiences provide authentic evidence of whether one has the ability to successfully accomplish the task at hand [2]. An individual is given an opportunity to perform the given task during a mastery experience. Successful completion or catastrophic failure of the task will become a major indication of whether someone believes in his or her ability to succeed in the future. In the absence of firsthand experiences, individuals can vicariously develop beliefs about their ability through observation of the behaviors of others who act as models. The observation of those who we view as having similar ability to ourselves provides an impetus for future action. A positive vicarious experience can promote action over apprehension and discourage mimicking behaviors that receive negative results. Social persuasion from those we determine to have prestige (e.g., teachers) or individuals we respect (e.g., family and friends) can provide added encouragement regarding our ability to succeed at a given task [10]. Finally, our physiological states combined with our interpretations of our physical and emotional reactions can potentially impact our beliefs in our abilities. For example, self-efficacy can be lowered from stress resulting from pressure to succeed. Each of these sources of self-efficacy can have both positive and negative impacts depending on the experience.

The efficacy beliefs we hold toward our abilities are oriented according to tasks. Task specific self-efficacy is defined as one's belief in his or her ability to complete a *given task*. What this means is that having low self-efficacy toward one task does not automatically mean having low self-efficacy toward another task in another context. Our perceived judgments of self-efficacy toward a given task can change over time as we acquire new information and experiences, both positive and negative [11]. The beliefs we hold about our abilities are oriented according to the successes and failures we have toward the given task. Training in a particular skill offers one way to enhance self-efficacy [11–13]. Our study focuses on the task of innovating and understanding how engineering students perceive confidence to innovate.

3. Literature review

A literature review was undertaken first to identify the components of innovation present in the self-efficacy and innovation literature. The search sought definitions, measures, constructs, and items that had been used to measure innovation or subsets of innovation. A three-person research team developed broad categories based on 70 articles across 12 different disciplines, including applied psychology, personnel psychology, personality psychology, social psychology, business, entrepreneurship, computer science, group and organization management, human resources, organizational behavior. The team looked across these articles for elements that had been found to influence innovation. Criteria that could not be evaluated for individual self-efficacy were separated out (for example, those that looked at more context-dependent criteria such as indicators of innovation within a collaborative group or workplace setting).

3.1 Task-specific abilities necessary for innovation

Our modern definition and task-specific abilities identified with innovation are understandably complex. Managerial research of innovation has historically focused on domain expertise, creative and analytical thinking, problem-solving, entrepreneurship, and interpersonal skills necessary to develop and implement creative ideas [14]. Engineering research of innovation focuses on creativity and entrepreneurship abilities, which are related but distinct [15, 16]. Creativity requires the ability to generate domain-specific, novel, and useful outcomes [17, 18], while entrepreneurship requires organization, management, and the assumption of risk to create value [16, 19]. Innovation adds the factor of implementation to differentiate itself from creativity and the factor of novelty to differentiate itself from entrepreneurship [8]. Curiously, the implementation factor is not always recognized by engineering students. Research investigating student understanding of innovation found that most students identified innovation as the development of creative, novel and useful ideas, but overlooked the need to understand desirability, feasibility, or viability [20].

Overall, our literature review found that these different perspectives share 9 common elements including: communication, creativity, exploration, flexibility, implementation, iteration, resourcefulness, and vision. Table 1 outlines possible task-specific abilities related to innovation categorized into clusters and broken down into indicators.

3.2 Initiatives to prepare students for innovation careers in engineering

Government and industry expect higher education to prepare students, especially those in engineering, for careers in innovation [21]. The engineering and technology accrediting agency, ABET, Inc., supports this expectation by requiring higher education to provide opportunities to practice innovation related tasks such as solving real problems, understanding societal issues, and working in multidisciplinary teams [22]. Previous research has shown that aspects of engineering education, specifically understanding [23–25], ideation [26–28], prototyping [29–32], testing [23, 24], pitching [25, 33], and implementing [34, 35], are enhanced when the innovation process is embedded [23, 29, 34].

A well-designed innovation education program should give students a hands-on experience with innovation that also raises a student's self-confidence [36]. A clearer understanding of innovation skill development with an understanding of students and/or practitioner's behavior toward innovation can inform how such programs can be developed and how different types of people can be active and successful members of an innovation team. This suggests that individuals may not engage or persist in innovative efforts if they do not believe in their abilities. Self-efficacy toward innovation not only supports innovation, it supports academic motivation, retention, learning, and achievement [57]. Researchers suggest strategies for positively influencing self-efficacy in the classroom, such as fostering successful experiences for students, using peers as role models, presenting students with choices, communicating recent successes, and lowering anxiety around exams or presentations [38].

3.3 Assessing innovation self-efficacy

Innovation self-efficacy refers to an individual's belief in his or her ability to accomplish tasks necessary for innovating [9, 39]. It is becoming more apparent in the literature that self-efficacy is a critical component for innovation [8]. The nature of innovation requires a high level of persistence to overcome setbacks. Positive self-efficacy beliefs are not only tied to persistence, but also have the potential to influence innovation by strengthening creative performance, increasing the tendency to engage in expended effort, and inducing learning from failure [14, 37, 40].

Bandura recommends tailoring measures to specific domains in specific contexts so that the measure can be predictive of a specific behavior [2]. In the past decade, scholars have enthusiastically responded to Bandura's recommendation, assessing self-efficacy toward various tasks including creativity [41, 42], engineering design [43], modeling [44], tinkering [45, 46], computer use [47–49], and entrepreneurship [50, 51]. While these tasks may be related to innovation work, scholars have yet to develop an integrated measure that relates to a collection of tasks associated specifically with innovation. Gerber and colleagues [39] suggest that innovation self-efficacy is not simply a blend of existing constructs, but rather an entirely new construct that is aligned with previous research incorporating the lens of practitioners, i.e., applying knowledge from one domain to another [52], developing novel and useful ideas [1], experimentation with ideas and learning from experimentation [53], and distribution and implementation of ideas [4].

A 2009 review of 16 schools in the United States teaching innovation to engineering students revealed that the majority were assessing innovation through the use of presentations and progress reports. Most of these assessments are facilitated through peer and self-evaluations [23]. The following study discusses the development and steps used to assess validity of a new tool that can be used across universities to compare the effectiveness of different engineering-based innovation interventions.

4. Expert interactions

Expert practitioners and academics from design and engineering-related fields were recruited to participate in providing content validity evidence [54]. First, we conducted expert interviews to provide insights in the development of an initial instrument. The resultant instrument was then pilot tested with a new group of experts.

4.1 Expert interviews

Four semi-structured interviews ranging from 45 minutes to one hour were audio recorded and transcribed to inform and supplement our literature review. Participants were recruited after they coached university students through an intensive summer engineering-design innovation institute. They were asked to reflect on innovation during their summer experience and in their own practice. All participants identified as women. Interviews asked the expert to define innovation, discuss how they recognize innovation, what specific innovation practices are most important in their work and potential barrier to innovation. The interviewer coded transcribed responses (unit of analysis being one answer turn) for broad themes informed by the literature review. All interview responses corresponded with one of the existing themes, and all themes were represented. This provided an exploratory qualitative alignment of contemporary authentic practice with the literature review synthesis. The research team (including the interviewer) then coded for indicators within each theme. The full list of indicators from the literature review and the interviewer were then collapsed to eliminate duplicate ideas. Interviews influenced the practice-oriented language used for the indicators.

The combined efforts of our literature review and interviews resulted in 42 possible indicators related to innovation grouped into nine clusters—*communication, creativity, exploration, flexibility, resourcefulness*, *implementation, iteration, synthesis*, and *vision* (Table 1)—to further conceptualize our framework. These clusters demonstrate the breadth of the innovation process and relevance of each subtask throughout the process of innovation.

4.2 Initial survey development and expert pilot

An initial survey was created based on the 42 possible indicators related to innovation that emerged from our literature review and expert interviews. Our survey design approach utilized task-specific self-efficacy items found in the literature as foundations for new items, following Bandura's guide for developing self-efficacy scales [70]. Three researchers first sorted through existing self-efficacy

Table 1. Outline of possible task-specific innovation-related clusters and indicators

Communication [7, 43, 55–56]
- Be persuasive—convince individuals of an idea.
- Express ideas—effectively communicate ideas through written and oral means.
- Express ideas visually—effective communication through visual means.
- Recruit supporters—build sponsorship for an idea and a coalition of supporters.
- Tell stories—craft and share information in an engaging and compelling way.

Creativity [33, 43, 55–56, 58–59]
- Be imaginative—have original or unique ideas.
- Have many ideas—come up with a large quantity of ideas.

Exploration [43, 60]
- Be aware—pay attention to what is happening, both locally and beyond.
- Listen—hear and process information.
- Observe—see and process information.
- Curiosity—willingness to question.

Flexibility [33, 61]
- Handle failure—recover and continue when faced with adversity.
- Handle complexity—deal with complex problems.
- Manage discontinuous activities—move between different projects, phases and activities.
- Have humility—recognize the inability to know everything.
- Work in multi-stage processes—function in the complexity of the process.

Implementation [33, 56–57]
- Work in an unstructured environment—manage work within loosely defined boundaries..
- Have intent—set goals and a pathway to reach that goal.
- Make decisions—choose how to proceed.
- Plan money—identify funding needed to complete a project.
- Plan time—identify time needed to complete a project.
- Follow through—take a concept from idea to reality.
- Be persistent—continue to approach problems despite setbacks or failures.
- Take risks—go against what is expected or safe.

Iteration [62–64]
- Prototype – physically represent an idea.
- Redesign—revisit solutions and ideas.
- Test proof of concept—assess ideas and artifacts for viability, feasibility and desirability.

Resourcefulness [14, 45, 55, 58, 65–67]
- Collaborate—work with others.
- Be interdisciplinary—work across different fields and disciplines.
- Know how to find/use help—effectively utilize people, tools, and other resources.
- Learn how to learn—identify gaps in knowledge and how to fill them.

Synthesis [45, 55, 57, 59, 63, 68–69]
- Abstract ideas—develop abstract frameworks and apply theoretical concepts.
- Find patterns—see themes in data.
- Make connections—find links within data.
- Think tangentially—draw parallels from unrelated concepts.
- Be empathetic—adopt and be sympathetic to others' viewpoints.
- Existing Knowledge—take ideas from the past and apply in new ways.

Vision [33, 57, 64]
- Act without social approval—pursue action without worry of social stigma.
- Identify need/problem—determine needs or problems.
- Identify small ideas for change—recognize possible innovations.
- Lead—take ownership.
- Question how things can be different—ask why

instruments to identify items with potential for inclusion or adaptation in a new measure of innovation self-efficacy. New items were created when needed. All three researchers reviewed and discussed existing items, adapted items, newly created items, confusions, inconsistencies, and questions. This work resulted in 285 possible task-specific self-efficacy items across the 42 indicators (see Example).

Example: Sample indicator with supplemental task-specific items.
Indicator*: Have Many Ideas*
Task-specific items:
- *"I have a lot of creative ideas"*
- *"I can think of many solutions to a problem"*

The initial 285 item survey was then tested using face validity [54]. Additional innovation expert participants were recruited to identify what was believed to be important and to obtain feedback on the items. A snowball recruitment approach was utilized starting with the authors' networks of senior professionals and academics and expanding to their additional contacts. A total of 22 experts completed the initial survey. Expert participants were asked to rate how important each indicator was to innovation on a 5-point Likert scale from *not at all important* to *extremely important*. Respondents were provided with a comment box for each item that allowed them to provide detailed feedback on the indicators and task-specific statements.

The indicators were subsequently analyzed regarding content and construct validity concerns [54, 71]. Results from the survey of indicator importance were used to explore which components to pursue in order to create a far shorter and much more manageable version of the Innovation Self-efficacy (ISE) Survey. Comments from participants were used to modify the indicators and their potential items in a way that addressed elements of confusion. We accounted for and revised our model when participants suggested changes. The preliminary criteria for inclusion in the pilot survey of innovation self-efficacy was that at least 90% of the participants believed the indicator was *important* or *extremely important* to innovation and the overall average rating across all experts was greater than 4.25 out of 5. This reduced the indicators to 18 with 75 accompanying items.

5. Testing with student samples

5.1 Pilot with engineering students

A student pilot survey was administered to 62 engineering students at a large state university. The survey asked students to rate their degree of confidence in their ability to do each of the remaining 75 tasks plus 4 new items. New items were created to ensure that each indicator was mapped to a minimum of 3 task-specific self-efficacy items on a 10-point Likert scale ranging from *zero—cannot do this at all to 100—highly certain can do* [72].

Exploratory factor analysis was conducted on items within each cluster or scale, which reduced the survey to 29 items. A test of reliability for each cluster using Cronbach's alpha was conducted to ensure values greater than 0.70 [73]; values ranged between 0.761–0.837. The results were presented as a work in progress at the 2012 Frontiers in Education Conference [39].

5.2 Large scale test across institutions

A large-scale analysis of engineering students was conducted to test the validity of the final remaining 29-item instrument (Appendix). The survey was administered to engineering students from multiple institutions, including public/private and large/small institutions across the United States. A sample of 619 students fully completed the survey.

Exploratory factor analysis revealed 8 factors aligning with the nine clusters (Table 2). The items previously grouped in the Flexibility cluster were merged with the items present in the Resourcefulness cluster as demonstrated by the factor analysis. All clusters consisted of three to six items. Factor loadings ranged from 0.715 to 0.899. Reliability for each factor ranged from a Cronbach's alpha of 0.743 to 0.864.

6. Discussion, limitations and future work

The goal of this study was to create and provide initial validity evidence to support a new instrument measuring the innovation self-efficacy of engineering students. A series of steps were undertaken to systematically design, develop, and test the new instrument. A mixed methods approach utilizing expert interviews, expert feedback and student responses lead to the current 29-item instrument seen in the Appendix.

The instrument has the potential be used as a pre-post test to evaluate the positive or negative impact an intervention designed to provide an innovation experience has on an individuals' judgment of their own innovation ability. Further testing of this new instrument is needed to better understand the sensitivity of the instrument's ability to reveal changes and to provide additional validity evidence.

We found that innovation self-efficacy is related to creativity and entrepreneurship self-efficacy yet remains a distinct construct. This is consistent with what we found in the literature on innovation [4], creativity [17, 41, 42], and entrepreneurship [16, 50, 51]. Creativity was one of eight factors in the

Table 2. 29 Item version of the ISE with exploratory factor analysis results (N = 619)

Factor	Item #	Factor Weight	Eigenvalue	Variance	Cronbach's Alpha
Creativity	6	0.899	2.360	79%	0.864
	12	0.863			
	26	0.899			
Exploration	1	0.760	2.447	61%	0.788
	8	0.779			
	18	0.815			
	29	0.773			
Iteration	9	0.808	2.188	73%	0.812
	22	0.884			
	27	0.868			
Implementation	7	0.715	2.466	62%	0.779
	13	0.744			
	21	0.843			
	24	0.831			
Communication	16	0.882	2.333	78%	0.856
	17	0.890			
	23	0.873			
Resourcefulness	3	0.736	3.529	59%	0.856
	14	0.784			
	15	0.749			
	19	0.742			
	20	0.814			
	28	0.773			
Synthesis	2	0.846	1.990	66%	0.743
	10	0.786			
	25	0.811			
Vision	4	0.836	1.994	66%	0.746
	5	0.804			
	11	0.806			

innovation self-efficacy measure. Factors of entrepreneurship self-efficacy including searching, marshaling, and implementing could be seen as closely related to four factors of innovation self-efficacy: exploration, implementation, resourcefulness, and communication. Flexibility is another closely related factor tied to entrepreneurship, which in our study was ultimately merged with Resourcefulness due to an inability to differentiate these two constructs. Vision, iteration, and synthesis appeared to be uniquely distinct factors in innovation self-efficacy.

The presented exploratory study is not without limitations. First, the diversity and size of our samples were limited during our initial steps. Expert innovators interviewed, and students included in the pilot testing came from universities characterized by their high commitment to innovation. This approach was taken because we found these institutions willing to readily participate and small deployments fit our iterative development and proof of concept process for identifying factors and their weightings. Recruiting and interviewing only expert innovators that identified as women was not an intentional step but may have provided a gender-biased perspective of innovation. Further interviews with expert innovators who identify as male will need to be undertaken to investigate any implications.

Second, our instrument development process is yet to be fully completed. A multi-phase validation process in line with recommended best practices requires that our next steps include conducting confirmatory factor analysis and an evaluation of convergent and divergent validity [72]. Completion of these steps will allow for future deployments of the instrument to include analyses that better understand the impact of personal (i.e., gender, expertise) and contextual factors (i.e., higher education, industry). Such studies may consider including populations with greater innovation experiences beyond those afforded an engineering student, seeking to understand the potential antecedents to innovation self-efficacy, and expanding beyond engineering to include business firms. These expansions will allow us to investigate correlations with job tenure, job self-efficacy, supervisor behavior, and job complexity [41], which can be used to differentiate between knowledge workers and manual laborers.

We would like to see additional future studies of innovation self-efficacy seeking to understand how the different dimensions relate to positions within or outside an organization. For example, do innovators within a firm differ on the eight dimensions of our instrument from innovators who work outside of a firm? It remains unclear if certain underlying dimensions are more important than others after an innovation is implemented. An expanded assessment of the impact each dimension has on innovation success would shine a light on the importance of each dimension identified in our instrument.

7. Conclusions and implications

The Innovation Self-Efficacy Measure (ISE) is a newly developed 29-item, 8 factor instrument designed to measure innovation self-efficacy. Our process utilized a literature review, expert interviews, and multiple pilot studies. The steps taken are important toward defining, refining, and standardizing assessment measures for innovation and builds on the growing number of task-specific self-efficacy instruments designed for use in engineering education contexts.

Innovation tasks are multidimensional and sequential by nature. Understanding how individuals gain confidence in their abilities to innovate is important to understanding how factors, such as synthesizing, iterating, and being resourceful, can attract nascent innovators to explore new opportunities.

We believe that widespread adoption of the instrument within engineering can enhance recruitment, preparation, and retention of students and employees. Such adoption would afford industry and academic leaders with the necessary data to ensure students are prepared and will be successful in their future engineering professions. We also envision this instrument having applications beyond engineering, since innovation is a task undertaken in many disciplines.

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Appendix: Innovation Self-Efficacy (ISE) Survey

Directions: Rate your degree of confidence that you can do each of the activities listed below on a scale from 0 (not at all confident) to 100 (extremely confident).

1. Understand the needs of people by listening to their stories.
2. Find connections between different fields of knowledge.
3. Seek out information from other disciplines to inform my own.
4. Identify opportunities for new products and/or processes.
5. Question practices that others think are satisfactory.
6. Come up with imaginative solutions.
7. Make risky choices to explore a new idea.
8. Consider the viewpoints of others/stakeholders.
9. Evaluate the success of a new idea.
10. Apply lessons from similar situations to a current problem of interest.
11. Envision how things can be better.
12. Do things in an original way.
13. Set clear goals for a project.
14. Troubleshoot problems.
15. Keep informed about new ideas (products, services, processes, etc.) in my field.
16. Communicate ideas clearly to others.
17. Provide compelling stories to share ideas.
18. Learn by observing how things in the world work.
19. Solve most problems if I invest the necessary effort.
20. Be resourceful when handling an unforeseen situation.
21. Suggest new ways to achieve goals or objectives.
22. Test new ideas and approaches to a problem.
23. Share what I have learned in an engaging and realistic way.
24. Make a decision based on available evidence and opinions.
25. Relate seemingly unrelated ideas to each other.
26. Think of new and creative ideas.
27. Model a new idea or solution.
28. Find new uses for existing methods or tools.
29. Explore and visualize how things work.

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