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Evaluation Of Current Assessment Methods In Engineering Entrepreneurship Education

ŞENAY PURZER

NICHOLAS FILA
Purdue University
West Lafayette, IN

AND

KAVIN NATARAJA
J. P. Morgan Chase
Chicago, IL

ABSTRACT

Quality assessment is an essential component of education that allows educators to support student learning and improve educational programs. The purpose of this study is to evaluate the current state of assessment in engineering entrepreneurship education. We identified 52 assessment instruments covered in 29 journal articles and conference proceedings that focused on engineering entrepreneurship. We evaluated these instruments using the unified theory of validity as a framework. Our analysis identified a variety of means through which entrepreneurial knowledge, skills, and attitudes are assessed in engineering. Self- or peer-report surveys, some of which were originally developed in business contexts, were the primary tool used for assessment. Another common tool was project deliverables. The assessment instruments often lacked features that can help differentiate levels of competencies and hence had limited utility for formative purposes. We argue that engineering entrepreneurship education would benefit from a system of assessment instruments designed through rigorous methods and developed to assess constructs specific to entrepreneurial engineering.

Key Words: Assessment, Entrepreneurial Engineering, literature Synthesis, Entrepreneurship Education

INTRODUCTION

Entrepreneurship education, especially with a focus on innovation, is an area of growing need and interest within engineering education [1–3]. Educators advocate for entrepreneurship education in engineering for diverse reasons. Some argue that preparing students for their careers in industry necessitates helping students develop entrepreneurship-related knowledge, skills, and attitudes to complement traditional engineering education competencies such as technical problem-solving [1,4,5]. Entrepreneurial engineers are expected to become leaders at the top of their organizations, to redefine markets, and to outperform their competition [6]. Others view entrepreneurial engineers as a driving force behind solutions to major technological problems and economic crises at both global and national levels [7,8]. Moreover, courses and programs with a focus on entrepreneurship can attract a diverse and exceptional student population to engineering programs [9,10], improve academic motivation and persistence in engineering [11], and inspire students to pursue their own entrepreneurial projects and ventures [12]. Regardless of differences in motivations, many educators desire entrepreneurial engineers, and believe academic courses and programs can help students develop into such engineers [1,6,13–15].

The trend towards developing new entrepreneurship courses and programs builds upon Standish-Kuon and Rice's [16] argument that entrepreneurial skills can be taught. Yet little research exists on the evaluation of student learning. We argue that high quality assessment instruments are needed in order to provide valid and reliable evaluation of engineering students' entrepreneurial development. While many programs use assessment instruments, the quality and diversity of these assessment instruments need to be determined.

The purpose of this study is twofold. First, we present the current state of assessment in engineering entrepreneurship education by synthesizing published assessment instruments compiled through a comprehensive literature review. This review helps identify the emphasis in literature and gaps in assessment. Second, we provide strategies to develop robust practices and research on assessment so that the gaps in engineering entrepreneurship can be addressed.

Need for Research on Assessment

Assessment has an important role in education. Quality assessment provides valid and reliable inferences that serve two critical purposes: to improve student learning (formative) and to improve curriculum, instruction, and programs (summative) [17]. Whether the purpose is formative or summative, the first step in assessment is developing a clear definition and understanding of what constitutes engineering entrepreneurship. Which types of knowledge and skills do students need? How can students demonstrate their competencies? What attitudes are essential for entrepreneurial engineers? The courses and entrepreneurship programs developed for engineering students as well as the assessment approaches used in relationship to these efforts provide some, often implicit, answers to these questions. Hence, our review provides not only an overview of the current state of assessment instruments but also a working definition of engineering entrepreneurship that we retrieved by analyzing the knowledge, skills, and attitudes that are emphasized in these efforts.

Current Status of Assessment in Entrepreneurial Engineering

Over the last ten years, three critical studies have evaluated the status of engineering entrepreneurship assessment [18-20]. The results of these studies find a dearth of high quality instruments in entrepreneurship, especially those that are directly relevant to engineering and can be used beyond the local classroom context. Duval-Couetil and her colleagues [19] note that a lack of consistency among engineering entrepreneurship courses and programs leads to difficulty generalizing assessment instruments to multiple contexts. They also note that many of the assessment instruments come directly from the management field rather than focusing on concepts unique to engineering entrepreneurship. Shartrand and her colleagues [20] further note that even within engineering-focused entrepreneurship education, the assessment of long-term impact, such as a program's effects on retention and post-graduation success is common, but the short-term evaluations needed to assess student learning and improve pedagogical practices have yet to reach a critical mass [20].

Among the short-term assessment instruments used in practice, many lack validity and reliability evidence necessary to support their usefulness and appropriateness. Besterfield-Sacre and colleagues [18], for example, surveyed 126 instructors (93 of which were in engineering disciplines) regarding the assessment methods used in their entrepreneurship courses. The results of this survey indicate a potentially large quantity and variety of available engineering entrepreneurship assessment instruments, but these assessment instruments are coupled with little evidence related to their effective use (e.g., reliability and validity). For example, only 40% of the instructors surveyed described evidence of validity. Further, among those instructors describing validity evidence, only 18% indicated validity outside their local context (e.g., use in industry or other institutions). It is therefore unclear whether these assessment instruments are generalizable to contexts beyond those in which they are employed, and whether they address the validity and reliability issues called for by Shartrand and colleagues [20].

Because assessment development is an on-going and iterative process, research in this area, especially in an emerging field like engineering entrepreneurship, is likely to be slow [21]. In fact, many fields lack sufficient research on assessment despite the critical role and potential benefits of assessment with appropriate use [22]. The paucity of assessment research and development, however, also highlights the opportunities we have to build a strong foundation as a community.

Framing the Study

In this study, we use a framework built on recommendations by a recent National Research Council (NRC) report on assessment [17] and Messick's unified theory of validity [23]. Our framework not only guides the evaluation of the current assessment methods but also provides a structure for filling the assessment gap.

The NRC report on assessment, led by James Pellegrino, states that assessment is a process of reasoning from evidence. The report also highlights that every assessment stands on three pillars: how students represent knowledge and develop skills, competencies, and attitudes; tasks or activities that allow us to observe these representations; and inferences on student learning that can be derived from these observations. Assessment instruments, therefore, should be developed in light of research and the best available understanding of how students develop competence in a domain and represent knowledge, skills, and attitudes. Only then can we be confident in our inferences on student learning.

Messick [23, pg. 13] defines validity as "an integrated evaluative judgment of the degree to which empirical evidence and theoretical rationales support the adequacy and appropriateness of inferences and actions based on test scores or other modes of measurement." According to his unified theory, aspects of validity previously viewed as separate forms of validity (such as content and criterion-related validity) are now considered as different facets of a single construct validity. In addition, Sireci [24, pg. 477] as well as Douglas and Purzer [21] outline fundamental aspects of validity that are often misunderstood:

- Validity is not a property of an assessment instrument; hence, an instrumentcannot be called valid. Rather, it refers to the interpretations driven from assessment results and their use for a particular purpose.
- Multiple sources of evidence should be presented to evaluate an assessment method's utility and appropriateness for a specific purpose.
- If an assessment instrument is to be used for a purpose different than what it is initially designed for sufficient evidence must be put forward to defend the use of the test for the new purpose.
- Validation is not a static, one-time event; but a continuous and iterative process.

As these researchers highlight, validity should be demonstrated in diverse ways. Empirical evidence necessary for establishing validity can take many forms. These can include content analyses through reviews by experts, focus group interviews, think aloud protocols with experts and novices, correlation studies showing the assessment's relationship to another variable identified by theory, factor analyses showing structure of the assessment, and pre- and post-test or group comparison studies demonstrating an expected difference [25]. The quality of an assessment depends on the quality of data and evidence derived from these methods. In addition, assessment instruments should have instructional sensitivity shown by their alignment with curriculum and instruction [26,27]. In summary, validation is accomplished by collecting evidence and making scientifically sound arguments to support the intended interpretation of assessment scores and their relevance to the proposed use [28].

While theories on validity are well established, applying theory to practice is a challenging task. To support practical application from theory, we translated critical aspects of validity theory to the context of engineering entrepreneurship education and developed a four-step process composed of a series of key questions that should be asked when developing assessment instruments (See

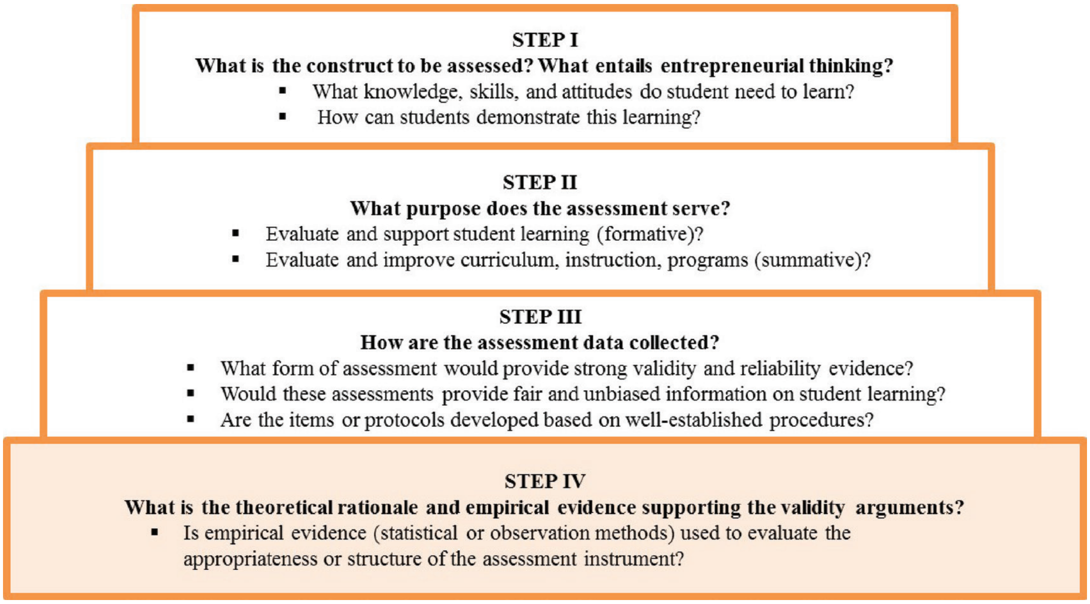

Figure 1. Four-step process for evaluating and designing assessment instruments.

Figure 1). More importantly, though, this model should help evaluate assessment tools and methods allowing educators to arrive at scores that are meaningful, useful, and appropriate for their selected purpose. A high quality assessment instrument would: 1) measure a clearly stated construct defined by clear and measurable learning objectives, 2) serve a purpose that can be formative or summative by design, 3) provide unbiased, reliable information on student learning, and 4) be accompanied with evidence supporting validity arguments.

The model outlined in Figure 1 starts with a first step of defining the construct (knowledge, skills, or attitudes) to be assessed. Previous studies and arguments on entrepreneurial thinking in engineering [29] can inform these decisions. The second step is determining the purpose of an assessment. These include formative purposes such as providing students feedback on their learning or summative purposes such as program evaluation. Next decision is the use of appropriate assessment instruments for evaluating given knowledge, skills, or attitudes. Finally, as a foundation to all previous steps, there should be justification that arguments made on student scores provide rationale for their use.

RESEARCH DESIGN

To evaluate the status of assessment in entrepreneurial engineering, we performed a search of the literature and conducted a content analysis on this literature. The following sections detail the literature search procedure, the sample of peer-reviewed journals and conference proceedings detailing assessment instruments, and our procedure for analyzing these data.

Selection of Assessment Instruments

Since the purpose of this study was to determine the current state of assessment in engineering entrepreneurship education, we focused our analysis on studies that were conducted in engineering education or with engineering students. Our literature search started by accessing four databases which include peer-reviewed publications on engineering education and entrepreneurship studies: ABI Inform/Complete, Business Source Premier, Compendex, and Web of Knowledge. We searched abstracts in these databases for the terms “engineer*”; “entrepreneur*”; and at least one of “assess*”, “measure*”, and “metric”. This search resulted in 396 journal articles and peer-reviewed conference publications. We reduced the sample to 105 articles by reviewing the content of each article’s abstract and removing articles that did not describe an assessment instrument or duplicated previous instruments. We then viewed the text of each article and evaluated whether the assessment instruments therein were described in sufficient detail and evaluated entrepreneurial development among engineering students. In the event that a paper described a previously developed assessment instrument, we identified the paper in which the assessment instrument was initially described and added it to the sample.

The literature search resulted in a sample of 29 articles that described 52 unique instruments or metrics to assess engineering entrepreneurship. The Appendix represents the article database. Although our search was extensive, a majority of the articles that made up our pool were conference proceedings from key engineering education conferences (59% of the sample). Twelve articles (41% of the sample) were published in journals that were equally distributed between business and engineering.

Data Analysis

We performed a content analysis of the final 29 articles and 52 assessment instruments with a goal of identifying key components of entrepreneurial activity in engineering classrooms and the validity of assessment in those contexts.

Content Analysis Coding Protocol

While the unified theory of validity guided the structure, Besterfield-Sacre and colleagues’ [18] descriptive study of the types of assessment instruments used by entrepreneurship instructors provided an initial classification scheme. This classification scheme contained five key categories: *type of assessment instrument/method*; *type of knowledge, skill, or attitude measured*; *(when)*

Category	Examples
Topic assessed	Leadership, risk-taking, communication
Dimension of topic assessed	Knowledge, skill, attitude
Purpose of assessment	Formative feedback, summative evaluation
Individuals assessed	Engineering students, capstone design teams, seniors in mechanical engineering
Type of assessment	Survey, business proposal, prototype, quiz
Evaluators/assessors	Faculty, student peers, self, industry professional
Reliability/validity evidence	Internal consistency, inter-rater reliability, group comparison

Table 1. Categories for Initial Coding Phase.

instrument/method was used; *(population) instrument/method used to evaluate*; and *focus of the instrument* (e.g., process or product). The scheme captured evidence on the instruments' use beyond the setting in which it was initially developed and employed.

We expanded the original classification scheme to include categories germane to our study (See Table 1). The *dimension of topic assessed* category was added to provide a more finely grained analysis of the topics assessed. For example, assessment instruments that evaluate attitudes towards business planning provide different information than assessment instruments that evaluate business planning skills such as need identification. The *purpose of assessment* category was added due to the importance of determining whether the assessment instrument was used for formative feedback or summative evaluation [17]. Further, the *validity* category was modified to include reliability evidence. We also excluded or modified categories such as the *when assessment is used* category as it had more to do with classroom logistics than content and strength of the assessment instrument.

During an initial coding phase, two researchers reviewed a subset of twenty assessment instruments in light of the initial coding categories described in Table 1. The researchers suggested new and revised codes whenever an aspect of an assessment instrument in the sample was not covered by the then-current coding scheme. The two researchers repeated this process iteratively, adding additional assessment instruments with each iteration, until they agreed on a final coding scheme that represented the extent of assessments reviewed. This final coding scheme is represented in Table 2.

The overall category structure of this coding scheme was different than the initial protocol in two ways. First, we removed the *individuals assessed* category. This category was unnecessary since each of the assessment instruments we identified was given to engineering students and a more finely grained analysis of assessment populations was beyond the scope of this study. Second, we added an *assessment context* category. This category emerged from the initial validity category (i.e., whether the instrument was used in other settings) as our new validity/reliability category

Category	Codes
Assessment context	General, Local
Assessment purpose	Formative, Summative
Assessment type	Concept Map, Essay, Interview, Observation, Project Deliverable, Quiz, Survey
Topic assessed	Business Planning, Business Realization, Communication, Design, Entrepreneurship General, Leadership, Professional Practice, Teamwork
Topic dimension assessed	Knowledge, Skill, Attitude
Validity evidence	Face Validity, Content Validity, Construct Validity, Reliability

Table 2. Final Coding Scheme.

focused on additional measures of reliability (such as internal consistency and inter-rater reliability) and validity (such as group comparison and expert review). Identifying the context for which the assessment was developed is important for determining the extent to which these instruments are disseminated and the ability to adapt their use to additional settings.

Once the coding protocol was established, one researcher reviewed the entire set of assessments and classified each assessment using the final coding scheme. A second researcher reviewed a sub-sample of 13 instruments (25% of the total sample), at an initial agreement level of 65%. The two researchers then met to discuss disagreements and clarify understanding of the coding scheme. A majority of the disagreements pertained to assessment instruments that registered multiple codes in one category. For example, one researcher initially coded "entreprepeneurship general" on instruments for which the other researcher coded multiple *topics assessed*. Once these issues were identified, the researchers reached 100% agreement on a sub-sample of 13 assessment instruments. The initial coder then recoded the remaining data based on the refined understanding of the coding scheme.

RESULTS

What is the Construct to Be Assessed? What Entails Entrepreneurial Knowledge, Skills, or Attitudesin Engineering?

In everyday language, and often in research literature, terms such as innovator, inventor, and entrepreneur are used interchangeably. According to theories of validity, the construct to be assessed should first be clearly defined and delimited [30]. Hence, before we attempt to assess student' competencies related to engineering entrepreneurship, we must explicitly define what construct or constructs comprise engineering entrepreneurship. Common methods used to establish construct definitions include expert consultations, interviews, and reviews of prior studies [31]. Here, we present patterns of agreement in defining engineering entrepreneurship retrieved from our review of the literature on assessment and curriculum development.

Definitions of the Entrepreneurial Engineer and Engineering Entrepreneurship

The construct of engineering entrepreneurship is discussed along three dimensions in the publications we reviewed: knowledge, skills, and attitudes (i.e., mindset). Knowledge refers to concepts students need to know and understand about engineering entrepreneurship. While entrepreneurial engineers are viewed as those who understand and promote entrepreneurship within companies [6], they are expected to have the knowledge of typical engineers as well as an understanding of economic and financial concepts [1,32]. More specifically, engineering entrepreneurs must demonstrate the math, science, and technical knowledge necessary to develop solutions to engineering and technical problems as well as knowledge of startup capital for new ventures, market forces, sales, intellectual property, and finance [7,29].

An engineering entrepreneur is also defined as one who organizes and manages the risk of an engineering business or enterprise [36]. They are required to have the skills to carry out or promote entrepreneurial ventures [35]. Noted skills of entrepreneurial engineers include the ability to create unique solutions to current problems [37], ability to create and carry out successful business ventures such as writing effective business plans [35], and ability to organize and manage projects and businesses [4,38].

The Kern Foundation's Engineering Entrepreneurship Network (KEEN) emphasizes the importance of mindset, stating that entrepreneurially minded engineers appreciate societal values of products they create and persist in an orientation towards customer needs [6]. Entrepreneurially minded engineers also have high entrepreneurial self-efficacy and show tendency towards risk-taking, persistence, autonomy, achievement, and leadership [33,34]. Entrepreneurial engineers are also called upon to demonstrate more general professional skills such as leadership, teamwork, and communication in addition to traditional technical skills [1,2,35].

Based on the literature then, a working definition of engineering entrepreneurship would be: *The knowledge, skills, and attitudes necessary to envision, lead, communicate, develop, and realize new technological and socially-sensitive processes and products in an established corporate setting or as part of a new venture.*

Frequency of Assessment Topics

The 52 assessment instruments demonstrated a broad range of topics applicable to engineering entrepreneurship that were consistent with the above literature. These topics, described in Table 3, represent

Category	Topic	Description
Business Aspect	Business Planning	Knowledge, skills, and attitudes necessary to begin new business ventures or projects, including identifying need areas and developing business plans.
	Business Realization	knowledge, skills, and attitudes necessary to promote the development of solutions and bring those solutions to market, particularly relating to core business concepts such as budgeting, finance, marketing, and human resources.
Engineering Aspect	Design	Ability to conceptualize and develop new and better solutions based on existing need areas.
Professional Aspect	Communication	Ability to communicate ideas and plans both in writing and orally through papers, presentations, and design/project reviews
	Leadership	Knowledge, skills, and attitudesrelated to setting the direction or scope of team projects or organizing/uniting a disparate team of people to work together effectively.
	Professional Practice	Awareness of and ability to deal with situations that may involve unethical practices or those that challenge some professional code or standard of conduct
	Teamwork	The ability of individuals or groups to function in or as a team. Knowledgeskills, and attitudesnecessary to function effectively.
General	Entrepreneurship General	A broad conceptualization of entrepreneurship without reference to any specific knowledgeskills, or attitudes.

Table 3. Entrepreneurship Topics Assessed in Literature.

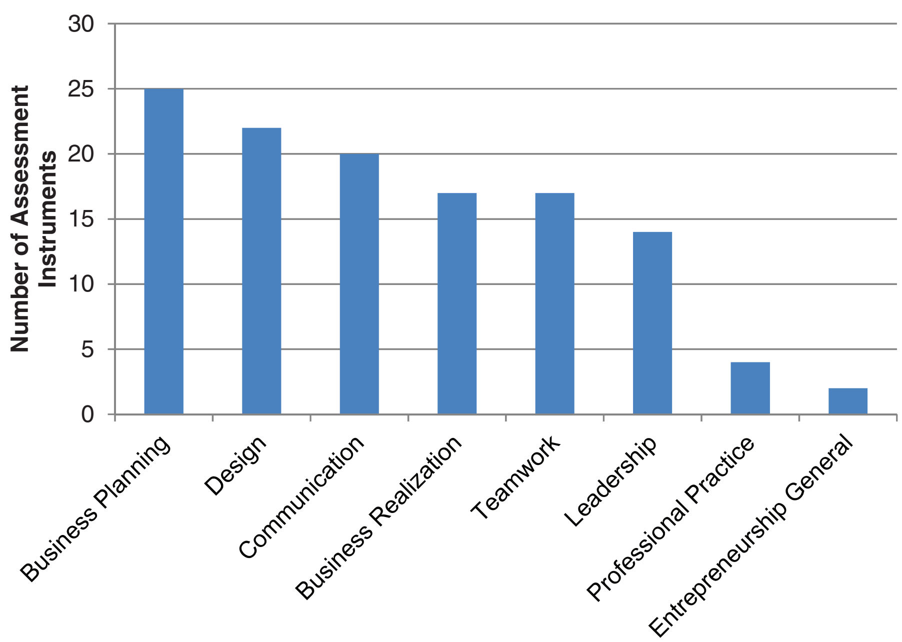

Figure 2. Frequency of Topics Assessed.

business-related aspects such as business planning, professional aspects such as communication, and engineering aspects such as design. As shown in Figure 2, *business planning* was the most frequently assessed topic (48% of assessment instruments). Other key topics were design (42%), communication (38%), business realization (33%), teamwork (33%), and leadership (27%). An interesting omission is consideration of technical engineering knowledge. While previous literature suggests that engineering entrepreneurs must have relevant technical knowledge in addition to business and social awareness, outside of design, the topics assessed align with a more general conceptions of entrepreneurship. There was no clear evidence that technical competencies were integrated with business competencies, although it is possible that technical competencies were assessed using different instruments.

Figure 3 presents the frequency with which each dimension of engineering entrepreneurship was assessed in the reviewed literature. It should be noted that some assessment instruments focused on multiple dimensions, thus values in Figure 3 will sum to greater than 52. The majority (65%) of the instruments focused on skill assessment. Only 29% of instruments assessed attitudes such as self-efficacy beliefs or entrepreneurial mindsets, and 21% assessed entrepreneurial knowledge. These differences are perhaps a result of the focus on project deliverables and self-report surveys, which tended to favor skill assessment. Previous literature demonstrates that self-efficacy, risk-taking, and customer orientation and knowledge of economics are also critical [19,33,34], thus the infrequency of knowledge and attitude assessments represents a gap in the literature.

Our analysis also included a more finely grained evaluation of the topics assessed within each of the three dimensions of assessment. Table 4 shows the joint occurrences of assessment topics and

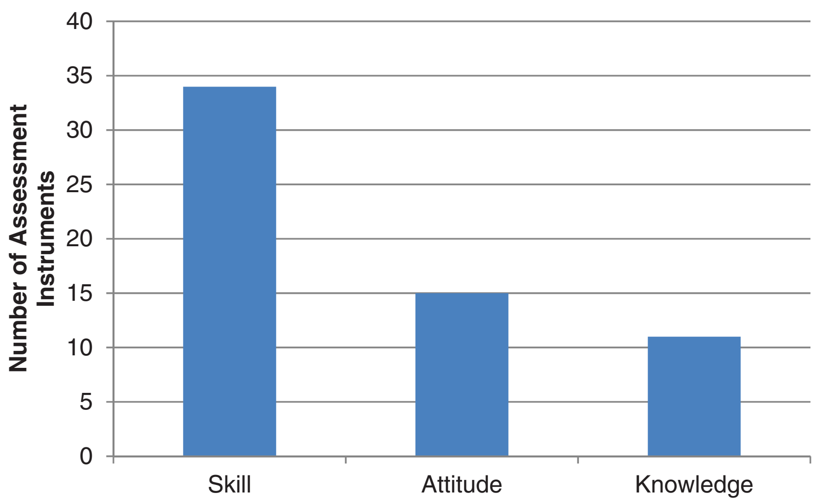

Figure 3. Frequency counts of topic dimensions assessed.

	Skill	Attitude	Knowledge
Business Planning	11	11	8
Business Realization	8	4	7
Design	14	7	3
Communication	18	3	2
Leadership	9	6	4
Professional Practice	2	1	2
Teamwork	14	4	2
Entrepreneurship General	0	2	0

Table 4. Distribution of entrepreneurship topics by assessment areas.

dimensions. It is important to note that some of the assessment instruments evaluated multiple topics, as well as topics across multiple dimensions (e.g., knowledge and skills), thus summing across rows and down columns provide larger values than suggested by Figures 2 and 3 respectively. The publications we reviewed covered a variety of topics ranging from design to leadership to business realization, demonstrating a complex categorization of the engineering entrepreneur (Figure 2). Table 4 demonstrates that the topics were assessed across the range of topic dimensions, but certain key topics were limited in at least one dimension. Design and teamwork, for example, were rarely assessed as knowledge. Communication was frequently assessed as a skill. The business-related aspects, however, were assessed almost uniformly as knowledge, skills, and attitudes. Since design, teamwork, and communication are more broadly applicable to engineering, the unequal distribution of assessments may reflect a unique emphasis on skills in these areas within engineering entrepreneurship. The focus on skills in those areas may demonstrate the importance of those skills, but may also represent an assessment gap to be considered in future assessment development.

What Purpose does the Assessment Serve?

Identifying the assessment purpose is an important step because an assessment instrument designed for a specific purpose or context may not be appropriate for use in a different context [17]. We found two dimensions of purpose used for entrepreneurship assessment (see Table 5). The first dimension, context of assessment, indicated whether an assessment was designed to be used in a single course or program (local context) or in a variety of contexts (general context). While assessment instruments designed for local contexts evaluated more precise constructs within local environments, assessment instruments for general constructs were more carefully developed and coupled with more reliability and validity evidence. The second dimension, feedback structure, indicated whether an assessment instrument was used to provide summative feedback, as in the

	Local Context	General Context	Total
Formative	5	none	5
Summative	26	13	39
Formative & Summative	8	none	8
Total	39	13	52

Table 5. Distribution of Local and General with Summative and Formative elements.

overall effect of an entrepreneurship program [39], or for the purpose of formative feedback to support student learning [40].

There are important differences between assessment instruments designed for formative or summative purposes. The former approach requires the development of instruments that would provide information on students' progressions in their competencies. These should go beyond pre-post assessment and employ milestones showing progressions of individuals or groups of students [17]. Summative assessment requires an evaluation of final outcomes or change, perhaps through pre-post assessment instruments. The key in designing these assessment instruments is ensuring the alignment of the assessment with the curriculum and instruction and an awareness of levels of transfer required between what is learned and what is expected to be demonstrated in an assessment [41].

The majority of assessment instruments were developed for local use and the most common purpose of these assessment instruments was summative evaluation. Forty-seven of the 52 assessment instruments (90%) were designed and used to evaluate student progress, individual courses, programs, and minors. Thirty-four of the forty-seven summative assessment instruments (72%) were developed in the local settings and were not intended for general distribution. Among the 13 summative assessment instruments developed for general contexts, seven were developed outside of an explicitly engineering context. Only 13 of 52 assessment instruments (26%) were designed for a formative purpose. This number includes eight instruments that provided feedback to both students and program administrators.

How are the Assessment Data Collected?

The analysis resulted in seven distinct types of assessment instruments used in both course and general contexts. Table 6 provides an overview of each of the seven types of assessment, their strengths and weaknesses. The frequency counts for each type of assessment are also presented in Figure 4. The two most popular assessment types were surveys—which included self or peer assessment of entrepreneurial skills, attitudes, and knowledge—and project deliverables—which included

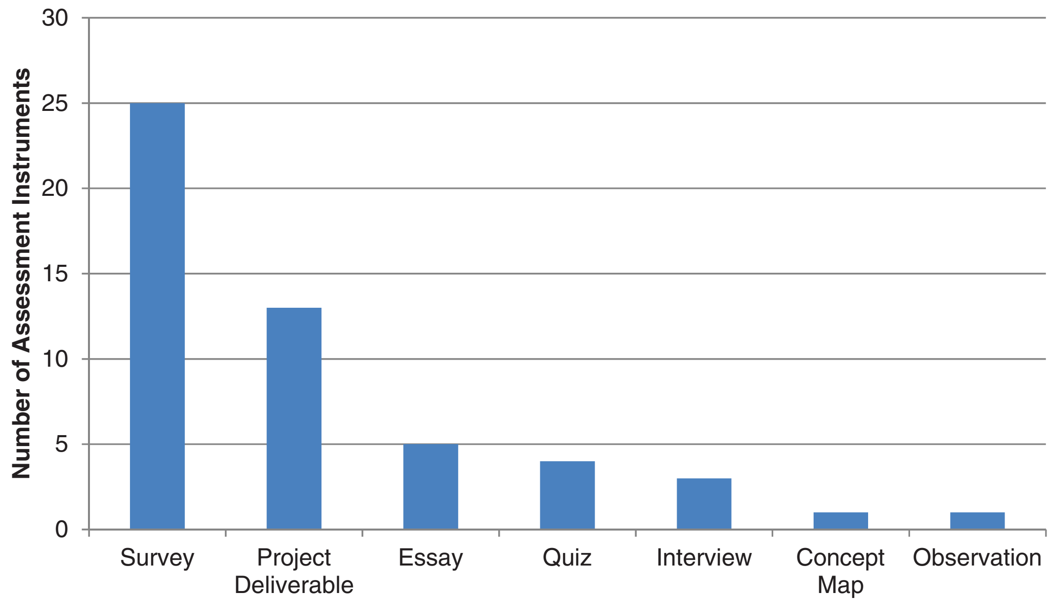

Figure 4. Frequency Counts of Assessment Types.

instructor or expert evaluation of student produced project reports, business plans, presentations, or design concepts/prototypes.

Surveys were the most common form of assessment (25 out of 52). Twenty-one of these were student self-report surveys. Some asked students to directly evaluate their own capabilities (e.g. [11]). Others asked students to group individual items into factors [19]. While these surveys are straightforward to develop, administer, and analyze, they are prone to self-report bias (i.e. students are not always accurate in assessing themselves). This effect seems to be stronger for constructs that are difficult to define or identify [42]. Peer evaluation surveys, which are also used for entrepreneurship skill assessment, are prone to similar biases [43,44].

Project deliverables were the second most common form of assessment (13 of 52 assessment instruments). These included reports or project artifacts—such as oral presentations, written reports, design prototypes or conceptual drawings, and written business plans—that were completed in fulfillment of a course project. Typically these were assessed by course instructors, members of industry, or combinations of the two. Assessment was occasionally guided by a rubric, but was often left to the judgment of the assessors. While project deliverables can represent greater authenticity they are often difficult to generalize to other contexts due to resources, assignment purpose, and subjective scoring.

Assessment Method	Strengths	Weaknesses	Best Suited to Evaluate	Used in Practice to Evaluate
Survey	• Validity evidence if provided • Straightforward to evaluate • Short administration time	• Self-report or teammate bias • Overused for assessing skills	• Attitudes	• Knowledge • Skills • Attitudes
Project Deliverable	• Classroom-embedded • Relies on expert judgment	• Potential for assessor bias	• Skills	• Skills
Essay	• Administration time can be short • Can produce detailed, open-ended responses • Can be based on or emulate authentic situations	• Evalaution can be labor intensive • Writing skills may obscure content	• Knowledge • Skills • Attitudes	• Knowledge • Skills • Attitudes
Quiz	• Short administration time • Easy to assess, can provide timely & specific feedback	• None were developed to measure competency • Typically designed for local contexts	• Knowledge	• Knowledge
Interview	• Allows depth and flexibility of responses	• Labor intensive • Time intensive"	• Knowledge • Attitudes	• Attitudes
Concept Map	• Short implementation time • Evaluates connections and deep understanding	• Evaluation can be labor intensive • Students may be unfamiliar with method	• Knowledge • Attitudes	• Knowledge
Observation	• Authentic context	• Evaluation can be labor intensive	• Skills	• Skills

Table 6. Engineering Entrepreneurship Assessment Methods.

Each tool and method has its own strengths and weaknesses. Table 6 provides the authors' comparison of these approaches, which is informed by prior work of Cross and Angelo [45] and Palombaand Banta [46] on various forms of assessment.

What is The Theoretical and Empirical Evidence Supporting the Validity Arguments?

The weakest aspect of a majority of assessment instruments was related to a lack of an explicit theoretical framework or research-based argument that guided their design. Many of the assessment instruments were developed to assess student learning in individual programs or courses and needed only be applied in local settings. As a result, assessment content was often guided by specific program or course needs. While it is possible that instruments and items therein were developed with theoretical frameworks or research-based arguments in mind, these were not evident in the written reports.

A handful of assessment instruments borrowed items from research-based general entrepreneurship assessment instruments such as Chen's *Entrepreneurship Self-Efficacy* instrument [47]. This instrument measures self-efficacy in entrepreneurial activities such as confidence in new venturing and new ideas, risk taking, and performing financial analysis [47, pg. 305].

It is crucial to identify elements of these more generalized surveys that are applicable to engineering entrepreneurship. Further, reliability and validity must be ensured for the modified survey as a whole and within the engineering student population.

Other researchers developed new surveys specifically to assess engineering entrepreneurship. Duval-Couetil and her colleagues developed an instrument, the *Engineering Entrepreneurship Survey,* using social cognitive theory [48] as a framework [1]. This instrument combined three formats including a five-point Likert scale self-assessment instrument of entrepreneurial knowledge, skills, attitudes, and awareness; a dichotomous (yes/no) self-assessment of entrepreneurial behaviors, and a ten-point measure of self-efficacy in entrepreneurial activities such as leading project teams and estimating project costs. Another survey, the *Entrepreneurship Knowledge Inventory* is based on extensive review of general and engineering entrepreneurship literature [7,20]. In this instrument, students are asked to assess their level of familiarity with a series of terms related to engineering entrepreneurship on a five-point scale as well as their level of participation in a series of entrepreneurship-related academic activities on a four-point scale. Further, the *Engineering Mindset Rubric* was developed based upon the framework presented in Covin and Slevin's [49] *Entrepreneurship Orientation Scale*. This instrument categorizes entrepreneurship along the themes of *product market innovation*, *proactiveness of decision-making*, and *risk taking* [20].

Only 10 of the 52 assessment instruments (19%) were coupled with direct evidence of validity (See Table 7). Among these, six were presented in papers focused on the development and validation of an assessment of engineering entrepreneurship [1,2,7,20,50,51]. An additional four of the 52 assessment instruments were borrowed or modified from instruments developed and validated in general business and entrepreneurship contexts [47,52–54].

The implementations of these ten assessment instruments in engineering education contexts show three key features of validation. First, validity can be demonstrated through a variety of means. Techniques used in these implementations include internal consistency, inter-rater reliability, group comparison, literature review, iterative development, participant review, expert review, and structural equation modeling. Validity contains multiple facets and thus a variety of techniques appropriate for the individual context should be utilized. Second, validation is an ongoing process. Validation techniques such as expert review, internal consistency, and group comparison not only demonstrate accurate and precise assessment of key constructs, but provide feedback for future improvements to the instruments. Finally, validity in one context does not guarantee validity in another context. The *General Enter-*

Assessment Name	Authors	Applications in Engineering Context	Reliability Evidence	Validity Evidence
Engineering Entrepreneurship Survey (EES)	Duval-Couetil, Reed-Rhoads, Haghighi (2012)	Concurrent implementation at three different schools by authors	Internal consistency: Cronbach's $\alpha \geq .80$ for all but one factor (.74 for other)	Expert review, group comparison, literature review, participant review
Entrepreneurial Intention Questionnaire	Liñán and Chen (2009)	Concurrent implementations at two schools (See [55])	Internal consistency: Cronbach's $\alpha > .70$ in engineering implementation	Literature review, structural equation modeling
Entrepreneurship Knowledge Inventory (EKI)*	Besterfield-Sacre, Robinson, Shuman, Shartrand, and Weilerstein (2012)	Concurrent implementation at 10 different schools by authors	Internal consistency: Cronbach's $\alpha \geq .90$ for all five factors	Expert review, group comparison
Entrepreneurship Mindset Rubric	Shartrand, Weilerstein, Besterfield-Sacre, Olds (2008)	Concurrent implementation at four different schools by authors	Inter-rater reliability: Cronbachs's $\alpha = .80$	Expert review
Entrepreneurship Self-Efficacy	Chen, Greene, and Crick (1998)	Three separate implementations at different schools (See [34,56,57])	Internal consistency (Cronbach's $\alpha = .92$ in single engineering implementation; Cronbach's $\alpha = .89$, .65-.86 on individual factors in original	Group comparison (in original paper)
General Enterprising Tendency	Caird (1991)	Two separate implementations at different schools (See [34,58])	Internal consistency: Cronbach's $\alpha = .42$ overall in engineering implementation	Group comparison
KEEN – TTI Performance DNA	Pistrui, Layer, and Dietrich (2012)	Concurrent implementation at 17 different schools and to 313 industry professionals by authors	Internal consistency: Cronbach $\alpha > .70$	Structural equation modeling – statistically significant path coefficient
Leadership Attitudes and Beliefs Scale	Wielkiewicz (2000)	Two separate implementations at different schools (See [34,56])	Internal consistency: (Cronbach's $\alpha = .82$ and .80 in separate engineering implementations	Group comparison
Leadership Self-Perception Instrument	Gerhardt, Carpenter, Grunow, Hayes (2010)	One implementation by authors	Internal consistency: Cronbach's $\alpha \geq .60$ for 74.3% of items; Cronbach's $\alpha \leq .70$ for 9.7% of items	Based on established survey questions, participant review
Survey of Entrepreneurial Intentions	Kuckertz and Wagner (2010)	One implementation by authors	Internal consistency: Cronbach's $\alpha \geq .64$ for all factors	Group comparison, iterative development, literature review

*Previously known as the NCIIA Entrepreneurship Inventory

Table 7. Assessment instruments with Reliability and Validity Evidence.

prising Tendency instrument, for example, did not translate well to an engineering education context as the instrument demonstrated poor internal consistency. Hence with each new implementation careful consideration of contextual differences and reevaluation of validity evidence are necessary.

DISCUSSION AND STRATEGIES FOR CLOSING THE ASSESSMENT GAP

Our analysis of the literature on engineering entrepreneurship resulted in two key findings. First, in agreement with previous similar analyses [18], we found a variety of purposes, methods, and forms used to assess engineering entrepreneurship knowledge, skills, and attitudes. However, these assessment instruments were not organized in a way that would provide systematic evaluation of curriculum and entrepreneurship programs. Nor did they completely align with conceptions of engineering entrepreneurship from the literature. Our analysis provides a structure and a set of taxonomies highlighting areas where there is significant emphasis and more work necessary. Potential gaps include limited emphasis on the assessment of knowledge, formative assessment, and novel forms of instruments that move beyond surveys or project deliverables.

Second, the quality of the assessment instruments varied. Two common issues were minimal description of instrument development processes and lack of evidence to support the validity of inferences derived from these instruments. Moreover, the publications we identified did not always differentiate engineering entrepreneurship from a general conception of entrepreneurship. While many professional and business-related competencies are considered critical for entrepreneurial engineers, it is often not clear what aspects of these competencies are unique to an entrepreneurial engineering endeavor. Such understanding is key, as we cannot assume that effective use in management or business contexts can translate well to engineering education contexts. Conversely, assessments often did not focus on technical competencies and thus do not demonstrate how these competencies can or should be integrated into entrepreneurial work. In light of these findings, we developed a set of recommendations and strategies on how to address them.

Developing a System of Entrepreneurship Assessment Instruments

As shown in our study and the previous literature, engineering entrepreneurship requires a variety of knowledge, skills, and attitudes; thus, it requires a variety of assessment techniques and foci [15,38,57,59]. As such, multiple forms of assessment instruments are needed to create a complete picture of one's entrepreneurial mindset and competencies [40,59]. It is unlikely that a single assessment can comprehensively capture one's engineering entrepreneurial abilities. Within the 29 papers we reviewed, we identified 52 unique assessment instruments. Engineering education would benefit from a system of instruments from which educators can select and to which researchers and educators can contribute new and revised instruments. This paper identified key gaps such as lack of knowledge and attitude assessments, especially in key topic areas such as design and communication; over-reliance on self-report surveys and project deliverables; and emphasis on summative rather than formative assessment. A first step in establishing the proposed system would be to explore the appropriateness of novel or underutilized assessment techniques and assessment instruments focusing on dimension-topic combinations (such as design knowledge and attitudes). Then assessment instruments to address gaps deemed as critical could be identified. In addition to addressing these gaps, researchers can collectively engage in research in effective use of assessment in diverse educational settings.

While identifying the variety of assessment instruments across the categories identified in this study may guide a comprehensive view of engineering entrepreneurship, it is important not to stress haphazard combinations of assessment instruments. Systems can easily become cumbersome, requiring a significant amount of time for students to complete and educators to analyze, and may include redundant or conflicting elements. Hence, a system of assessment instruments would need to be effective, complementary, and efficient and provide syntheses of existing elements. The design of an online database can facilitate these criteria as well as easy sharing and dissemination of assessment instruments [18].

Identifying Empirical Validity Evidence. Few publications presented validity evidence and thus it is difficult to determine whether they consistently measured the intended constructs. For example, only ten of the 52 assessment instruments included appropriate validity and reliability data. Validation studies can show that assessment instruments may vary in what they measure despite the initial conceptualization of the educator. For example, McGourty and his colleagues [40] developed and compared data from a series of assessment instruments. One of their findings was that conceptual understanding of the project realization process, assessed using a concept mapping task, did not match the understanding students demonstrated through other course projects.

In addition, the various ways in which engineering entrepreneurship is assessed show that engineering entrepreneurship is not viewed as a unified construct but composed of diverse knowledge, skills and attitudes. While we propose the need for a system of assessment instruments that together form a full definition of entrepreneurial competencies, we also argue for narrower (more focused) definitions and assessment instruments. For example, rather than designing an instrument on general communication skills, educators should identify and assess communication skills critical to engineering entrepreneurship. Effective assessment systems can only be built upon clear definitions that impart specific competencies. The KEEN – TTI Performance DNA is perhaps a step in this direction [29,59]. Assessment instruments that can provide evidence of validity and reliability are critical for the evaluation of student learning and or programs.

Utilizing Research & Theoretical Frameworks

Efforts to improve assessment would not be successful unless accompanied with research on student learning. Assessment instruments, especially those that can provide formative feedback, should be developed in light of studies that can help educators differentiate levels of competencies in engineering entrepreneurship. While limited, there are examples of such research. For example, Golish and colleagues [60] compared the project realization processes of industrial and academic innovators using a process mapping task. They found that industrial innovators placed stronger emphasis on creating customer value and market analysis than academic innovators. Academic innovators were more focused on feasibility analysis than industrial innovators. This finding suggests there are different approaches to innovation. Surveys that can measure students' tendencies towards an approach such as valuing customer needs (desirability), market opportunities (viability), or technical aspects (feasibility) can provide information on changes in their views.

Further, researchers might explore methods to classify individuals as novices, emerging experts, and experts in engineering entrepreneurship [61]. Research using think-aloud protocols can guide design of new assessment instruments [62]. Other research methods, such as concept map activities, observations of student teams, and case study responses present promising opportunities.

Engineering educators are invited to utilize the assessment framework in Figure 1 to guide the evaluation of existing assessment instruments or the design of new ones. This evaluation structure and subsequent analysis on the current literature helps provide an overview of current instruments and will help strengthen future work in entrepreneurship assessment in engineering.

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AUTHORS

Şenay Purzer is an Associate Professor in the School of Engineering Education. She is the recipient of a 2012 NSF CAREER award, which examines how engineering students approach innovation. She serves on the editorial boards of Science Education and the Journal of Pre-College Engineering Education (JPEER). She received a B.S.E with distinction in Engineering in 2009 and a B.S. degree in Physics Education in 1999. Her M.A. and Ph.D. degrees are in Science Education from Arizona State University earned in 2002 and 2008, respectively.

Nicholas D. Fila is a Ph.D. candidate in the School of Engineering Education at Purdue University. He earned a B.S.in Electrical Engineering and a M.S. in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign. His current research interests include innovation and its relationship to empathy and teamwork in engineering design.

Kavin M. Nataraja is a software developer at J.P. Morgan Chase. He earned a B.S. and M.S. in Computer Graphics Technology from Purdue University. His research interests include game based learning, energy education and sustainable energy. Kavin contributed to this paper as an undergraduate research assistant in the School of Engineering Education.

APPENDIX

Papers Describing Assessment Instruments for Engineering Entrepreneurship

1. Basu, Anuradha, and Minnie Patel. 2009. Experience of developing and assessing a case study for teaching engineering entrepreneurship at San Jose State University. Paper read at 2009 ASEE Annual Conference and Exposition, June 14, 2009 - June 17, 2009, at Austin, TX, United States.
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