

Rubric-Based Assessment of Entrepreneurial Minded Learning in Engineering Education: A Review*

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Existing literature of entrepreneurial mindset (EM) assessment has focused primarily on measuring psychological constructs, and little has been reported on other forms of assessing EM. A rubric – an explicit set of criteria to assess a particular type of performance – is an important tool to directly assess students' development of the entrepreneurial mindset. Despite the impact of rubrics on assessing and improving engineering entrepreneurship education, there is currently a lack of systematic examination of rubrics as assessment tools used in entrepreneurial programs in engineering education. To fill this gap, this paper explores rubric-based assessment of entrepreneurial minded learning (EML) by examining (1) the underlying pedagogical approaches, models, and theories that contextualize rubrics-based assessment, (2) elements of rubrics relevant to the assessment of EM-related learning outcomes, (3) the benefits and challenges of creating and implementing rubrics according to educators' reported use, and (4) the implications of using rubrics to promote EML. Several databases and both national and international journals were systematically searched for rubric-based assessment of EML. According to our inclusion and exclusion criteria, this paper selects and reviews 23 studies of this kind. The major finding of this systematic review is that rubrics may offer a promising platform of assessment for entrepreneurial minded learning in engineering.

Keywords: entrepreneurial minded learning; assessment; rubrics; engineering education; systematic review

1. Introduction

Engineering education has traditionally focused heavily on technical skills, but in the past two decades, an increasing number of engineering education programs have come to recognize that technical skills should be coupled with an entrepreneurial mindset so that engineers can create extraordinary value for employers and society. For example, 42 universities and colleges in the United States have joined the Kern Engineering Entrepreneurship Network (KEEN), a network “dedicated to preparing undergraduate engineering students for success with the entrepreneurial mindset” [1]. Students with an entrepreneurial mindset foster their own curiosity by making connections, creating value, developing strategies for effective communication, and embodying character traits that allow them to collaborate, pursue life-long learning, and practice as ethical engineers. Furthermore, entrepreneurial education for engineers has led to an emerging body of literature on assessing entrepreneurial minded learning (EML) in engineering programs.

Several systematic and critical reviews of entrepreneurial mindset (EM) assessment [2–5] have examined a broad spectrum of entrepreneurship education and the assessment of EM-related psy-

chological constructs. In contrast, relatively few studies [4, 6, 7] have discussed the effective use of rubrics and other methods of directly assessing EML. Through this review, we seek to fill this gap in the literature by promoting and improving the development and application of rubrics as a major tool for directly assessing EML in engineering.

This paper seeks to answer the following research questions:

- (1) What pedagogical approaches, models, and theories support the use of rubrics in assessing EML in engineering?
- (2) What EM related learning outcomes are currently being assessed by rubrics?
- (3) What are the benefits and challenges of creating and implementing rubrics for assessing EML in engineering?
- (4) As suggested by the literature reviewed, what are the implications of using rubrics to promote the entrepreneurial mindset?

2. Literature

2.1 Definition of Entrepreneurial Minded Learning (EML)

Entrepreneurial minded learning (EML) refers to “a pedagogical approach emphasizing discovery, opportunity identification, and value creation, while building on other active pedagogies such as

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problem-based learning” [8, p. 17]. In addition to delivering knowledge and skills of engineering to students, technical instruction is provided with opportunities to approach engineering problems and challenges by promoting curiosity, discovery, connection, and value creation. In order to do this, curriculum should be combined with an ‘entrepreneurial mindset.’ It should be noted that EML is not intended to be a business minor focusing on venture creation for engineering students [8].

2.2 EML in Engineering Education

Engineering educational institutions have introduced entrepreneurial education and developed the new EML programs [6, 9]. Different from business schools, engineering education has focused more on an entrepreneurial mindset beyond solely teaching engineering students to create ventures [10]. EML education can help engineering students generate economic and/or social value by applying their technical engineering knowledge and develop entrepreneurial mindsets that many established organizations and companies seek when they hire engineering graduates [8].

For these pedagogical and practical reasons, engineering educators have actively developed an EML community through engineering-specific entrepreneurship programs and courses, conference divisions (e.g., ASEE/Entrepreneurship Division, VentureWell Open), KEEN networks, and new journals (e.g., *Journal of Engineering Entrepreneurship* and *Entrepreneurship Education and Pedagogy*) [2]. With this scholarly effort in the engineering community, more engineering students have been exposed to EML in higher education; however, relatively little research has investigated the impact of an EML-infused education on engineering students’ learning outcomes or entrepreneurial mindsets [11].

2.3 Rubric-Based Assessment of Student Learning

(1) *Definition and Characteristics of Rubrics.* Assessment is based on student behaviors or products that demonstrate attainment of learning outcomes [12]. In particular, types of direct assessment include tests, assignments, activities/tasks, and portfolios. Carnasciali et al. [13] indicate that direct assessment is “tangible, visible and measurable, and provides more compelling evidence of student learning” [13, p. 2].

Scholars in general have defined a *rubric* as a scoring tool for artifacts with explicit and clear benchmarks of performance criteria [14–17]. Almarshoud [18] specifies a rubric as “a series of narrative statements describing the levels of performance . . . [and] a set of criteria and standards linked to learning outcomes that are used to assess a

student’s performance” [18, p. 861]. Reid and Cooney [16] describe five characteristics of effective rubrics:

- Language that is understandable to the learner and teacher;
- Terms which are clearly defined and measurable;
- Descriptors that encourage a ‘continuous improvement’ mindset;
- Avoiding double-barrel questions (i.e., questions composed of more than two separate issues or topics);
- Avoiding duplication of questions [16, p. 893]

According to Reid and Cooney [16], effective rubrics with these characteristics provide a method to assess student work and performance objectively and repeatedly, demonstrating “ease of use, clarity of criterion, and effective definition of levels of success” [16, p. 899].

Rubrics are mostly used for two ways of scoring student work: holistic and analytic. Holistic rubrics assess an overall impression of the student work in a less objective manner than analytic rubrics [19]. Holistic rubrics require simultaneous use of all criteria with a single score to assess the work as a whole [20]. Thus, the benefit of using holistic rubrics is efficiency with regard to scoring time, but not much specific feedback is offered to students. Due to this pitfall of holistic rubrics, analytic rubrics are more often used. Analytic rubrics provide a more objective way of assessing students’ strengths and weaknesses [19]. Analytic rubrics require separate scoring of each criterion, and a total score is aggregated from those individual scores [20]. The use of analytic rubrics can provide a clearer view of the elements where students have difficulties in completing the work. Bailey and Szabo [19] acknowledge that a disadvantage of using analytic rubrics for assessment is that student performances are assessed by ready-set standards developed according to teachers’ expectations about learning objectives, not reflecting on student outcome or achievement. Although analytic rubrics take longer to score, they clearly show the areas in which students are proficient or need work [21].

(2) *Using Rubrics in Higher Education.* Rubrics have widely been used and investigated in higher education. Reddy and Andrade [22] provided an overview of rubric use in higher education by identifying several themes: (1) student perceptions of rubric use, (2) instructor perceptions of rubric use, (3) academic performance along with rubrics, (4) rubrics for instructional and program assessments, and (5) validity and reliability of rubrics. Both students and instructors have positive attitudes of using rubrics [23–25]. Reddy and Andrade [22] introduced both positive and contrasting find-

ings in terms of academic performance. Rubric use showed some significant effects in different disciplines, such as Management of Business Information [26] and food preparation course [27], while Green and Bowser's [28] work presented no difference between scores of the master's thesis literature reviews with and without rubrics. Rubrics have been used for instructional and program assessments [29] to make improvements to courses and instruction.

Issues of validity and reliability are crucial but challenging to researchers and educators with regard to scoring rubrics [28, 30, 31]. Thus, Moskal and Leydens's [31] article illustrated definitions and issues of validity and reliability in the development of scoring rubrics. Overall, Reddy and Andrade's [22] review showed that rubrics serve instructional and evaluative purposes by providing feedback on student products and evaluating them.

(3) *Using Rubrics as an Assessment Tool in Engineering Education.* While rubrics have been used and investigated extensively in education in general [22], rubrics have been highlighted in engineering education fairly recently [14–19, 32–34]. Briedis [14] focuses on student professional outcomes, especially lifelong learning included in the ABET-designated Criterion 3: student outcomes. To develop effective assessment strategies, Briedis uses rubrics to assess professional skills, such as addressing the impact of engineering solutions in a global and societal context. Sindelar et al. [35] use rubrics to assess engineering students' abilities to resolve ethical dilemmas based on the ABET's accreditation criterion – to act in an ethically responsible manner. They employed a quasi-experimental design with case scenarios including ethical dilemmas and applied holistic scoring rubrics to students' written responses to assess their level of ethics learning in design projects. Bailey and Szabo [19] develop a tool to assess engineering design process knowledge with the use of an analytic scoring rubric based on Bloom's Taxonomy. Reid and Cooney [16] emphasize implementing rubrics as part of an assessment plan in engineering and engineering technology education. As meaningful assessment involves constructive feedback, the authors considered using rubrics as effective assessment practices by providing suggestive and consistent feedback to students [33]. Almarshoud [18] stresses developing a "rubric-based framework" for measuring the ABET outcomes as for a continuous improvement process of the learning outcomes. Barney et al. [32] conduct an experiment to evaluate the effect of rubrics and oral feedback on student learning outcomes in a software engineering course. In this study, rubrics were used as a self-assessment technique. The results showed that the

rubric-based self-assessment led to the improvement of learning outcomes and corresponding increase in student understanding of teachers' expectations [32]. McCormick et al. [34] also highlight the use of an analytic rubric to assess students' conceptual understanding of sustainable engineering.

In brief, rubrics have demonstrated their value in engineering education. Several studies used analytic rubrics to measure professional skills (e.g., the outcome of lifelong learning) connected to ABET outcomes. Engineering educators have acknowledged the importance of using rubrics and paid attention to their sophistication. Grounded in the existing literature, we examine how rubrics have been incorporated in assessing EML in engineering.

3. Method

3.1 Systematic Review Strategy

Systematic reviews have the potential to advance the field of engineering education by "uncovering patterns, connections, relationships, and trends across multiple studies" [36, p. 46]. Engineering education is an interdisciplinary field embracing a variety of disciplines (e.g., psychology, education, business); thus, it is crucial to develop foundational frameworks and progression by tracing up-to-date research trends and facilitate collaborations within and beyond engineering education.

Following pre-established methods used in conducting systematic literature reviews [36, 37], this review includes four steps: (1) search (to retrieve studies), (2) selection (to apply inclusion criteria), (3) coding (to evaluate the studies), and (4) synthesis (to analyze the results). We explored the literature databases by searching relevant studies from major journals of engineering education. Then, inclusion criteria were used in narrowing down the scope of articles for reviewing. A set of selected studies were coded and evaluated with emerging criteria. Finally, the results were synthesized to answer the research questions. To avoid duplicating previously published findings, we also compared our findings with other systematic or critical reviews of EML assessment [2, 5].

3.2 Inclusion Criteria and Search Strategy

To comprehensively retrieve studies that are of interest to the engineering education community, our inclusion criteria include peer-reviewed journal articles (including research and educational briefs) and conference proceeding papers focusing on EML assessment and evaluation, and more specifically, reporting of using rubrics to assess college level engineering students in the U.S. We searched several databases and journals for publications in

the last decade (2008–2020) due to the recent focus of EML in engineering education. We excluded non-research-based articles, such as editorials and book reviews, as well as studies conducted outside of the U.S. Duplicated articles were removed in the search stage. To increase the reliability of inclusion, we cross-checked the eligibility of the 23 articles included in the final analysis after two rounds of search and initial screening.

The key search terms included: (“entrepreneurial mindset” OR “entrepreneurial minded learning” OR “entrepreneurship”) AND “engineering education” AND (“assessment” OR “evaluation”). The search was conducted in major databases (Elsevier’s Scopus in Engineering, ERIC EBSCO in Education, Entrepreneurial Studies Source in Business, and Google Scholar) as well as national and international journals (*Advances in Engineering Education*, *Engineering Entrepreneurship Education*, *International Journal of Engineering Education*, *Journal of Engineering Education*, *Journal of Engineering Entrepreneurship*, and *Journal of Professional Issues in Engineering Education and Practice*). Another key term, “rubric/rubrics,” was searched later by reading the abstracts and full-texts. The search controlled the time frame of publications from 2008 to 2020 – a blooming era for studies of the entrepreneurial mindset. It should be noted that we also included related literature from Google Scholar from 2000 to 2020 for a broader scope of the field. In Advanced Search, all of the key search terms above were included in the function of “with all of the words.”

3.3 Selection

Titles and abstracts of the publications through the search procedure were screened for relevance of the research, and a total of 3,288 titles and abstracts were found. Studies were selected through two steps: (1) a broad scrutiny of a focus on entrepreneurial mindset assessment and evaluation; and (2) a specific scrutiny of a focus on the use of rubrics. During the first step, titles and abstracts were read in order to determine whether they contained relevant information of entrepreneurial mindset assessment and evaluation, and whether they met the inclusion criteria. In the second step, each article was read in order to establish a concrete set of review on rubrics of EML and extract the information of our interest for this review. 249 studies were selected through the broad scrutiny; then, 23 studies were selected after two rounds of selection processes as shown in Fig. 1.

3.4 Coding

To evaluate the articles selected according to the

inclusion criteria, each article was coded according to the research questions as the following:

- Constructs: entrepreneurial mindset, entrepreneurial minded learning, entrepreneurship;
- Context: participants, location;
- Foundation: pedagogical approaches, theories, frameworks, models;
- Rubrics: criteria, performance levels;
- Type of class: content, assignment types, teaching methods
- Rigor: validity, reliability;
- Implication: strengths, challenges, implications.

All the authors read the list of codes to verify information and checked if any of the details were not present in the text of the review. The authors discussed issues of agreement and disagreement at meetings on a regular basis.

4. Results

4.1 Pedagogical Approaches, Models, and Theories to Support Using Rubrics in Assessing EML in Engineering

In the exploration stage of EML, much attention has been paid to describing the development and creation of courses and programs in EML [38]. As developing new curriculum of EML is important, it is also critical to consider its evaluation and assessment in the cycle of education. Relevant existing approaches and theories provide a foundation of curriculum and instruction by solving important problems of classroom teaching and learning. With a relatively new effort of cultivating EML in engineering, programs models and pedagogical approaches are found to vary greatly [9]. In this regard, we should examine how engineering educators have made an effort to incorporate existing theories or approaches of teaching and learning into EML assessment. Huang-Saad et al.’s recent research review offered new insight of EM by making connections between learning theories and EML constructs, and we considered it a valid move to strengthen the foundation of EML assessment in engineering [2]. Therefore, we also strived to make connections to pedagogical approaches, models, and theories of using rubrics in EML in engineering as a way of establishing a robust grounding of using rubrics to assess EML in the engineering community.

In this review, we adopted the terms “approaches,” “models”, and “theories” with a recognition of their subtle distinctions in the literature. The term “approaches” indicates ways of delving into teaching and learning with procedural views [39, 40]. According to Celine [41], models can serve as a structure to formulate a theory or a tool

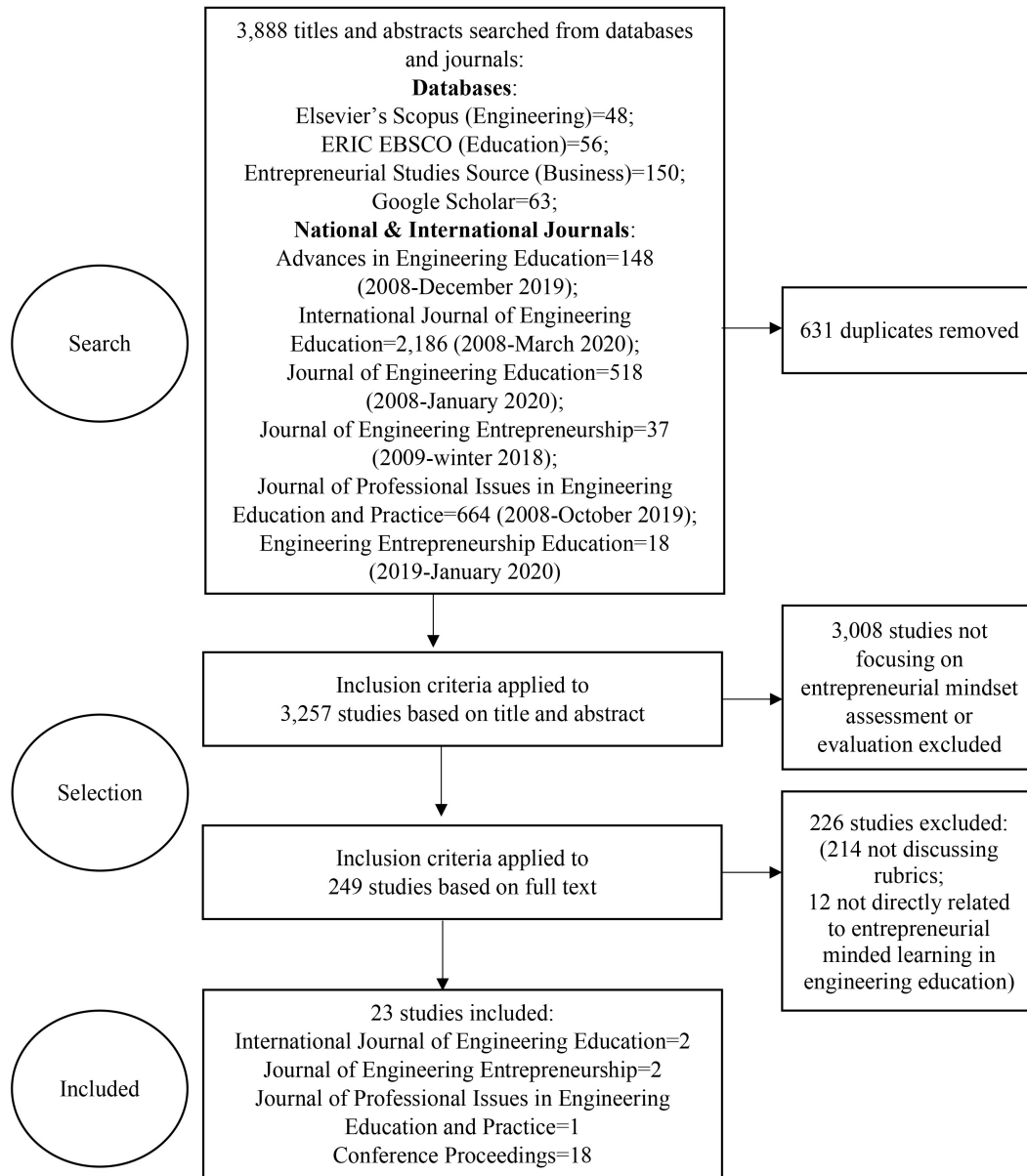


Fig. 1. Flow Chart of Search and Selection Process (Journal of Engineering Entrepreneurship has no longer been available since March 2020).

to verify theories. In comparison, theories are generalized statements to explain a phenomenon, and they can become a basis for creating models that reveal the possibilities of a subject [41]. Therefore, both models and theories provide possible accounts for natural phenomena or objects. In this review, we categorized pedagogical approaches, models, and theories as the authors have indicated in their studies.

Most studies we reviewed report their underlying pedagogical approaches, models, and theories connected to EML. In particular, Problem/Project-Based Learning and Active Collaborative Learning are the most frequently cited approaches that are connected to the use of rubrics. The use of rubrics

also appeared in studies that are based on theories about leadership, experiential learning, and social construction of knowledge. In addition, several studies created their own EML models that guide the assessment of an entrepreneurial mindset. In general, Problem/Project-Based Learning and Active Collaborative Learning have been considered particularly suitable for rubrics-based assessment, as these pedagogical approaches allow for a great depth of learning through all stages of the project design and collaboration [42]. For example, Liu et al. [44, 45] use rubrics in Problem-Based Learning to assess the quality of problem solutions in EML. Nezami et al.'s [53] study also connects rubric-based assessment of problem solving and

teamwork in contexts of Problem-Based Learning and Active Collaborative Learning.

Despite the fact that a variety of approaches, theories, and models were reported in most of the reviewed studies, few studies articulate how their underlying theories and pedagogical approaches inform their use of rubrics in assessment. Only six studies [6, 42–45, 53] made a connection between Problem-Based Learning and rubric use (i.e., a Problem-Based Learning Rubric). Kleine and Yoder [6] presented Entrepreneurial Mindset Program Development & Assessment Process Model as a rubric-based approach that EM is well-aligned with learning outcomes.

As a major underlying pedagogical approach, *Problem-Based Learning* was reported in six studies included in this review [42–45, 53]. With the emphasis on traditional teaching pedagogies (e.g., explicit instruction of engineering knowledge and skills), there has been a gap between the active nature of engineering practice and the passive classroom experience [47]. Currently, employers desire engineering students with an entrepreneurial mindset. To facilitate this paradigm shift in engineering teaching and learning, many engineering educators have turned to a problem-based learning approach to promote engineering students' entrepreneurial, creative, and critical thinking and to prepare them to become active and effective members of a global society [47]. Rubrics appear to be appropriate to capture the multiple learning outcomes that are often integrated in a problem-based learning environment where assignments and projects are developed with the rubric criteria and transformed from process-based to open-ended approaches [48].

Given that engineers need knowledge, skills, and attitudes beyond technical knowledge to be successful in a complex environment, Problem-Based Learning seems well-suited to prepare future engineers, as the five studies we reviewed indicate [42–45, 53]. Carpenter et al. [42] assess mechanical engineering students' problem-solving through design/build/test assignments using Problem-Based Learning Rubrics. Gerhart and Fletcher [43] also use Problem-Based Learning Rubrics to assess three student projects and compare instructor assessment results (based on rubrics) with student self-report (using a questionnaire). Their results indicate that the students were self-motivated in the engineering design process through Problem-Based Learning. Liu et al.'s [44, 45] studies apply problem-based learning approaches to mechanical engineering curriculum to foster the entrepreneurial mindset.

Project-based learning is closely connected to Problem-Based Learning. Shekar [49] describes pro-

ject-based learning as a comprehensive pedagogical approach to engage students in authentic problems. Project-based learning empowers students to become active learners engaged in hands-on activities and enhances student motivation and their adaptive expertise by applying theoretical knowledge into practice [49]. Palmer and Hall [50] explain a number of benefits of project-based learning for students, such as development of self-motivation, and experience of problem solving, authentic engineering problems, and professional practices. Many of these benefits are tightly linked learning outcomes that contribute to the development of an entrepreneurial mindset.

In this review, three studies [43, 51, 52] explicitly indicate incorporation of project-based learning, and all the projects reported in these studies involved engineering design. Design is considered one of the central functions of engineering practice [50]. Gerhart & Fletcher [43] emphasize the process of engineering design with eight steps. Hassan et al.'s [51] study presents a project to assess entrepreneurial outcomes: effective communication, critical thinking, and collaboration in teams. LeBlanc et al.'s [52] study was particularly interested in enhancing professional skills, such as communication, management, learning from failure, and problem solving. The studies imply that rubrics are practically useful in project-based learning.

Active Collaborative Learning (ACL) is another major pedagogical approach adopted by studies in this review. According to Prince [54], *active learning* involves instructional methods that engage students in meaningful learning activities and critical thinking. In comparison, *collaborative learning* focuses on working together in groups and enhances academic achievement, student attitudes, and retention [54]. Four studies included in this review [42, 53, 55] indicate the effectiveness of ACL. Carpenter et al. [42] suggest that ACL is an effective pedagogical approach to reinforce teamwork, communication, and critical thinking skills, and ultimately, to foster the entrepreneurial mindset along with customer awareness, social responsibility, project management, and business acumen. Two studies [53, 55] also emphasize ACL in accomplishing KEEN Student Outcomes (e.g., implementing curiosity, learning from failure, and applying creative thinking to problems) and empowering students as entrepreneurial minded engineers.

Ferguson et al. [56] suggest a number of other pedagogical models, including Wiggins and McTigue's Learning Outcome Model, Pelligrino's Assessment Triangle Model, and Perkins' Student Learning Activities Model, to redesign a course, Principles of Entrepreneurship, to focus more effec-

tively on student learning outcomes. Wiggins and McTigue’s model categorizes learning outcomes into three levels with varying importance: (1) enduring understandings, (2) important to know insights, and (3) good to know information. Pelligrino’s assessment triangle approach was used to assess entrepreneurial competencies in [56]. Perkins describes his approach as “learning by wholes” and expounds seven principles with a sports metaphor: (1) play the whole game; (2) make the game worth playing; (3) work on the hard parts; (4) play out of town; (5) uncover the hidden game; (6) learn from the team; and (7) learn the game of learning [57]. These learning experiences are integrated and reinforced in order to help engineering students acquire and retain the desired learning outcomes with entrepreneurship [56].

In addition to pedagogical approaches and models, several theories, i.e., experiential learning, leadership theory, and social construction of knowledge, were reported to support EML in engineering education. Ferguson et al. [56] employ pedagogical strategies grounded on Kolb’s learning cycle for experiential learning and social construction of knowledge. Leadership theory was introduced in [58], whose study explicates the entrepreneurial elements in *entrepreneurial leadership*, such as communication, teamwork, and problem solving skills important to careers in engineering and STEM fields.

Two studies of assessing EML cite the Bloom’s taxonomy [6, 56]. Ferguson et al. [56] use the Revised Bloom’s Taxonomy with six levels of cognitive difficulty ranging from remembering to creating/synthesizing. The authors chose at high cognitive levels (i.e., analyzing, evaluation, and creating) to assess entrepreneurial competencies [56].

Lastly, some engineering education researchers [6, 13] have developed their own models or frameworks that are aligned to the KEEN learning out-

comes. 63% of the studies (14 out of 22) in this review were engaged with KEEN, and these authors’ institutions have strived to meet the learning outcomes by initiating and implementing EML-focused models into the engineering curriculum. For example, Kleine and Yoder [6] developed an entrepreneurial mindset program development and assessment process model using a rubric-based approach. With the foundation of entrepreneurial mindset learning outcomes, rubrics play a major role in operationalizing the entrepreneurial mindset. Carnasciali et al. [13] propose an Entrepreneurial Mindset (EM) Learning Index to quantify EM learning outcomes from integrated e-learning modules.

In brief, the pedagogical approaches, theories, and models shown in Table 1 are foundational premises for the use of rubrics in EML assessment in the reviewed studies. The major forms of learning are Problem/Project-Based Learning and Active Collaborative Learning, which are aligned with EML learning outcomes.

4.2 Elements of Entrepreneurial Minded Learning Currently Being Assessed by Rubrics

Our strategy for investigating the EML-relevant elements of rubrics involved compiling and analyzing the criteria (e.g., design functionality, language mechanics, budget constraints) of rubrics used to assess EML. We chose rubric *criteria*, instead of other properties of rubrics (e.g., structure/format, method of creation), because the criteria capture what each rubric assesses, and they were readily available for most of the articles being reviewed. Throughout this section, the investigation process will be illustrated by the example of LeBlanc et al.’s [52] rubric for a written proposal, whose four criteria are as follows: Overall Quality of the Report, Deliverables Related to Manufacturability, Deliverables Related to Cost Estimate and Delivery, and Design Functionality.

Table 1. Pedagogical Approaches, Theories, and Models Used with Rubrics in EML Assessment

Pedagogical Approaches, Theories, and Models	Paper
Problem-Based Learning	[42, 43, 44, 45, 46, 53]
Project-Based Learning	[43, 51, 52]
Active Collaborative Learning	[42, 46, 53, 55]
Bloom’s Taxonomy	[6, 56]
Entrepreneurial Mindset (EM) Learning Index	[13]
Entrepreneurial Mindset Program Development & Assessment Process Model	[6]
Experiential Learning	[56]
Pelligrino’s Assessment Triangle Model	[56]
Perkins’s Student Learning Activities Model	[56]
Social Construction of Knowledge	[56]
Wiggins and McTigue’s Learning Outcome Model	[56]
Leadership Theory	[58]

Two additional considerations guided our analysis of the rubric criteria. First, we identified articles that specifically describe the use of rubrics in assessing EML. Next, we retrieved the articles that explicitly report the criteria for rubric-based assessment. Through this two-step process, we identified 16 articles for the rubric criteria analysis. Contained in these articles were 32 rubrics, with a total of 180 criteria.

While the rubrics were being compiled, some sets of criteria appeared, either identically or nearly identically, in more than one article. 51 replicated criteria were identified, leaving 129 unique rubric criteria. These replications were due, in some cases, to the articles referencing one another, or, in the other cases, to the authors of the articles otherwise sharing rubrics through institutional or professional networks. For instance, four studies [42–45] utilized a PBL rubric with the same criteria.

Once compiled through an inductive coding process, the unique criteria were each assigned to a category as follows: 33 to Technical Communication (26%), 30 to Content Knowledge and Problem Solving (23%), 17 to Collaboration (13%), 15 to Problem Identification and Value Creation (12%), 15 to Society (12%), and 11 to Finances (8%), where the percentage is the proportion of unique criteria assigned to that category. For example, LeBlanc et al.'s [52] rubric for written proposal contains criteria that belong to Technical Communication, Content Knowledge and Problem Solving, Finances, and Content Knowledge and Problem Solving, respective to the order of criteria listed earlier. Additionally, eight criteria in the articles we reviewed did not fall into any of these categories, and they were dissimilar enough from each other that none could reasonably constitute a new category. Thus, these eight criteria were left uncategorized. The proportion of unique criteria enveloped by each category is summarized in Table 2. These proportions include some takeaways regarding the nature of existing EML rubric criteria – for instance, that Technical Communication, despite not being one of the KEEN Framework's Three C's, is the most commonly assessed category of

unique EML rubric criteria. This could indicate that instructors have, in practice, identified and operationalized an important ability of entrepreneurial minded engineers – to effectively communicate technically-challenging ideas – which has not yet been emphasized in KEEN's theoretical framework. On the other hand, these rubrics lack explicit evaluation of curiosity and connections, two of the primary constructs emphasized by the KEEN framework.

Next, a coverage map (shown in Table 3) was created to describe the types of criteria in each of the 32 rubrics. A rubric “covers” a category if it contains at least one criterion that was classified into that category. For example, in the row for LeBlanc et al.'s [52] written proposal rubric, Technical Communication, Content Knowledge and Problem Solving, and Finances are marked because the rubric contains criteria that fit into those categories. The average number of categories covered by each rubric was 2.00 with standard deviation 0.94. In fact, no rubric covered more than three categories. This indicates that existing EML rubrics tend to assess a subset of student outcomes associated with EML. For instance, the six rubrics in [6] were each made to assess different aspects of the entrepreneurial mindset. The most covered category was Technical Communication, which was covered by 18 of the 32 rubrics, followed by Content Knowledge and Problem Solving, which was covered by 17.

4.3 Benefits and Challenges of Creating and Implementing Rubrics for Assessing EML in Engineering Education

While rubrics were an instrument used in all of the studies examined in this review, the benefits and challenges of their implementation were only explicitly discussed in a subset of these papers. Of the 23 papers included in this study, 12 directly discussed the benefits of rubric implementation and 5 discussed the difficulties, limitations, and challenges of doing so (see Table 4). For the purposes of this review, implied benefits and challenges were also recorded from the studied papers. The term “implied” is used to indicate that the papers did

Table 2. Proportion of Total Unique Criteria by Category

Category	# of Unique Criteria	Proportion of Unique Criteria
Technical Communication	33	26%
Content Knowledge and Problem Solving	30	23%
Collaboration	17	13%
Problem Identification and Value Creation	15	12%
Society	15	12%
Finances	11	8%
Uncategorized	8	6%
Total	129	100%

Table 3. Individual Rubric Coverage Map

Paper	Assignment/Project	Technical Communication	Content Knowledge & Problem Solving	Collaboration	Problem Identification & Value Creation	Society	Finances
[4]	Innovation Process Map Evaluation				X		X
[6]	Apply Critical and Creative Thinking to Ambiguous Problems	X	X		X		
[6]	Construct a Customer-Appropriate Value Proposition		X		X		
[6]	Demonstrate Voluntary Social Responsibility					X	
[6]	Effective Communication of a Customer-Appropriate Value Proposition	X					
[6]	Effectively Collaborate in a Team Setting			X			
[6]	Relate Personal Liberties and Free Enterprise to Entrepreneurship					X	
[13]	Thinking to Drive Innovation		X				
[38]	Entrepreneurial Mindset Rubric						X
[42]	PBL Rubric	X	X		X		
[43]	PBL Rubric	X	X		X		
[44]	PBL Rubric	X	X		X		
[45]	PBL Rubric	X	X		X		
[46]	Student Design Project	X	X				X
[48]	Apply Critical Thinking to Complex Problems	X	X		X		
[48]	Collaborate in a Team Setting			X			
[51]	Written Proposal	X	X				X
[51]	Poster	X					
[51]	Pitch	X					
[52]	Pitch	X	X				X
[52]	Poster	X					
[52]	Written Proposal	X	X				X
[56]	Assessing Entrepreneurial Competencies Reflection	X	X				
[56]	Idea Pitch Competition Presentation	X			X		X
[56]	Feasibility Analysis of a New Venture		X		X		X
[58]	Ropes Course		X	X			
[59]	Hands-on Project/ Research Experience	X	X		X		
[59]	Interdisciplinary Curriculum					X	
[59]	Entrepreneurship	X	X		X		
[59]	Global Dimension					X	
[59]	Service Learning					X	
[60]	Team Effectiveness			X			

not explicitly discuss the benefits or challenges of rubric implementation or creation, but that sections or comments made in the paper could corroborate their existence. Table 4 also uses “N/A” to indicate which studies did not implicitly or explicitly discuss these topics. This is not to say that this is an important discussion that was neglected in these studies, but that the works focused on topics irrelevant to this review.

According to the reviewed studies, the use of rubrics provides several benefits. Rubrics, in conjunction with other assessment tools, allow for researchers to create a comprehensive story that a single assessment tool would not be able to provide [58]. Studies also reported triangulating rubrics results with other assessment tools to provide more convincing evidence that their activities and

courses were making the impact that they desired [58, 61, 62].

Rubrics also enable the identification of student strengths and weaknesses [4, 7, 43, 58, 59]. Rubrics, along with other forms of direct assessment, provide a tangible and measurable way to classify student performance and what students have and have not learned [13, 59, 61]. Although rubrics are traditionally used to determine students’ mastery of content knowledge, they may also be used to quantify other characteristics or behaviors of students. For example, one study reported using rubrics as a form of blind assessment to indicate levels of students’ self-motivation [42]. In addition to assessing student performance, this data may also be used for evaluating the program – pinpointing areas of the course that need refinement, which

Table 4. Benefits and Challenges of Rubric Implementation Discussed

Paper	Explicit Benefits	Explicit Challenges	Implied Benefits	Implied Challenges
[4]	Students’ Strengths and Weaknesses	Reliability and Validity	N/A	Insufficient Alone
[6]	Enhances Uniformity Across Sections, Conveys Expectations to Students, Course and Assignment Development	N/A	N/A	Insufficient Alone
[7]	Sufficient IRR	Rubric Development/ Implementation	Easily Categorize Student Achievement	N/A
[13]	Direct Assessment (Strong Evidence)	N/A	N/A	Interrater Reliability
[38]	Reliable and Valid Assessment (High IRR)	Limited Scope	N/A	N/A
[42]	Indicates Students’ Self-Motivation	N/A	N/A	Misaligned Rubric Criteria
[43]	N/A	N/A	Student Achievement	N/A
[44]	N/A	N/A	N/A	N/A
[45]	N/A	N/A	N/A	N/A
[46]	N/A	N/A	Program Assessment	N/A
[48]	Course Assessment, Conveys Expectations to Students, Data Triangulation	N/A	N/A	N/A
[51]	N/A	N/A	N/A	N/A
[52]	N/A	N/A	N/A	N/A
[53]	N/A	N/A	N/A	N/A
[55]	Consistency Across Sections	Rubric Development	N/A	N/A
[56]	N/A	N/A	Represents Learning Goals, Works Students Through Difficult Problems	Rubric Development
[58]	Highlights Assignment and Student Strengths/ Weaknesses, Data Triangulation	N/A	N/A	Insufficient Alone
[59]	Highlights Assignment and Student Strengths/ Weaknesses	N/A	N/A	Interrater Reliability
[60]	N/A	N/A	N/A	N/A
[61]	Program Assessment and Improvement	Scaling	N/A	N/A
[62]	Demonstrate Learning Outcomes	N/A	Data Triangulation	N/A
[63]*	N/A	N/A	N/A	N/A
[64]	N/A	N/A	Program Development	N/A

* Note: Rubric was self-assessment for the implementation of KEEN at the college. Not applicable for this research question.

** IRR: inter-rater reliability.

in turn drives curriculum development and improvement [59].

Additionally, rubrics meet a need for assessment tools that can be applied to large groups of students with high reliability. While the development of rubrics may be time intensive and require the work of many individuals, the process pays off with rubrics that can be used for quick, consistent evaluation across instructors and graders [55]. According to several studies, rubrics have been found capable of displaying evidence of high inter-rater reliability [7, 38]. Rubrics also provide a form for standardizing courses by enhancing the uniformity of learning objectives and clearly conveying performance expectations to students [6, 48].

However, the implementation of rubrics is not without challenges. Scaling courses and their assessment rubrics to include multiple instructors and graders raises issues of rubric alignment, reliability, and different interpretations [61]. In order to accurately measure student outcomes and performance, rubrics need to be tailored to each course and assignment. Misaligned or poorly written rubrics may show unexpected trends, which allows for user subjectivity to influence scores, or otherwise inhibits successful implementation [7, 42]. Inter-rater reliability, while addressed in several studies, remains an issue that becomes more significant when applying rubrics on a larger scale [4, 13, 59].

Furthermore, rubrics alone are often not sufficient as an assessment tool. It was implied by several studies, and directly stated in one, that rubrics should be supplemented with additional assessment tools to effectively determine students' or programs' strengths and weaknesses [4, 6, 58]. Additionally, rubric results have a limited scope, and they may not be considered effective indicators of future performance or actions. It was noted that rubrics only measure students' entrepreneurial knowledge in a short timeframe, and future work is needed to determine if follow-up assessments and professional behaviors outside of the classroom are correlated to the results acquired from rubric-based assessment [38].

4.4 The Implications of Using Rubrics to Promote the Entrepreneurial Mindset from the Literature

Rubrics have demonstrated both positive effects and areas for improvement [42, 58, 59]. The reviewed studies discussed the implications of using rubrics to assess EML from different perspectives: students, faculty and instructors, and institutional programs.

First, rubrics allow for assessing students' entrepreneurial knowledge, skills, and performance associated with the entrepreneurial mindset. Rubrics as an assessment tool can be used to scaffold

student learning in ways that recognize and adapt to their varying level of cognitive ability, prior knowledge, and entrepreneurial skills [44, 45, 51, 56]. In particular, proper use of rubrics helps enhance students' implementation of and proficiency with the engineering design process [43]. Hence, it is important to develop rubrics as a pathway for exposing and equipping students with entrepreneurial knowledge [13]. It is also essential to consider whether rubrics provide future opportunities to enhance student performance of innovative thinking and open-ended problem solving [48] and support student development of entrepreneurial strategies and entrepreneurial ways of thinking [38].

Second, rubrics are also helpful in the professional development of faculty and instructors. Rubrics enable faculty to better understand teamwork, student motivation, communication, and student design in light of the entrepreneurial mindset [6, 42]. Kriewall [63] encourages faculty and university administration to speak with each other in the process of direct assessment and use the shared insights to inform pedagogical changes that will cultivate entrepreneurial mindset in engineering.

Third, many studies implied the use of rubrics for the development and improvement of program level curriculum and instruction. Rubric-based assessment of student performance provides important information for course or program evaluation and improvement [61, 64]. Rubrics can suggest better programmatic protocols and classroom practice (e.g., the creation of problem-based learning) [42] to meet program learning objectives [59] and to determine the effectiveness of courses and programs [6]. In particular, rubrics can be an adaptable and applicable assessment tool for the KEEN student outcomes [62].

While being helpful in promoting students' entrepreneurial minded learning, faculty professional development, and program level evaluation and improvement, researchers have also expressed concerns for the use of rubrics. Gerhart et al. [55] maintain that consistency between sections is critical, both in content delivery and in scoring. The rubric assessment needs to be implemented with a larger sample of students in order to provide evidence of reliability and validity [4]. In line with this recommendation, several studies [7, 13, 38] report the reliability of their own rubric instruments, particularly inter-rater reliability or agreement, in an attempt to make their rubric-based assessment more consistent and rigorous. Kleine and Yoder [6] assert that future work is necessary to refine and validate the rubrics, and they encourage faculty to employ rubrics and provide feedback on their experiences. Dancz et al. [59] also stress the importance of utilizing inter-rater reliability as best

practices to understand the impact of the evaluators on assessment results. Shartrand et al. [38] critique the lack of valid and reliable assessment tools in assessment literature and further discuss the expansion of different rubric-based approaches to engineering entrepreneurship education.

5. Discussion

This review contributes to educating entrepreneurial minded engineers by identifying pertinent literature sources and research strategies for assessing the impact of entrepreneurial pedagogy on student learning in engineering, a field that is growingly interested in cultivating entrepreneurial minded learning. In this article, we seek to understand the connection of theories in rubric use, the elements of rubrics, and the benefits, challenges, and implications of using rubrics in assessing EML. Our findings help enhance the development and application of rubrics in order to promote an entrepreneurial mindset in engineering. Our work also identifies areas for improvement as educators continue to apply best practices of assessing EM related learning outcomes in engineering.

First, approaches, theories, and models were addressed with two modes: (1) pedagogy (e.g., PBL and ACL) and (2) the rubric's operationalization of the entrepreneurial mindset (e.g., EM Learning Index). The results of underlying theories and approaches show that EML often takes place in the context of Problem/Project-Based Learning and Active Collaborative Learning. Given the open-ended tendencies in EML and in these active learning approaches, it is not surprising that engineering educators turn to these pedagogical approaches as preferred means to cultivate EML. However, it can be overlooked that the choice of assessment strategies should be carefully aligned with the pedagogical theories and approaches. The limited articulation of this alignment in the studies we reviewed here calls our attention to this important yet under-examined linkage. Another pattern that we found is that most rubrics do not sufficiently address theory. Some authors operationalized what they consider an entrepreneurial mindset and developed their own models and approaches. They are also valuable in innovating EML curriculum and instruction. However, as seen in this review, it should be noted that successful assessment of EML are grounded on underlying learning theories that inform the identification of evidence for learning. Therefore, we recommend more explicitly aligning rubrics with underlying theories of EML.

Second, technical communication, content knowledge, and problem solving are the most commonly-assessed criteria in existing rubrics for

EML. This is unsurprising, as they are easily measured and observable criteria in direct assessment. Additionally, collaboration and problem identification, as well as the social and financial aspects of EML, are also measured by rubrics, but are done so less commonly. In contrast, other EM related learning outcomes, such as curiosity and connections, were not explicitly assessed by the reviewed rubrics. This could reasonably be attributed to an increased difficulty in operationalization of less familiar and well assessed constructs, as compared to technical communication or content knowledge. That is, it may be more difficult to create rubric criteria that adequately assess a student's curiosity or connection-making ability. While curiosity in particular has been widely evaluated with indirect assessment tools, such as surveys of psychological constructs, such methods invite issues related to self-reporting, including possible discrepancy between students' perceptions of their performance and their actual performance. Our results strongly indicate that rubrics can be exploited in assessing a broad range of EML constructs, while also suggesting that theoretical frameworks of EM may need to be further detailed and elaborated.

Third, the validity and reliability of the rubrics in research have not received enough attention. Only four studies [7, 13, 38, 55] in this review addressed reliability issues, while very few among the other 18 studies report them explicitly. We recommend that future studies of rubric use should gather and carefully document evidence for validity (both "local" and "EM related" validity) and reliability, including inter-rater reliability and rater training. Another suggestion would be to increase reliability through the use of research-based work, such as Valid Assessment of Learning in Undergraduate Education (VALUE) rubrics [65]. VALUE is a campus-based assessment approach developed by AAC&U as part of its Liberal Education and America's Promise (LEAP) initiative. According to [65], VALUE rubrics are being used to assess student accomplishment of progressively advanced and integrative learning. Above all, the VALUE rubrics contain evidence of validity and reliability throughout the use of various colleges and universities. Engineering researchers have recently paid attention to incorporating the VALUE rubrics into the engineering courses to assess curiosity [66]. The models of EM may drive the decisions on using the VALUE rubrics. For example, if problem solving is a target construct in EML courses, Problem Solving VALUE Rubric can be an adequate source for the course developers by considering definition, framing language, and glossary, and the components of assessment rubrics – criteria, standards, and descriptors.

Several limitations confront this review. First, it was challenging to systematize categories of the rubric criteria in different studies. Although the reviewed studies all utilized rubrics to assess EML components, the criteria were distinctively described depending on instructional strategies and activities, which cannot be standardized due to the variation of rubrics. Second, in terms of publication selection, proceedings articles were dominant because of scarcity of published studies of using rubrics for assessing EML in engineering education journals. This indicates a need for more research on rubrics-based assessment in EML. We hope to see more empirical research in the use of rubrics for developing and implementing EML in engineering education.

6. Conclusion

The review finds that rubrics provide a promising form of assessment for EML in engineering. Incorporating rubrics may be challenging in light of the subjectivity of making ratings, non-uniformity in assessment implementation and faculty facilitation, and the intricacy of validating and refining rubrics. However, rubrics play a significant role in assessing EML components, such as value creation and collaboration, which requires a sophisticated human judgement. The paper recommends evidence-based findings to help researchers and educators in engineering education develop valid and reliable rubrics and to disseminate effective rubrics for assessing EML.

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