ENTREPRENEURSHIP IN ENGINEERING PROGRAMS: A METHODOLOGY FOR SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Understanding and implementing educational approaches that integrate entrepreneurship and innovation in engineering education (CDIO Syllabus 4.1, 4.2, 5.2) plays a pivotal role as part of Technical University of Catalonia's (UPC) core strategic plan for the upcoming years. In engineering programs, educational models have evolved from teacher-guided to more "real world", challenged-based practical approaches (CDIO Standard 5) which increases the likelihood of engineering students becoming entrepreneurs. Scholarly research that assesses the validity of these new pedagogical models or that measures entrepreneurial throughput in a country is constantly growing, which makes staying up-to-date with relevant academic work an arduous task. Moreover, several systematic reviews have highlighted the shortcomings of traditional methodologies to synthesise primary studies in engineering education in this regard. We put forward a three-step methodology using mining techniques and statistical software that allows for a more refined identification of papers, with two improvements for a systematic review: 1) automatically identifying extended keywords and 2) ensuring relevant studies are not discarded, with a second iteration. We tested this methodology with literature of the last three decades, with a focus on papers that measure outcomes in engineering education. The initial results of our study revealed that surveys are the predominant measurement tool utilised to assess entrepreneurial skills, traits, intention, or mindset. However, there is a lack of agreement in the existing literature on the definitions of these terms. Furthermore, these initial results suggest the need for additional methods of measuring outcomes in Engineering Entrepreneurship programs.

KEYWORDS

Engineering Education, Entrepreneurship, Systematic Review, Outcomes Measurement, Standards: 5,12

INTRODUCTION

The integration of entrepreneurship and innovation within the realm of engineering education in higher education institutions worldwide is receiving much attention lately. As the field of engineering education continues to evolve towards more practical, implementing more real-world pedagogical approaches, it becomes increasingly important to comprehend and integrate models that foster entrepreneurial mindsets among undergraduate and graduate students. Scholarly research that assesses the validity of these new educational models or that measures

entrepreneurial throughput in a country is constantly growing, which makes staying up-to-date with relevant academic work an arduous task. Moreover, several systematic reviews have highlighted the shortcomings of traditional methodologies to synthesise primary studies in engineering education.

In the CDIO knowledge library, there are several papers about approaches to promote innovation and entrepreneurship skills in engineering graduates; some of these papers describe long term actions and include measurement indexes as improvement of the employment rate (Kallio-Gerlander, Puhakainen, & Kettunen, 2013) or describe the results of several initiatives (Hallenga-Brink, 2017). Bibliometric studies have also been performed in the CDIO community. Meikleham, Hugo, and Aldert (2018) visualised the evolution of CDIO influence in the field of engineering education since 2000 including the journals and conference proceedings available in Scopus and Web of Science. Malmqvist, Machado, Meikleham, and Hugo (2019) analysed the historical and geographical trends over time of the conference paper publications available in the CDIO Knowledge Library which are, however, not included in Scopus and Web of Science.

The goal of this paper is to propose a three-step methodology that builds on top of traditional methodologies for systematic literature reviews in engineering education (Borrego, Foster, & Froyd, 2014). We use this methodology to cluster and identify studies from two different databases that evaluate the outcomes of entrepreneurship education in engineering studies and to explore the ways in which these outcomes measurement methods are conducted (e.g. surveys). We make use of text mining techniques and statistical software that allows for a more refined identification of papers, with two improvements for a systematic review: 1) automatically identifying extended keywords and 2) ensuring relevant studies are not discarded, with a second iteration. We tested this methodology with literature of the last three decades, with a focus on papers that measure outcomes in engineering education when there are entrepreneurship and innovation programs in place. This approach allowed us to identify the fundamental theories, themes, and constructs used in prior research, and also to examine how the research design and the tool selected shapes the interpretation of the value of entrepreneurship education and the research findings. In addition, it also allows us to better understand the ways in which entrepreneurship education has been evaluated and the potential limitations and biases present in the existing literature.

LITERATURE REVIEW

In this section, we examine the different methodologies employed in previous systematic reviews on the topic entrepreneurship in engineering. This review includes literature from the field of engineering education as well as literature that pertains to novel approaches in performing systematic searches.

The first study that is relevant for the present study is Borrego et al. (2014). In their systematic review of systematic reviews in engineering education, they proposed a step by step methodology for conducting reviews in this area by adapting procedures that were initially designed for other disciplines. Their methodology has been widely applied in the recent literature and has, as well, served as inspiration to our methodology. Huang-Saad, Morton, and Libarkin (2018) also used this approach to conduct a systematic literature review examining the state of the art in engineering entrepreneurship education in 2018. The scope of their review was broader than the

present study, as it included disciplines beyond Engineering, however. According to the authors "outcomes are often not aligned with engineering outcomes, or assessment instruments have shown to be invalid for engineering students" which calls for a reevalution of these assessment practices in engineering (Huang-Saad et al., 2018, p.284). Similarly, Cruz, Saunders-Smits, and Groen (2020) conducted a systematic review focusing on the state of the art in competency measurement methods for assessing Engineering students' mastery of skills such as innovation/creativity, communication, lifelong learning, and teamwork in higher education. Although their review was specific to engineering education, it was not limited to entrepreneurship and innovation assessment. They identified measurement tools used by educators and researchers which lacked validity and that called for more standardised methods. The last study that is relevant for our paper is Grames, Stillman, Tingley, and Elphick (2019), who conducted scientific literature review using a reproducible method that employs text mining techniques to avoid bias in the search strategy and ensure the inclusion of all relevant keywords. This method, however, was tested in the fields of ecology, evolution, conservation biology, and related disciplines, but not in engineering education to the best of our knowledge.

In recent years, the methodology for conducting systematic literature reviews within the field of engineering education has gained significant attention and undergone significant refinement, although it remains in its nascent stage (Borrego et al., 2014). The present study departs from traditional methodologies in order to conduct a more comprehensive examination of the existing literature pertaining to a specific topic (i.e. outcomes measurement methods) within engineering education. The current study aims to identify various measurement methods in engineering education and evaluate the entrepreneurial activity reported in the existing literature using a new search methodology. To guide this review, the following research question is formulated: Does the three-step methodology proposed in this study enable the identification of relevant publications on entrepreneurship in engineering education that may be overlooked by traditional search methods?

METHODOLOGY

As has been shown, systematic literature reviews and their associated methodology have acquired widespread acceptance and the numerous publications in the literature have made significant contributions to further research on assessing the outcomes of entrepreneurship and/or innovation programs or subjects in engineering programs. However, these reviews can sometimes struggle to keep pace with the rapid progress of research in this area. To address this challenge, new approaches that partially automate the process through the use of text mining techniques may increase efficiency and reduce the time and resource costs associated with conducting such reviews. In the following paragraphs we provide a detailed description of the three-steps methodology proposed, taking Borrego et al. (2014)'s methodology as a foundation and adapting Grames et al. (2019)'s mining techniques to engineering education; we also added semantic analysis and used a statistical software to make sure the search identified all the studies that were relevant for our purposes.

The starting point for our naive search was a combination of different keywords we would expect to find in the title, abstract or authors' keywords in all the studies included in our systematic literature review. We ran our initial search query in two databases: Scopus (primarily focused on indexing science, technology, medicine, humanities, social sciences and art publications)

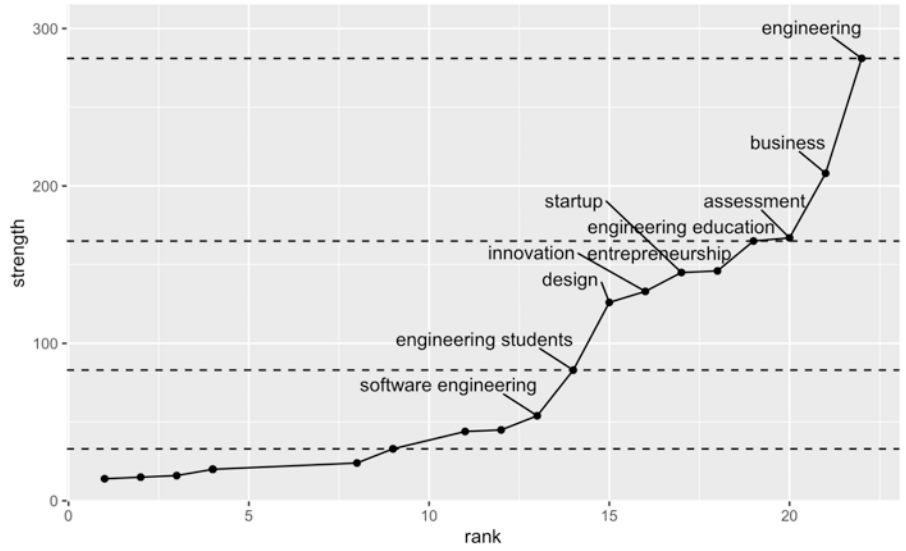

Figure 1. Strength of the top keywords found on first naive search.

and Web of Science (primarily focused on indexing social sciences, humanities and art publications). As a result, 64 and 17 studies were identified on each database respectively with 12 duplicates, after querying for ”engineering education”, ”measure / assess / evaluate”, ”innovation / entrepreneurship, and ”start-up”. We subsequently searched for potential keywords, in title, abstracts and also considering authors' keywords. After applying semantic analysis techniques that included removing stopwords and tokenising terms, not only considering single words but also bigrams and trigrams, we ranked them based on their strength. In other words, we ranked each term in the network based on the number of other terms that it appears together with; that is, the more strength a term has, the more interesting to be included in a new search query. Our results are displayed in Figure 1 where only the top terms are labeled, together with different change points using dashed lines representing where there is a greater difference between contiguous values.

Expanded search: step one

After conducting a thorough review of the previous research found, we identified three additional key terms, namely ”business”, ”design”, and ”engineering students”, that were not included in our initial query. As a result, we added these terms to our query and grouped them as follows: *(”engineering education” OR ”engineering students”) AND (measure* OR assess* OR evaluate* OR design*) AND (innovat* AND entrepreneur*) AND (start-up* OR business*)*. On January 10th, 2022, we performed the last search utilising Scopus and Web of Science and identified a total of 1010 and 279 citations, respectively. Upon removing duplicates, we were left with a final pool of 1137 citations to be screened. It is important to note that our search was limited to English language publications in journals and conference proceedings which are indexed in the mentioned databases, with no restriction on publication year; they were all published in the last three decades, however.

Screening: step two

The next step involved a screening process to determine the final sample of publications for examination in the present study. To achieve this, we established a set of inclusion criteria for publications to be considered in our final sample. Firstly, we only included publications that focused specifically on engineering students in formal higher education institutions. As such, publications discussing broader, non-specific programs or institutions were excluded, as were publications discussing alumni or students at lower education levels. Additionally, publications not strictly related to engineering education were also excluded, as they often encompassed other types of higher education programs such as business studies. Finally, publications involving actual business stakeholders in the entrepreneurship or innovation programs were excluded to limit the present study to situations where engineering students are solely responsible for the business idea and not just contributing from a technical standpoint. Secondly, we included all publications that described the implementation of entrepreneurship and/or innovation programs aimed at providing engineering students with the necessary competencies for entrepreneurship and innovation. Specifically, only intervention studies were considered while characterisation studies were excluded. Additionally, publications that only examined a particular skill or knowledge such as Agile Development, Design Thinking or Project Management were not considered, as well as publications that did not describe any intervention on entrepreneurship or innovation programs at a higher education institution since they centered their study on assessing entrepreneurial mindset or intent using variables such as gender, social background, type of engineering, or student grades among others.

In order to establish the final sample of publications for examination in the present study, a thorough screening process was employed. This process entailed a comprehensive evaluation of the title, abstract, and authors' keywords (when available) of each publication. Additionally, a semantic analysis was conducted to identify relevant keywords in context. To aid in this process, R programming language was utilised to extract keywords through the utilisation of techniques such as stemming, stopword removal, and keyword combination. As a result of this screening process, a final list of 183 publications were selected for analysis in the subsequent sections of the study. Upon completion of the screening process, the final sample of publications to be analysed was grouped and presented per publication year in Figure 2. A visual examination of this figure reveals a higher representation of the targeted publications within the most recent 5-10 year period.

Network analysis: step three

In order to identify potential relevant papers that were either discarded during the screening process or were not identified in the final query across the previously mentioned databases, we conducted the final portion of the methodology using the 183 publications obtained. Upon verifying the availability of Digital Object Identifiers (DOIs) via lens.org, we found that only 120 of the citations had DOIs. utilising the R package developed by Haddaway, Grainger, and Gray (2022), we extracted both the publications that were referenced in our bibliography and those publications that cited our bibliography. The resulting network visualisation of publications with frequency greater than or equal to five, as depicted in Figure 3, illustrates the size of the node being directly proportional to the number of citations the publication has received, and distinguishes between references represented in red and citations represented in blue.

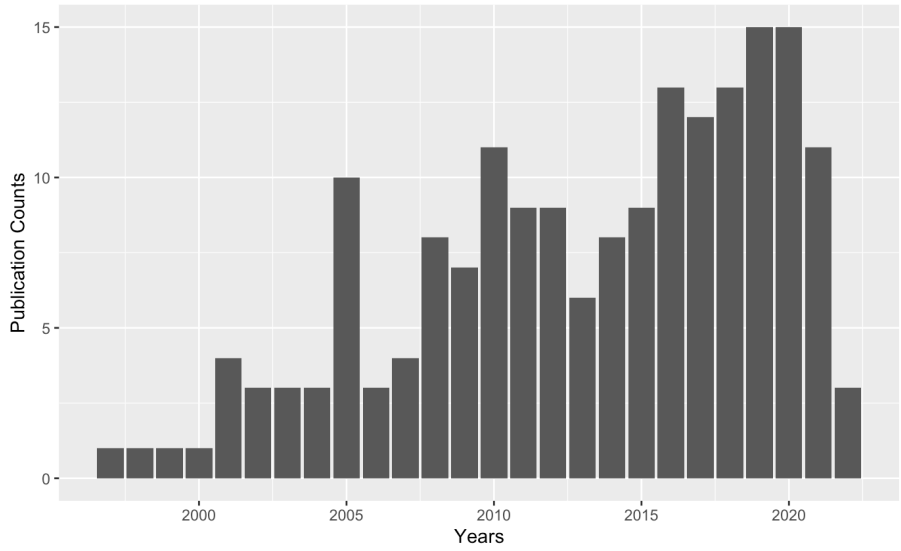

Figure 2. Screened publications (n=183) subject to analysis, grouped per publication year.

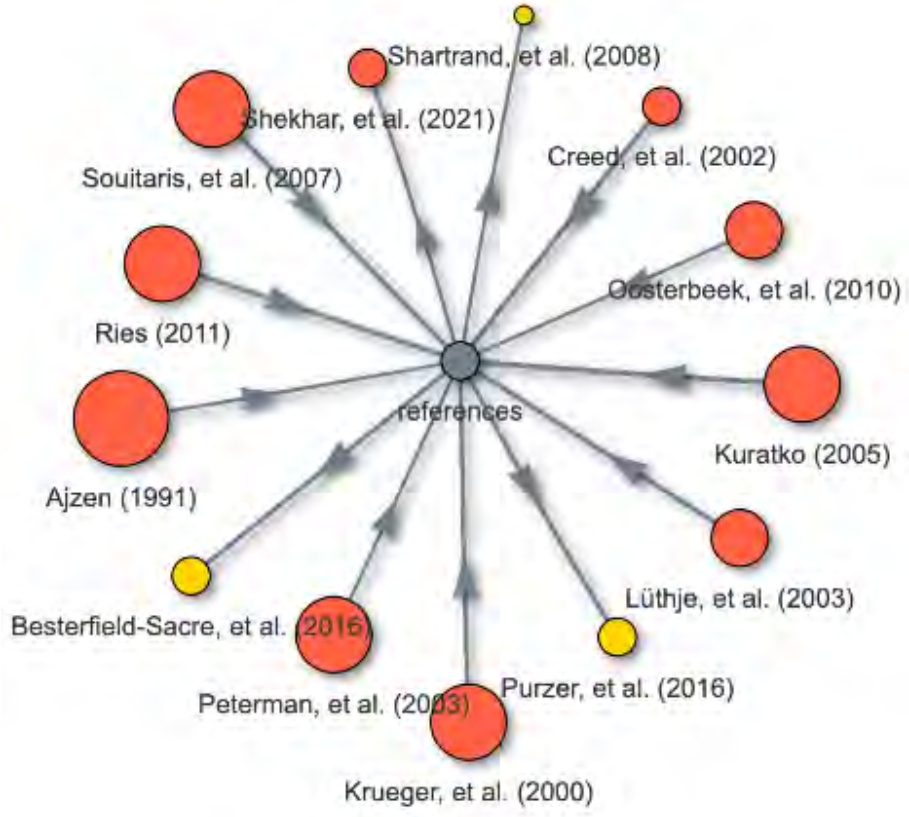

Figure 3. Network representation for references and cites with >5 appearances in our sample.

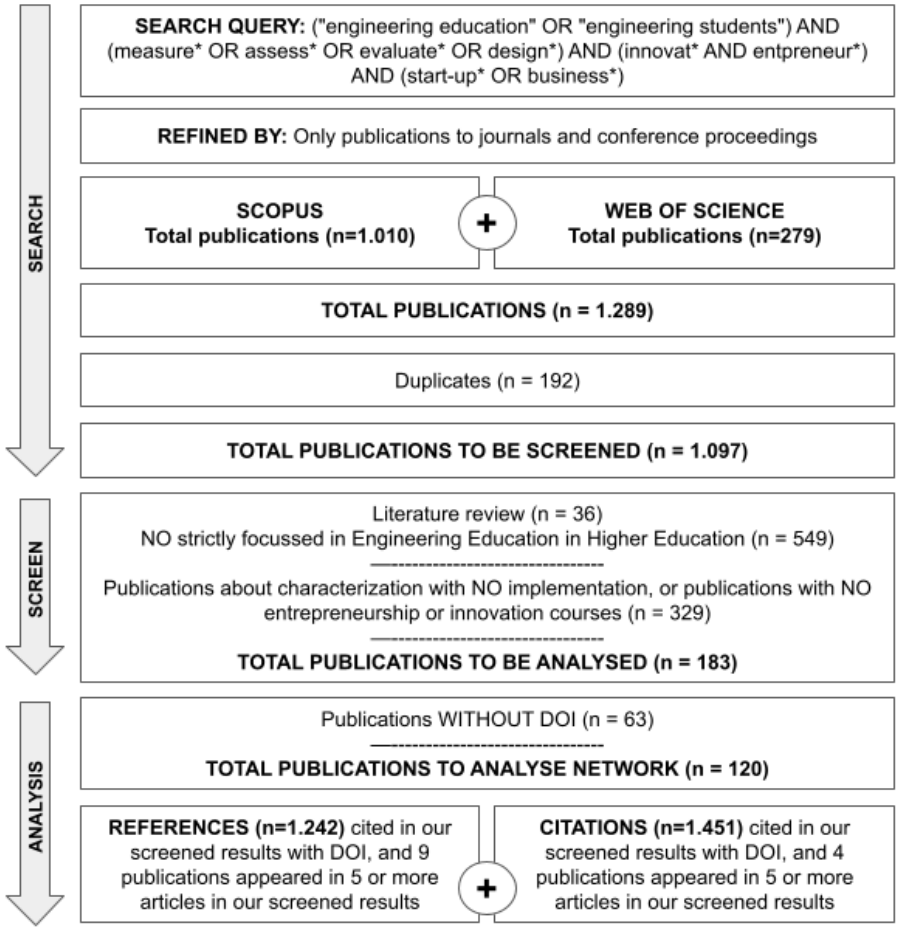

Figure 4. Summary of the methodological approach

A summary of the complete methodological process described in this section is depicted in Figure 4, starting from the expanded search to the network analysis. In the following section of this study, we investigate the suitability of the most highly ranked references, based on citation count for our research focus, which specifically examines the use of interventions in engineering education to promote entrepreneurship and innovation. We also consider the type of program and evaluation methods employed.

The subsequent section of this study evaluates the appropriateness of the references that have received the highest citation counts for our research focus, as a preliminary examination of the methodology proposed in this study.

RESULTS AND DISCUSSION

We now report the preliminary examination of the methodology proposed for the development of a comprehensive systematic literature review on the topic of interventions in engineering education to promote entrepreneurship and innovation. For this paper we selected the most relevant publications (10), ranked by citations, from the expanded search results, as well as an equal number of publications obtained through network analysis of both references and ci-

Table 1. Summary of the reviewed publications

Categories	References (10)	Broader Search (10)	Citations (10)
Engineering Education	4	9	10
Intervention	2	5	3
Entrepreneurship program described	2	5	1
Outcomes measurement			
Qualitative interviews	1	2	
Surveys, entrepreneurial intentions	1		1
Surveys, entrepreneurial skills		4	

tations. The study specifically investigates the use of interventions in engineering education to foster entrepreneurship and innovation, and also focuses on evaluating the presence of entrepreneurship and innovation programs, as well as any methods of program evaluation employed, such as surveys or interviews. In Table 1 the results of these publications reviews are tabulated, differentiating when each set of publications were retrieved.

The reviewed literature that meets the purpose of this study reveals that the majority of the publications that are centered in describing a given intervention in engineering education degrees where a program in entrepreneurship and / or innovation has rolled out, just consider a few different ways of assessing the program. Surveys, both pre and post course, are widely used as in Bellotti et al. (2013) where authors describe the use of surveys to assess entrepreneurial skills, although with no conclusions as they did not process the data. Also, in Bilén, Kisenwether, Rzasa, and Wise (2005) and Wang and Kleppe (2001) the authors complement data coming from students' surveys, with additional qualitative data from interviews, but in both cases still centered on assessing entrepreneurial skills. Additionally, the same trend of outcomes measurement has been used in the existing literature to correlate the results of positive measurement on entrepreneurial skills with higher grades and higher rate of students' retention Ohland, Frillman, Zhang, Brawner, and Miller III (2004). On the other hand, in Joseph (2013) and Souitaris, Zerbinati, and Al-Laham (2007) authors, in both cases, use surveys to assess their entrepreneurship programs, but this time with a focus in entrepreneurial intentions rather than skills and using, in the case of the latter, some survey adaptations from previous studies in the literature. Lastly, in Creed, Suuberg, and Crawford (2002) the authors center their measurements in the use of qualitative students interviews. They concluded that "the ultimate success story would be to see one of these student's companies spin off as a real company" (Creed et al., 2002, p.194), which is probably one of the key metrics to incorporate to the previous outcomes measurement methods that would count with major consensus; not being immediately available is its main drawback, however.

CONCLUSIONS

As seen in Figure 2 there is a growing body of literature over the recent years and, for this reason, we aimed to provide a three-step methodology that builds on the existing methodology to conduct systematic literature review of studies that focus on engineering education, as in Borrego et al. (2014), so that our research in the field keeps pace with the production of academic texts on the topic. Our methodology allowed for a better search in that, through an expanded

search, new keywords related to the main topic were automatically found. Additionally, through a second iteration, our proposed methodology identified studies that would otherwise have been lost in the search. Our reviewed publications revealed that most of the measurement tools are based on surveys to assess entrepreneurial skills, traits, intention or mindset, with no common consensus in the existing literature on the definition of each concept (Huang-Saad et al., 2018), and that additional outcomes measurement methods for Engineering Entrepreneurship programs are also required (Creed et al., 2002).

It is important to highlight the limitations of the present study. First, rather than providing an exhaustive systematic review of the literature, this paper aimed to highlight a new methodological procedure to undertake a systematic review of studies centered in entrepreneurship in engineering education. Second, even though the literature is all related to engineering education, the terminology may vary; in this regard, authors may make a different use of the same terminology. This idiosyncratic use of terminology may have affected the results of the search presented in this paper and would require a manual, deeper analysis of the studies found; it also calls for peer-review processes to reach greater consensus. It would be interesting to apply our methodology to complete the systematic literature review not limited to the publications with most citations; this would perhaps allow to find papers that put forward different outcomes measurement methods for entrepreneurship and innovation programs in engineering education. Moreover, this methodology can be extended to other domains of inquiry, potentially encompassing additional CDIO standards, such as program assessment (CDIO Standard 12), where it is usually needed to perform literature reviews with a view of finding out what is being done in other institutions in a given area of focus.

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APPENDIX

Table 2. Complete list of reviewed publications.

	Publications	EE	IN	EP	MM
References	Krueger, Reilly, and Carsrud (2000)				
	Souitaris et al. (2007)	x	x	x	Surveys, entrepreneurial intentions.
	Creed et al. (2002)	x	x	x	Qualitative interviews.
	Peterman and Kennedy (2003)				
	Bird (1988)				
	Lüthje and Franke (2003)	x			
	Kuratko (2005)	x			
	Oosterbeek, van Praag, and Ijsselstein (2010)				
	Ries (2011)				
	Ajzen (1991)				
Expanded Search	Bellotti et al. (2013)	x	x	x	Surveys, entrepreneurial skills.
	Bilén et al. (2005)	x	x	x	Surveys, entrepreneurial skills.
	Creed et al. (2002)	x	x	x	Qualitative interviews.
	Van Looy et al. (2011)	x			
	Vodă and Florea (2019)	x			
	Bellotti et al. (2014)	x			
	Wang and Kleppe (2001)	x	x	x	Surveys, entrepreneurial skills.
	Ohland et al. (2004)	x	x	x	Surveys, entrepreneurial skills.
	Maia and Claro (2013)	x			
	Tessema Gerba (2012)				
Citations	Cico, Jaccheri, Nguyen-Duc, and Zhang (2021)	x			
	Duval-Couetil, Reed-Rhoads, and Haghighi (2010)	x			
	Purzer, Fila, and Nataraja (2016)	x			
	Shartrand, Weilerstein, Besterfield-Sacre, and Olds (2008)	x			
	Prateek and Huang-Saad (2021)	x			
	Thompson (2012)	x	x		
	Besterfield-Sacre, Zappe, Shartrand, and Hochstedt (2016)	x			
	Hassan, LeBlanc, and Al-Olimat (2013)	x	x		
	Joseph (2013)	x	x	x	Surveys, entrepreneurial intentions.
	Celis Guzman (2015)	x			

Notes: EE = Enginnering Education, IN = INtervention, EP = Entrepreneurship Program, MM = Measurement Methods.

BIOGRAPHICAL INFORMATION

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