PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

DEVELOPMENT AND STATISTICAL VALIDATION OF AN INSTRUMENT TO ASSESS ENTREPRENEURIAL BEHAVIORS IN ENGINEERING EDUCATION

TRINIDAD SOTOMAYOR

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:
CONSTANZA MIRANDA

Santiago de Chile, (January, 2021)

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All I'm armed with is research

- M. W.

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I want to thank my family and Srdjan. For motivating me, being patient, and always listening about my progress, learnings, and difficulties.

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These two pillars taught me the value of interdisciplinarity and the rigor on how to get things done. This thesis project is just one of the results that I take from my learning with them; the rest are present in everything I do every day.

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ABSTRACT

Within the last decade, engineering entrepreneurship education has grown exponentially in universities worldwide. However, this growth has been accompanied by great challenges when devising theoretically sound and context-sensitive assessment methods. This thesis's purpose is to design a qualitative and quantitative approach to construct an instrument to assess the entrepreneurial mindset in the context of engineering education. In a first stage, this research critically explores the literature in education, business and engineering education to identify key components of the entrepreneurial mindset and associated behaviors. The process was followed by a qualitative data collection with students and professors to contrast information. The qualitative analysis used Grounded Theory methodology with the objective to create items inductively through the coding of themes. Based on these results and expert validation, an initial 27 item instrument was developed.

Before the instrument could be used, it needed to be validated. The quantitative phase involved the statistical construct validation and reliability of the scale, carried through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The EFA and CFA provided strong validity evidence for the indicators used to assess the proposed three constructs of the entrepreneurial mindset. The broad result of this research is an initial 15 item instrument that could be applied in entrepreneurship engineering education. The overall process could be replicated in the creation of new assessment instruments for higher education.

Keywords - Education, Assessment, Entrepreneurship, Engineering, Validity, Reliability, Factor analysis, EFA, CFA, Psychometrics.

RESUMEN

En la última década, la enseñanza del emprendimiento en ingeniería ha crecido exponencialmente en universidades de todo el mundo. Sin embargo, este crecimiento ha ido acompañado de grandes desafíos al diseñar métodos de evaluación teóricamente sólidos y sensibles al contexto. El propósito de esta tesis es diseñar una investigación exploratoria, con fase cualitativa y cuantitativa para construir un instrumento para evaluar la mentalidad emprendedora en el contexto de la educación en ingeniería. En una primera etapa, esta investigación explora críticamente la literatura en educación, negocios e ingeniería para identificar los componentes clave de la mentalidad emprendedora y los comportamientos asociados. El proceso fue seguido por una recopilación de datos cualitativos con estudiantes y profesores para contrastar la información mediante *focus groups*. En el análisis cualitativo se utilizó la Teoría Fundamentada con el objetivo de crear ítems de manera inductiva a través de la codificación de temas. Con base en estos resultados y la validación de expertos, se desarrolló un instrumento inicial de 27 ítems.

Antes de poder utilizar un instrumento cuantitativo, es necesario validarlo. La fase cuantitativa involucró la validación del constructo estadístico y la confiabilidad de la escala, a través del análisis factorial exploratorio (EFA) y el análisis factorial confirmatorio (CFA). El EFA y CFA proporcionaron pruebas sólidas de validez para los indicadores utilizados para evaluar los tres constructos propuestos de la mentalidad empresarial. El resultado general de esta investigación es un instrumento inicial de 15 ítems que podría aplicarse en la educación en emprendimiento en ingeniería. El proceso general podría replicarse en la creación de nuevos instrumentos de evaluación para la educación superior en ingeniería.

Palabras clave - Educación, Evaluación, Emprendimiento, Ingeniería, Validez, Análisis factorial, EFA, CFA, Psicometría.

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1. INTRODUCTION

Over the past 20 years, entrepreneurship education has seen a significant growth outside of business schools (Morris, Kuratko and Pryor, 2013). Due to the accelerated pace of technological change and pressure on countries to transition into knowledge-based economies, entrepreneurship and innovation have become imperative to engineering education (Weilerstein and Byers, 2016; Shartrand, Weilerstein and Besterfield-Sacre, 2010). As Weilerstein and Byers (2016) explain, entrepreneurship has become more predominant in engineering, in part because of the communities and institutions that have supported the integration of entrepreneurship in engineering more intensely than in any other field of study outside business schools. For instance, in the United States, organizations such as VentureWell (formerly called the National Collegiate Inventors and Innovators Alliance) and The Kern Engineering Entrepreneurship Network (KEEN) have financed and promoted engineering entrepreneurship education among several colleges. Meetings such as Stanford's Roundtable on Entrepreneurship Education (REE) and The Entrepreneurship and Innovation Division of the American Society for Engineering Education (ASEE) have created networks and encouraged practitioners and researchers to engage with engineering entrepreneurship. In addition, projects such as the NSF-funded National Center for Engineering Pathways to Innovation (Epicenter) have developed programs and initiatives for engineering entrepreneurship education using federal funding (Weilerstein and Byers, 2016).

There has also been institutional support for engineering entrepreneurship education in other countries outside the United States, for example, in Chile. Through the government initiative “Nueva Ingeniería 2030” (New Engineering 2030), launched in 2012, it has provided significant funding to universities to support their efforts to promote applied research, technological development, innovation, and entrepreneurship into their curricula and campuses (Celis and Hilliger, 2016). Additionally, academic conferences like the SOCHEDI (The Chilean Society of Engineering Education) Conference have raised interest and best practices in the teaching and learning of entrepreneurship in engineering by having “experiences of incorporation of entrepreneurial and innovation competencies into engineering curricula” as one of their recurrent topics (SOCHEDI, 2019).

Although several organizations and initiatives promote entrepreneurship nationally and globally, this thesis’s theoretical framework involves the concept of engineering education in particular.

1.1 Engineering Entrepreneurship Education

Apart from programs and funding, there has been a worldwide exponential growth regarding the publication of articles related to the entrepreneurial mindset within the engineering education community (Farina, Fleury and Carvalho, 2019). Today’s engineers are perceived in need of entrepreneurial thinking to contribute to society's technological advancement (Winters, 2014). However, the definition of entrepreneurship for engineering is still an ongoing debate (Farina, Fleury and Carvalho, 2019). The conceptual understanding of engineering entrepreneurship education is evolving by examining current educational practices and using theory to critique them (Huang-Saad, Brodnar, and Carberry, 2020). The reality is that most engineering education programs are designed to provide business tools to engineers (Gilmartin, Shartrand, Chen, Estrada, and Sheppard, 2016) and not necessarily to promote other entrepreneurial learning paradigms that emphasize general attitudes, skills, and traits that are not exclusive to business creation. In sum, there is a current lag in theory about how to conceptualize the entrepreneurial mindset in a way that is comprehensive enough for all relevant stakeholders (students, teachers, and decision-makers, among others). As Huang-Saad, Brodnar, and Carberry (2020) state: "Theoretical frameworks, research, and reviews of engineering entrepreneurship are needed to advance the understanding of this emerging discipline" (p.4).

1.2 Assessments

Engineering entrepreneurship students have been assessed using different methods. These range from quizzes to project deliverables, surveys, interviews and concept maps (Purzer, Fila, Nataraja 2016). Although diversity in assessment is considered positive, most of the assessment tools typically used in engineering entrepreneurship education lack a "theoretical framework or research-based argument that guided their design" (Purzer, Fila, Nataraja 2016).

Engineering entrepreneurship started by adapting business education into the engineering curricula with the goal of creating new technology-driven startups (Weilerstein and Byers, 2016). However, as the field developed over time, more and more researchers and practitioners have become interested in the significance of entrepreneurship beyond the creation of new enterprises. In this line, Anderson (2015) points out that researchers have usually reduced entrepreneurship to generate economic growth while the social, emotional and aspirational aspects of the construct are often underplayed. This is what the author calls the economic reification of entrepreneurship (Anderson, 2015). Additionally, there is an argument to be made about the educational benefits of defining entrepreneurship as more than venture creation in the context of formal education (Miranda, Goñi, Berhane and Carberry, 2020). In engineering, this has meant that the conversation has changed from promoting an entrepreneurial intent for the creation of new businesses to the development of an entrepreneurial mindset (Huang-Saad, Morton and Libarking, 2018).

If the entrepreneurial mindset is based on the ability 'to sense and adapt to uncertainty' (Haynie, Shepherd, Mosakowsky and Earley, 2010, p.218), it makes sense that it appears to be of value to all engineering students tackling complex real-world challenges, regardless of whether they seek to start a business or not. Otherwise, one may ask: what is the value of entrepreneurship education to students who do not seek to engage in economic ventures?

In other words, despite the fact that engineering entrepreneurship education has mostly focused on business tools (Huang-Saad, Morton and Libarking 2018), the current consensus is drifting towards the idea that engineering entrepreneurship should not be limited to venture creation (Huang-Saad, Brodnar and Carberry, 2020).

On the one hand, many of the surveys created to assess engineering entrepreneurship education are based on venture creation. Some examples are the Engineering Entrepreneurship Survey by Duval-Couetil, Reed-Rhoads and Haghighi (2011) and the Engineering Mindset Rubric by Shartrand, Weilerstein, Besterfield-Sacre, and Old (2008). Although based on rigorous research standards and theoretical frameworks, these assessment tools do not avoid the preceding business-creation paradigm. There are similar issues with the GUESSS Survey. This is a survey that collects data around the globe on the students' entrepreneurial spirit. It yields reports and academic publications. Even though it evaluates aspects like motivation, social identity, and family structure, it also assesses the entrepreneurial business intentions, performance on new ventures, and family firm succession.

On the other hand, there has been a surge of assessment methods beyond business creation, but struggle to meet high research standards. Most of these instruments are based on the KEEN framework (Rae and Melton, 2017; Kriewall and Mekemson, 2010). Some examples are the instruments developed by Li, Harichandran, Carnasciali, Erdil, and Nocito-Gobel (2016), Schoonmaker, Gettens, and Vallee (2020), or the Engineering Student Entrepreneurial Mindset

Assessment (ESEMA) by Brunhaver et al. (2018). Some of these were validated using psychometric standards and provide enough evidence for reliability as quantitative measures. However, the KEEN 3C's model (Curiosity, Connections and Creating Value), is restricted to one particular stakeholder's perspective (The Kern Foundation). Although the KEEN framework is popular among researchers and is useful as a non-business oriented guideline, KEEN-created models lack the full research underpinning necessary for open, critical, and theory-driven, or based on evidence, research (Huang-Saad, Brodnar, and Carberry, 2020).

1.3 Research questions

Aforementioned, there are still major challenges when devising theoretically sound and context-sensitive assessment methods in engineering entrepreneurship education. In particular, three major gaps have been identified through the theoretical framework. In the first place, there is a lack of surveys or instruments that focus on entrepreneurship beyond business creation. Secondly, there is a lack of surveys that are generated without emphasizing one particular institutional framework (for instance, the KEEN framework). Finally, there is still a challenge in the operationalization of the entrepreneurial mindset in a way that is sensitive to the cultural context and the specific domain of engineering (Miranda et al., 2020).

The purpose of this research was to build a statistically validated instrument to assess the measurable dimensions of the entrepreneurial mindset in the context of engineering education in a research-based way, detached from a specific institutional framework and that goes beyond the concept of business creation. Therefore, the research questions were:

RQ1. What are the measurable dimensions of the entrepreneurial mindset in the context of engineering?

RQ2. How can these dimensions be translated to observable and quantifiable items for instrument assessment?

RQ3. What are the statistical properties of validity and reliability of the instrument?

2. METHODOLOGY

This research was built as a sequential exploratory mixed design, often used to develop comprehensive instruments (Creswell and Plano Clark 2007; Tashakkori and Teddlie 2003). This approach is used to create standardized quantitative instruments in a relatively unstudied area (Borrego, Douglas, and Amelink, 2009). Exploratory designs begin with a primary qualitative phase, and the findings are validated by quantitative results. Figure 2-1 portrays the methodological overview of these sequential quantitative and qualitative phases developed in this research, which will be explained in detail. Both quantitative and qualitative data collection were carried at the School of Engineering from the Pontificia Universidad Católica de Chile.

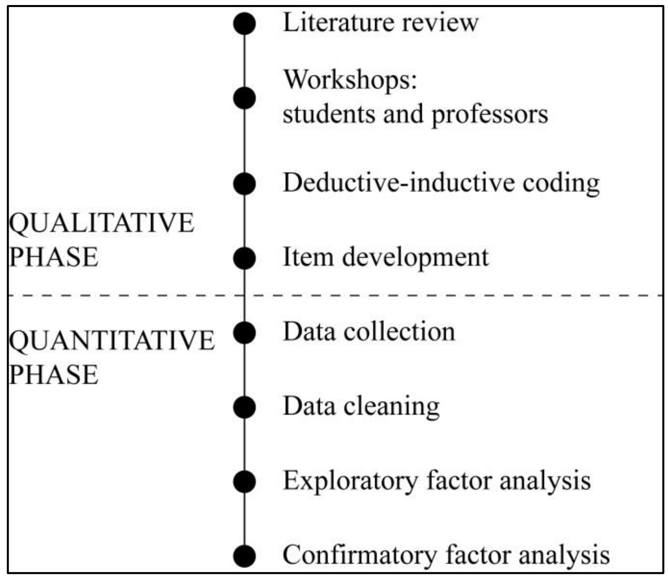

Figure 2-1. Methodological Overview

2.1 Qualitative phase

2.1.1 Literature review

There are many challenges and theoretical considerations when conceptualizing and defining the entrepreneurial mindset in engineering.

There is a need to discover the components that cross the different entrepreneurship paradigms beyond business creation. In this matter, there are key publications that already reviewed the entrepreneurial mindset components through different types of literature. Although these broad constructs are not specific to engineering education, they can be initially used as a guidance for the search of information. This enabled to triangulate literature components with the ones defined by empirical information in the specific context of engineering education.

The main objective of the literature search was to guide the construction of items and provide the theoretical grounding for the overall definition construct of engineering entrepreneurial mindset.

From the literature review, some common characteristics and challenges were found in order to identify components of the entrepreneurial mindset. Key publications founded that already revised the components of the entrepreneurial mindset through different types of literature. For instance, Clark and Harrison (2019) conducted a multi-perspective and integrated review of the literature to identify patterns in all Entrepreneurship Studies schools. They concluded that four key elements should be present in an integrated definition of entrepreneurship, namely: (1) Opportunity, (2) Risk, (3) Pro-activity and (4) Innovation. This synthesis provides a broad but sound initial composition. Nonetheless, other elements could be incorporated.

For example, many scholars in the 'new venture tradition' (Clark and Harrison, 2019) have focused on the entrepreneur as a lone hero, however this is not representative of the actual entrepreneurial process, usually carried out in teams (Cooney, 2005). As Warhuus and Jones (2016) put it: 'in reality, developing collaborative competencies is more in line with the life of everyday entrepreneurs who have to form networks and learn to draw on the resources of others' (235). Therefore (5) Collaboration was also included in the list.

Another major component of entrepreneurship is the creation of value for others. Shepherd et al. (2019) literature revision is consistent with the previously mentioned components but focuses more closely on value creation in initiating business endeavors. To Shepherd et al. (2019), value can be social, economic, or environmental. This is also consistent with Korte et al. (2018) review of empathy as a key component of entrepreneurship. Therefore, (6) Empathy and Value creation for others were also incorporated into the initial list. This final list of components reflects most of the dimensions present in other reviews, such as London et al. (2017) or Commarmond (2017). These components are:

1. Identifying opportunities
2. Taking risks and dealing with uncertainty
3. Being proactive
4. Being innovative
5. Collaborating and leading
6. Being empathetic

Based on these initial components, the next step of the study was to include the perception of students, instructors, and professors involved in the engineering education environment in order to create an instrument from scratch. The question was: How do these broad components translate into the experience of a particular population and their context?

2.1.2 Qualitative data collection

Students were selected using a purposive sampling (Patton, 1990) which ended when data saturation was achieved, contingent on the ultimate goals and analytical framework developed (Saunders et. al, 2018). Four 1-hour-long workshops and semi-structured interviews were carried out. Three of them were done with engineering students and one of them with engineering professors/instructors. In particular, the instructors and tenured track faculty professors involved were linked to courses that specifically taught entrepreneurship using problem based learning. The number of students that participated were 16, all from undergraduate programs. Ages ranged from 18 to 25 years old, 11 were men and 5 were women. Their engineering sub disciplines involved: industrial engineering, mechanical engineering, civil engineering, environmental engineering, biomedical engineering, computer sciences, electrical engineering and transportation engineering, among others.

As Figure 2-2 shows, the workshops used probes to engage in activities that would yield specific conversations about identifying examples, conduct, and educational practices related to entrepreneurship in engineering. The questions and protocols were developed and were subjected to a first iteration after testing with a few individuals. The research protocol for the workshop implied one moderator and one individual taking notes and recording. All participants were informed about the nature of their participation and signed informed consent documents approved by the IRB. The workshop started with an opening part where the team and the participants introduced themselves. Then, to break the ice, a free-listing (Weller and Romney, 1988) activity was deployed where the participants were asked to write down all of the words related to entrepreneurship and explain their choices. This part of the activity also explores the cognitive domain or categories that the individuals attribute to entrepreneurship as a contested concept. Finally, participants are presented with fictional characters and are asked about visible behaviors and practices related to the categories identified in literature like collaboration, empathy, and risk-taking, among others. All of the workshops were video-recorded and transcribed in order to do qualitative data analysis with their results.

Figure 2-2. Workshops pictures and probes used.

2.1.3 Qualitative data analysis

A two-phase coding process was employed for the raw qualitative data obtained from the transcriptions. Having the research objectives in mind, in the first coding phase, each workshop was purposely coded as behaviors/practices and classified under the attribute being asked. They were also classified into three categories: 1) conducts, 2) examples and 3) educational practices. In the second phase, identified behaviors/practices were inductively regrouped into qualitative themes regardless of their initial attribute or data production event. Behaviors and examples were coded independently from educational practices.

The first phase used a deductive approach with theory-driven codes (Fereday and Muir-Cochrane, 2006) to bridge theory with raw data. Non-positivist qualitative researchers often use theory-driven analysis to allow for perspective-taking and critical distance with the final result (Haardörfer, 2019). This strategy intended to connect qualitative data with the review of the literature in order to produce a theoretically strong final survey.

All conducts and educational practices that participants associated with these attributes were extracted from the transcripts into a digital table, dividing conducts/examples in one table and educational practices in another. Each data production event was coded independently. This coding phase used an inductive approach with data-driven codes in the more traditional spirit of Grounded Theory (Glaser and Strauss, 1967). In this sense, the methodological approach is more aligned with Strauss conceptual approach to Grounded Theory over Glaser's empiricism (Heath and Cowley, 2004).

In this phase, themes were created inductively by identifying patterns and similarities across behaviors regardless of the initial attribute and data production event they originated in. Codes were independently grouped by researchers and then collectively negotiated and discussed as to achieve sufficient (1) internal consistency (2) clarity (3) theoretical meaningfulness and (4) groundedness in data. The final result was translated into another unified digital table. Table 2-1 displays the final themes obtained during the coding process.

Table 2-1 : Qualitative themes

Theme	**Description**
Ignition	This theme describes the entrepreneurial mindset as the ability to be creative and proactive (think of engineering ideas, start projects, come up with solutions to engineering challenges, etc.).
Persistence	This theme describes the entrepreneurial mindset as the commitment to educational tasks, personal projects and the ability to learn from mistakes and avoid discouragement.
Collaborative leadership	This theme describes the entrepreneurial mindset as the ability to lead engineering groups by managing group conflict, administrating tasks and being a good listener.
Empathetic (with the problem)	This theme describes entrepreneurship as concern about and empathy with the world or society problems. This is depicted as being motivated when engineering challenges relate to real-world issues and to be emotionally involved in the engineering projects that involve real people.
Curious	This theme describes entrepreneurship as being well-informed about the latest technologies and trends. This, in turn, is perceived to lead to more interest in life-long learning and taking advantage of learning opportunities outside the classroom.
Goal directed	This theme describes entrepreneurship as having achievement goals and being ambitious. This is depicted as aspiring to have your work recognized by others, as aspiring to get good results in your engineering projects and as aspiring to being recognized by your peers and teachers.
Participative	This theme describes entrepreneurship as participation in different events (social, political, religious) and membership in different organizations (sports, politics, religion, social help, etc.).

2.1.4 Instrument development

For the items generation, recommendations provided by DeVellis (2017), Krosnick (2018) and Vanette (2018) were followed. With these considerations in mind, it was decided to design a five-point (with word labels) unipolar survey to ask behavioral questions (Tourangeau et al. 2000) about the entrepreneurial mindset. Rohrmann's (2015) frequency scales were chosen, as they are qualifiers to maximize familiarity and equidistance of results. These are "never", "seldom", "sometimes", "often" and "always". Item ideas were generated based on the qualitative findings. To facilitate the process a theme-item table was used. Table 2-2 shows an example of the theme-item table used to generate items.

Table 2-2: Theme-item table

Themes	Code	Quote	Items ideas
Ignition	In the course, groups go beyond what they've been asked to do	I think that in our course class projects for example, they try to take risks, meaning they are asked for "something" and they go beyond what they've been asked to do, they do more advanced work.	1. I do more advanced work when working on class projects in my engineering courses 2. I try to take risks when working on a class project in the university
	Students go further than the achievable	There is a word that a professor uses that sums it up: "audacity", meaning how bold you are in your project. If the students are actually thinking beyond what someone might think as achievable. They go further. There you have someone really innovative	3. I try to do more than what the teachers demand from us when planning my project at group discussions

After all the items were developed independently for the item pool, 7 items per theme were selected. For the process of item selection, guiding questions proposed by Blair, Czaja and Blair were used (2013, p.153). After the selection process was carried out the first pool of items was created containing 90 questions.

To examine the content validity of our survey, these first item pools were sent to be examined by experts in the field (Boateng et. al, 2018). The items were individually reviewed by two experts in engineering education (one from Universidad de Chile and one from Universidad de Santiago), and two experts in the specific context of engineering entrepreneurship. Of these experts, three of them hold PhDs and do research in higher education. The other expert coordinates the division of Innovation and Entrepreneurship of one of the best ranked Latin American Engineering schools.

As an additional step to examine the content validity of the survey, cognitive interviews with students were held. An approach to cognitive interviewing (Willis 2018) was used.

Through an analysis of both experts' comments and through a triangulation with data from the cognitive interviews, 27 of 90 items were selected and improved as part of the second pool of items. All 27 items were distributed among six from the seven dimensions stated before. The dimension deleted was the “goal-driven” category. Its items were removed following the advice of experts because, although it was notably present in the qualitative data, it reflected a more competitive side of engineering entrepreneurship that an educational-driven survey should not help reproduce.

2.2 Quantitative phase

2.2.1 Data collection

The participants of the questionnaire were students from an entrepreneurial course named “Investigation, Innovation and Entrepreneurship” (ING2030). This is a mandatory course for third-year undergraduate engineering students, and it is project-based. It is relevant to highlight that, due to the COVID pandemic, the course was adapted and held remotely during 2020. The questionnaire was implemented in the first and second semester of 2020.. The instrument was added to a larger survey taken by the Research in Engineering Education group at UC. The platform used was Survey Monkey. An informed consent approved by the university’s ethics committee was used at the beginning of the survey. Table 2-3 shows the demographic information of the 2020-1 (March) and 2020-2 (August) samples. The first one that involved 256 students and the latter 348.

Table 2-3: Participants demographic information

	2020-1	2020-2
	First sample	Second sample
n	256	348
Gender		
%Female	29	27
%Male	69	71
%Rather not say	2	2
Age		
%24 or more years	11	6
%23 years	20	12
%22 years	30	23
%21 years	34	47
%20 years	5	11
%19 years	0	1

2.2.2 Data analysis

Factor analysis is a statistical procedure for describing the interrelationships among some observed variables. It is used to measure variables that cannot be measured directly, summarize large amounts of data, and develop and test theories. To achieve this purpose, an exploratory factor analysis (EFA) nurtures a confirmatory factor analysis (CFA). This will be described in the following section.

About the requirements needed, there is not a clear agreement on the minimum sample size for this procedure. To conduct an EFA the minimum sample is often considered to be 50 and can yield reliable results even below that number (Winter, Dodou & Wieringa 2009). According to the rule of thumb, the minimum sample for CFA is 300 (Wilson Van Voorhis & Morgan 2007).

Based on this, the first admissible responses database (N=256) was used for CFA and the second admissible responses database (N=348) for EFA.

a) Exploratory factor analysis

The goal of exploratory factor analysis (EFA) is to explain the relations among observed variables through a reduced number of non-observed variables (or latent). This technique reveals the underlying structure among items and helps define a set of highly interrelated variables, known as factors, that represent dimensions within the data (Hair, Black, Babin, and Anderson, 2018). This technique allows to find the factor structure of a newly developed scale (Fabrigar, Wegener, MacCallum & Strahan, 1999) and therefore is a valuable tool for the researcher. This is achieved using the smallest number of items to explain the maximum amount of common variance in a correlation matrix (Tinsley and Tinsley, 1987). Another popular technique for instrument validation among scholars is principal components analysis (PCA). However, it is frequently confused as an estimation method of common factor analysis (Brown, 2006). PCA does not differentiate common and unique variance; thus, it does not explain the correlations among items. Many authors consistently condemn its use and affirm that the reason for this misconception is that PCA is the default function in many statistical analysis programs (Carpenter, 2018; Osborne and Costello, 2011; Matsunaga, 2010).

Before running the EFA, the first sample was primarily inspected to verify that the items were significantly correlated and suitable for factor analysis. Bartlett's test of sphericity was used, with a result of $2=306.9$ ($df=26$, $p<.001$), corroborating that the sample's correlation matrix was significantly different from an identity matrix. The adequacy of the sample was then analyzed using the Kaiser-Meyer-Olkin (KMO) test. In this test, the semi-partial correlations of an item with the rest of the items are examined. It evidences if the items share sufficient variance with the Measure of Sample Adequacy (MSA) metric, indicating how correlated the items are as the MSA approaches value 1. A total MSA of .81 was obtained with the 27 original items, with a minimum MSA of .66 and a maximum of .89. Based on Kaiser (1974), a total MSA greater than .80 is "meritorious" for proceeding with an EFA (p.35). Other references, such as Kim and Mueller (1978), Hair, Anderson, Tatham, and Black (1996), confirm that values greater than .80 are considered excellent.

Once the sample's adequacy was confirmed, it was also tested whether there was multivariate normality. Mardia's test was used, where the assumption was not fulfilled since non-item univariate normality was found. According to this finding, the extraction method chosen for exploratory factor analysis was principal axis rather than maximum likelihood. This method was selected because it is recommended when the assumption of multivariate normality is “severely violated” (Fabrigar et al., 1999). According to Osborne and Costello (2005), principal axis factors will give the best results when data are significantly non-normal. Additionally, principal axis method reveals underlying latent factors based only on the shared item variance, including communalities and excluding unique and error variance (Kim & Mueller, 1978).

Another decision the researcher needs to make is to choose the factor rotation method. Factor rotation is a mathematical transformation that facilitates interpretability; its purpose is to obtain theoretically meaningful factors and look for the simplest structure (Hair et al., 2018). This is achieved by rotating the factors' reference axes and allowing them to get closer to the variables' location. As Brown (2006) states, there are two types of rotation, orthogonal and oblique. Orthogonal rotation constrains the factors to be uncorrelated (90° from each other), while in oblique rotation, the factors correlate (less than 90° from each other).

In most disciplines, constructs tend to be at least marginally correlated with each other, so oblique rotations are mostly recommended (Osborne and Costello, 2005; (Fabrigar et al., 1999). Obliques rotations are also more realistic because the theoretical underlying dimensions should always be correlated (Hair et al., 2018). Therefore, a type of oblique rotation named direct oblimin (with gamma value zero) was used because it was also expected to discover correlations among factors.

To define the best structure, it is necessary to establish the number of factors to extract. There are several approaches; although some work better than others, none of them is valid for all cases (Lewis-Beck, Bryman, Futing, 2012). Therefore it is needed to use different criteria and look for convergence among them, simultaneously to the solutions' interpretability. Based on this, three different criteria were used. First, Kaiser rule (1970) was used, that proposes that a factor could be worthwhile if its eigenvalue is higher than 1.0. The eigenvalue equals the sum of each item's squared factor loadings; therefore, eigenvalues above 1.0 are only achieved when there are large factor loadings to square and sum (Osborne & Costello, 2005).

According to Brown (2006), another popular approach is scree plots (Catell, 1966). This method consists of examining the graph with eigenvalues plotted and looking for sections where the curve flattened to determine the number of factors (Netemeyer, Bearden, & Sharma, 2003). It is important to consider that the number of factors is determined by the point where the curve bends and not when the drastic break occurs (Osborne & Costello, 2005). The third criterion is parallel analysis, introduced by Horn (1965). This technique consists of comparing the sample's eigenvalues with eigenvalues from generated random uncorrelated data. The factors that should be retained are those above the line of the simulated eigenvalues. With the 27 items, the suggestion provided by Kaiser rule, scree plot, and parallel analysis were three, four, and four factors, respectively. Therefore, the analysis was run with three and four factors, aiming to find the precise number of factors that produced the best conceptual sense. However, the four-factor solution was uninterpretable and also involved one factor with two items, that is highly not recommended (Viswanathan, 2010). It was then chosen to explore a three-factor structure for the first EFA because it displayed conceptual sense and model parsimony.

b) Confirmatory factor analysis

Since exploratory factor analysis allows to explore underlying factor structures, confirmatory factor analysis (CFA) is used to confirm a hypothesis. In this technique, the researcher has a conceptual foundation about the constructs and their relationship based on empirical work results. It is needed to specify the factors, their associations, and the relations with their indicators. The purpose is to assess which of the hypothesized or imposed models fit a different sample's data (Finch and French, 2015). A CFA is carried on a separate sample to confirm the proposed scale structure resulting from EFA (Kline 2013; Costello and Osborne, 2003). CFA must be used to validate the dimensional structure of a measure in every developed scale, to prevent literature from being built on illegitimate instruments as this usually happens (Levine, Hullet, Turner and Lapinski, 2006). This procedure is mostly deductive, focusing on the extent to which the hypothetical covariance matrix imitates the observed covariance matrix, adding restrictions to the model.

For the execution of the CFA, the measurement model must be identified. It was decided to fix one loading of each factor to 1.0 to estimate the factors' variance freely. Multivariate normality was checked on the second sample with Mardia's test. The assumption that data followed a normal distribution was rejected. Therefore, the maximum likelihood estimator was used, with robust Huber-White standard errors (MLR in lavaan package).

Once parameters are estimated, there is a need to evaluate if the model fits the data. As Finch and French (2015) state, the question is, "Is the model able to reproduce with accuracy the covariance matrix of the observed variables?" (p. 40) This question can be assessed by three types of indices: absolute fit, comparative or incremental fit, and fit adjusting for model parsimony. The most used absolute fit indices are chi-squared and standardized root mean square residual (SRMR), although the first is rarely used in applied research as a single index of model fit and will almost certainly be rejected when the sample size is sufficiently large (Finch and French, 2015; Brown 2006). The incremental fit indices compare a baseline model that has all indicators covariances fixed to zero. The comparative fit index (CFI) and Tucker-Lewis index (TLI) have demonstrated the best performances of all indices introduced in the literature (Brown, 2006). The most utilized and recommended index which adjusts model parsimony is the root mean square error of approximation (RMSEA). It incorporates a penalty function for less parsimonious models. All these indices were used to assess our model.

2.2.3 Results

a) Exploratory factor analysis

Exploratory factor analysis was performed iteratively and with examination of the theoretical sense of each structure. Items were removed one at a time and reran the factor determination using the Kaiser criterion on eigenvalues, a scree plot, and parallel analysis. In every decision, parsimony was the goal. The first criterion for item elimination was low loadings. A factor loading represents how meaningfully related is the item with a factor. There is no consensus in the literature on which factor loading cut-off to maintain. There is literature supporting that maintaining loadings above .30 is acceptable (Tinsley and Tisley, 1987; Kachigan, 1986; Pett, Lackey and Sullivan, 2003), and Kline (1994) defines loadings above this threshold as moderately high. Another rule of thumb is setting .32 as a minimum loading for an item, as Tabachnick and Fidell (2001) recommend, as well as Worthington and Whittaker (2006). However, to pursue a more parsimonious structure, it was desirable to ensure that each instrument's item represented the construct of each factor accurately. The decision was to set .40 as the minimum for item retention as several statisticians recommend (Ford, MacCullum and Tait, 1986; Floyd, 1995; Reinard, 2006; Hair, Black, Babin and

Anderson, 2018). Seven items were removed based on this criterion (20 items remained).

After obtaining a model with loads above .40, cross-loadings were then analyzed. A cross-load is defined as a large factor loading onto multiple factors. Minimizing cross-loadings helps achieve a simpler structure solution where there is only one high loading for each variable in one factor. Although most scholars do not report cross-loading cut-offs, some established an unvarying difference of 0.2 or 0.1 (Howard, 2016). However, the guidelines described in Hair, Black, Babin, and Anderson (2018) were used. They compare ratio variances instead of loadings and address relative magnitude loading. Based on this principle, items Q12 and Q22 were removed because they had problematic cross-loading (ratio of 1.17 and 1.3 respectively) and Q21 because it had a potential cross-loading (ratio of 1.7).

After the removal of the items, 17 items were retained, and all criteria that aim to determine the number of factors (eigenvalues, scree test, and parallel analysis) suggested three factors. One of the factors gathered items regarding curiosity, information seeking, and self-learning. This factor was primarily named "Learning autonomy". Another factor associated with good team players behaviors such as listening, team collaboration, and project commitment. This factor was named "Committed collaboration". Finally, the "Creating direct value" factor gathered items about social problems and constant search for meaningful projects. Although each factor's conceptual core was well defined, two items added noise to the interpretation. As Matsunaga (2010) stated, the resultant pool of items should contain only items that tap theoretically meaningful and interpretable factors. In this case, the question Q7 "I assume leadership roles in my courses projects," was not related to its factor "Creating direct value," and Q11, "I work well with people with different academic interests," could be held to confusion. Those items were removed from the scale. The conceptualization of these factors and their descriptions are further discussed in the "Discussion" and "Conclusion" section of this article.

The final structure proposed has 15 items, with loading ranging from 0.4 to 0.78 and communalities ranging from 0.28 to 0.66. Although communalities are low, all fulfill Child's (2006) threshold of 0.2. This can be found in Table 2-4. All factor eigenvalues are greater than the minimum reference of 1.0. For unrotated factors, the values are 2.83 for the "Creating direct value" factor, 1.40 for the "Committed collaboration" factor, and 1.02 for the "Learning autonomy" factor. After rotation, eigenvalues are 2.15, 1.67, and 1.43 respectively. The 15-item instrument explained 35% of the variance in the pattern of relationships among the items.

Table 2-4: Exploratory Factor Analysis Result

Item	Creating direct value	Committed collaboration	Learning autonomy	Communality
Q24: I keep up with any new developments and advance within issues that interest me.	0.6			0.33
Q19: I learn tools and knowledge on my own that would help me in the future	0.51			0.26
Q26: I seek to learn about issues unrelated to engineering	0.5			0.28
Q13: On my own time I review complementary material that isn't in the syllabus	0.49			0.23
Q25: I propose diverse solutions to the challenges given to me within my engineering projects	0.42			0.35
Q20: I actively work to connect my engineering knowledge with social problems		0.78		0.66
Q15: I spend part of my time considering how to improve aspects of our society (for example, a more environmentally conscious city, social injustices)		0.67		0.42
Q4: I participate in projects that have an impact on real people.		0.64		0.37
Q2: I am motivated to acquire knowledge that allows me to directly help others when I work		0.54		0.34
Q8: I am emotionally invested in my class projects		0.46		0.28
Q16: I listen to feedback from others without interrupting to explain or justify my decisions			0.69	0.47
Q9: In project meetings, I listen patiently to all my partners.			0.64	0.39
Q17: I work well with individuals who have different work styles than me			0.5	0.28
Q18: I actively listen to my teammates in group projects			0.54	0.36
Q5: I quit projects that become too complicated			0.4	0.22

b) Confirmatory factor analysis results

The next step was to fit the second sample with the structure previously found with the first sample. After the CFA execution, it was found that the three-dimension model fits the empirical data well. The robust CFI and robust TLI values were 0.93 and 0.92, respectively, above the 0.9 thresholds (Hu and Bentler, 1995). The robust RMSEA was a significant .04, with a 90% confidence interval of .029 and .056, indicating a good fit (MacCallum, Browne & Sugawara, 1996). The robust SRMR was .063 that is below the .08 value proposed by Hu and Bentler (1999) as a good fit. Although all fit indexes indicated a good model fit, the chi-square obtained was 139.5 (df= 87) with a significant p-value ($p<.001$). This indicates that there is a significant difference between the observed covariance matrix and the estimated covariance matrix. However, it is known that statisticians disagree about the utility of this metric for evaluating model fit as it is susceptible to sample sizes greater than 200 (Brown, 2015; Schumacher & Lomax, 2004; Hair et al., 2018). The second sample used in CFA is larger than 200, then it is considered accurate to use the previous fit index reported as it is less sensitive to sample size. The confirmed structure and all their significant loadings (p-value < .01) can be found in Figure 2-3. Due to the lack of tau-equivalent measurement models, the omega reliability test was used (McDonald, 1999) with an overall value of .83 that indicates good reliability (Nunnally and Bernstein, 1994). Factors indicated acceptable reliability (.75 for CDV, .73 for CC and .63 for LA).

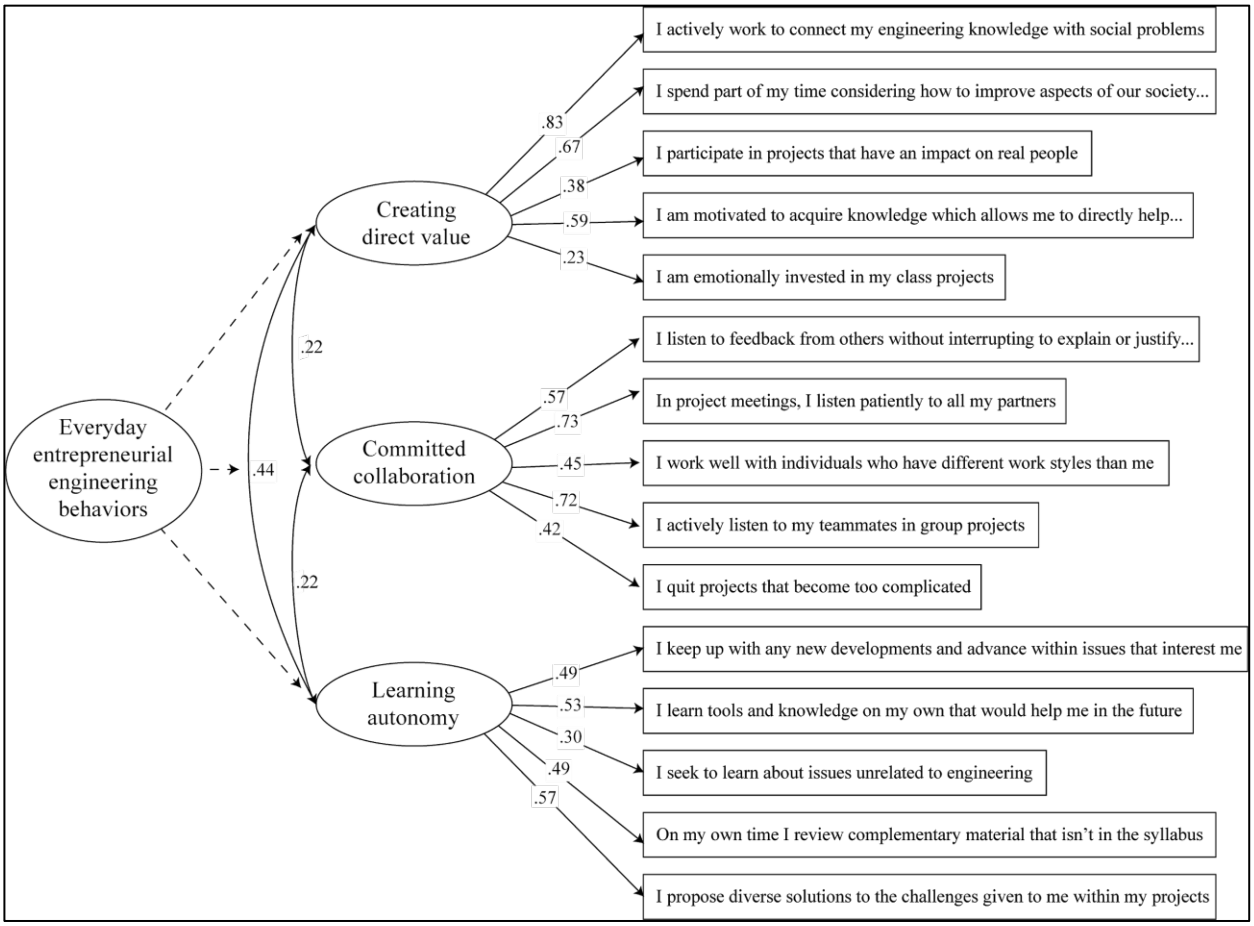

Figure 2-3: Confirmatory factor analysis result

3. DISCUSSION

This study was carried out using an exploratory research design with a qualitative phase that nurtured a quantitative phase, in order to develop an instrument to assess the entrepreneurial mindset in engineering education.

In the literature review, patterns among literature were found, and initial components were used for qualitative data collection.

The information gathered from workshops was analyzed using Grounded Theory methods, identifying themes among responses. These themes were translated into items that assessed attitudes and behaviors around entrepreneurship in particular contexts. After expert validation that studied each item's content, 27 of the 90 items were used for the initial instrument. The scale was applied in two cohorts of an entrepreneurial course, where 256 students voluntarily participated in the first sample and 348 participated in the second. After missing data was handled, factor analysis was executed to achieve construct validity. The structure found in the exploratory factor analysis has high loadings and few cross-loading, providing a robust solution that was later verified through confirmatory factor analysis. Fit indexes indicated that the model has a good fit (CFI=0.93, TLI=0.92, RMSEA=.04, SRMR=.063) and that the three-factor model measures what it is supposed to measure.

Through this study, different entrepreneurial mindset conceptualizations were carried out. Figure 3-1 displays the process.

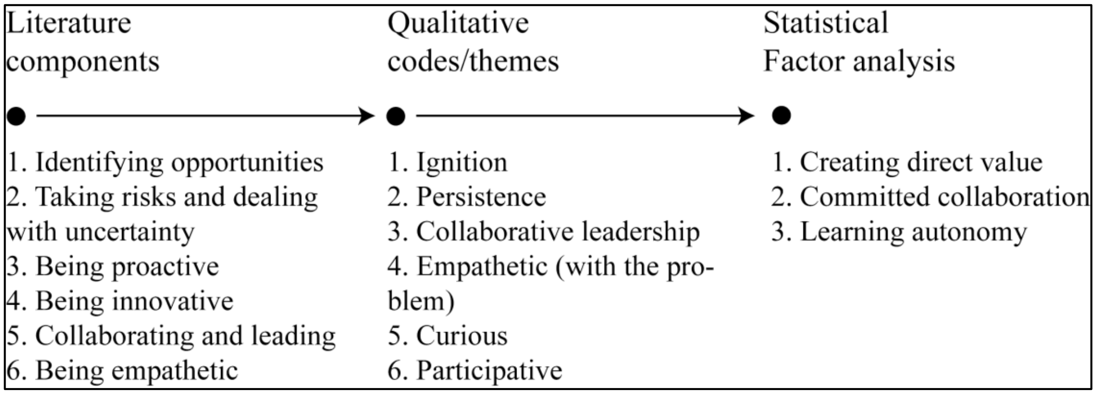

Figure 3-1: Entrepreneurial conceptualization process

The three-factor structure obtained, and the factor definitions are based on the items kept from the qualitative themes. For example, in the case of the "Committed Collaboration" factor, it gathered items from the Collaborative Leadership theme but excluded all leadership questions. For example, Q9: "In project meetings, I listen patiently to all my partners" and Q18: "I work well with individuals who have different work styles than me" were included. However, items such as "I assume leadership roles in my group projects" and "I avoid taking an active role in my projects because I am afraid it could affect the group result" were removed. Also, a question from the persistence theme was merged into another factor, Q5: "I quit projects that become too complicated."

The constructs identified in this study align with themes and traits found in related fields of entrepreneurial education. In the case of "Committed Collaboration," this factor gathered items about being an active listener, promoting a good team environment, and committing to the project. This factor's content is in concordance to Hoegl's (1998) social interaction model in innovation teams. One of the sixth factors he conceptualized and empirically tested was (1) communication (defined as the openness of the information exchange), and (2) cohesion (which is defined as the commitment to the team task). Although this framework is not directly attached to entrepreneurship education, authors have reinforced these concepts in the field (Zeng and Honig, 2016; Pisanu and Menapace, 2014).

Additionally, the factor "Creating direct value" grouped questions about tangible actions related to social conscience. It was found that although values like altruism and humanitarianism can be detached from reality, this factor translated the sense of responsibility for the problems of society into direct and concrete activities. Similar dimensions can be found in social entrepreneurship, which is sometimes considered a different field than conventional entrepreneurship (Steyart and Hjorth, 2006). The factor found has commonalities with Pache and Chowdhury model (2012) for social entrepreneurship in higher education as it recognizes students' social logic and their concrete goals to improve social and world conditions. The translation of students' social conscience to tangible activities is directly related to the educational institution policies and its influences in the curricula (Urbano, Ferri, Peris-Ortiz, Aparicio, 2017).

Lastly, the factor "Learning Autonomy" relates to curiosity and going beyond what is expected in engineering courses, carrying an autonomous and self-regulated learning process. These similar dimensions are most commonly described in entrepreneurship literature as broad concepts, like autonomy being the aim of entrepreneurship education (van Gelderen, 2010) and key factors for entrepreneurial well-being (Shir, Nikolaev, Wincent, 2019), although superficially related to curiosity. It is important to note that these were the validated constructs found in the research process related to the same unique latent variable, but the other discarded dimensions might be relevant for exploring other possible latent constructs.

4. LIMITATIONS

Although the exploratory methodology and phases displayed in this thesis can be replicated universally, the results should be applied thoughtfully. The qualitative information and analysis can be generalizable to the Chilean higher education context, although expert validation and student testing are suggested. For the factor structure found, it is needed to implement a measurement invariance for verification that the model fits the same way in different universities. Additionally, the items could be added to a new developing scale if it is theoretically pertinent. For the Pontificia Universidad Católica, the instrument could be applied in entrepreneurship courses to assess the entrepreneurial mindset.

5. CONCLUSIONS AND FUTURE WORK

This research provides evidence that a qualitative-quantitative approach can overcome the challenge in the operationalization of the entrepreneurial mindset in a way that is sensitive to the cultural context and the specific domain of engineering.

The present study has presented evidence showing that the generated scale shows considerable promise as a valid measure of self-reported engineering entrepreneurial behaviors. Therefore, this instrument can be used for several different applications, including efforts to evaluate various educational or training interventions to increase entrepreneurial behaviors among students and practicing engineers. More importantly, if coupled with other measures, the scale and its factors can provide a comprehensive assessment of the students' learning level at courses that teach entrepreneurship. The results can be used to inform the development of targeted interventions and program modifications to thrive and excel the behaviors of an entrepreneur in engineering students and prospective engineering professionals.

This research provides a validated instrument to assess the three-factor structure obtained in engineering education in the Pontificia Universidad Católica de Chile and a structure that can be explored in other universities with a proper adjustment and validation. The possible applications of this research and how they can be used are described as follows:

- To use the initial components to implement a qualitative collection for information through workshops or interviews
- To replicate a methodology for qualitative information analysis based on inductive Grounded Theory

- To use themes and codes that can be compared in different settings
- As evidence that business and venture creation tend to be detached to the entrepreneurial mindset in the qualitative information obtained from the actors in engineering education
- A methodology for factor analysis, relevant statistic literature, exclusion criteria, and model fit indexes
- A factor structure that can be tested in different national entrepreneurial environments through measurement invariance
- To test measurement invariance among gender, age, and engineering degree
- The use scale variables and their results for inferential statistics in entrepreneurship courses like ANOVA, Factorial ANOVA, MANOVA, and ANCOVA. The variables could also be used as predictors of other constructs by simple or multiple regression. This can be explored if it is theoretically appropriate.
- To use scale variables and their results for multivariate analysis, like Structural Equation Modeling (SEM) and Path Analysis. This can be explored if it is theoretically appropriate.

There are multiple valuable possibilities regarding this research project; the readers can replicate the research process for their own scale development in engineering education or use the scale displayed in this manuscript. For the second option, it is recommended to validate its use with one or more validation types like face, content, criterion, convergent, discriminant, or internal validity.

The next step in this research project is to create another version of the instrument for other cultural spaces and identify educational differences. It is also needed to nurture the instrument, evaluate its practical use and validate it externally.

There is entire disposal to continue collaborating with the project or any assistance regarding the methodology, results, or statistical procedures applied in this thesis.

"Validity is never quite over. It is a goal we strive for, but given the nature of engineering educational variables, the process of reevaluating the appropriateness of an instrument's use is ongoing." (Douglas and Purzer, 2015)

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APPENDIX

A. Final Scale

1	LA	I keep up with any new developments and advance within issues that interest me
2	CDV	I am motivated to acquire knowledge that allows me to directly help others when I work
3	CC	I actively listen to my teammates in group projects
4	LA	I propose diverse solutions to the challenges given to me within my engineering projects
5	CDV	I participate in projects that have an impact on real people.
6	CC	I quit projects that become too complicated
7	LA	I learn tools and knowledge on my own that would help me in the future
8	CC	I work well with individuals who have different work styles than me
9	CDV	I am emotionally invested in my class projects
10	CC	In project meetings, I listen patiently to all my partners.
11	LA	On my own time I review complementary material that isn't in the syllabus
12	CDV	I spend part of my time considering how to improve aspects of our society (for example, a more environmentally conscious city, social injustices)
13	LA	I seek to learn about issues unrelated to engineering
14	CC	I listen to feedback from others without interrupting to explain or justify my decisions
15	CDV	I actively work to connect my engineering knowledge with social problems

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Due to the use of double blind reviewing, please enter ALL co-authors into Manuscript Central!

An instrument to assess everyday entrepreneurial behaviors and mindset in engineering education: from qualitative workshops to psychometric validation

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An instrument to assess everyday entrepreneurial behaviors and mindset in engineering education: from qualitative workshops to psychometric validation

Abstract

Background: Current definitions and assessment of entrepreneurship in engineering education rely heavily on business education tools and venture creation. Literature argues the need for a redefinition and an evidence-based framework to evaluate the entrepreneurial mindset in the specific domain of engineering education.

Purpose/ Hypothesis: This article describes the development and psychometric validity of an instrument that measures the entrepreneurial mindset operationalized through everyday behaviors.

Design/ Method: Qualitative workshops were deployed to dig deeper in the components and to identify observable traits. Data was analyzed using Grounded Theory. A list of 90 items was created. Experts in engineering education analyzed the items and user-testing was done shortening items to 27. A first draft with 27 items was administered in a mandatory entrepreneurship course. An EFA was carried out in a 258 sample, and a CFA was executed on a 350 sample.

Results: For the qualitative stage 7 themes that describe everyday entrepreneurial behaviors were discovered. EFA resulted in three factors. CFA demonstrated that the correlated three-factor model provided an acceptable fit with the data. Evidence of validity indicates the scale's appropriateness for measuring the proposed behaviors.

Conclusions: This article shows that the entrepreneurial mindset in engineering can be operationalized through everyday behaviors. It provides the foundation for a redefined entrepreneurial behavior conceptual framework with revised items that are evidence-based and unique to engineering education. The three-factor model is validated in its context and has the potential to be complemented with other types of data to answer engineering entrepreneurship questions.

Keywords: engineering education; entrepreneurship education; exploratory factor analysis: confirmatory factor analysis

1 | INTRODUCTION

Over the past 20 years entrepreneurship education has seen a significant growth outside of business schools (Morris et al., 2013). Due to the accelerated pace of technological change and pressure on countries to transition into knowledge-based economies, entrepreneurship and innovation have become imperative to engineering education (Weilerstein and Byers, 2016; Shartrand, et al., 2010). Entrepreneurship has become more predominant in engineering (Weilerstein and Byers, 2016) in part because of the communities and institutions that have supported the integration of entrepreneurship in engineering more intensely than in any other field of study outside business schools.

In addition, there has been a worldwide exponential growth regarding the publication of articles related to the entrepreneurial mindset within the engineering education community (Farina et al., 2019). Today's engineers are perceived in need of entrepreneurial thinking to contribute to society's technological advancement (Winters, 2014). However, the definition of entrepreneurship for engineering is still an ongoing debate (Farina et al., 2019). The conceptual understanding of engineering entrepreneurship education is evolving by examining current educational practices and using theory to critique them (Huang-Saad et al., 2020; BLINDED, 2020). The reality is that most engineering education programs are designed to provide, and assess, business skills to engineers (Gilmartin et al., 2016; BLINDED, 2020) and not necessarily to promote other entrepreneurial learning paradigms that emphasize general attitudes, abilities, and traits that are not exclusive to business creation.

There is a current lag in theory about how to conceptualize and measure the entrepreneurial mindset in a way that is comprehensive enough for all relevant stakeholders (students, teachers, and decision-makers, among others). Huang-Saad et al. (2020) state: "Theoretical frameworks, research, and reviews of engineering entrepreneurship are needed to advance the understanding of this emerging discipline" (p.4). An evidence-based framework for the evaluation of a redefined entrepreneurial mindset in the specific domain of engineering education is needed (BLINDED 2020;). The existing ones seem to have issues with their psychometric properties (Douglas and Purzer, 2015; Moskal et al., 2002), are "borrowed" or adapted from other disciplines, are non-specific to engineering or are solely interested in business creation (Duval-Couetil, 2011).

This article thoroughly describes the development of an empirical-based instrument that evaluates a redefined entrepreneurial mindset, and it is operationalized through everyday behaviors. The methodology describes a three-stage process that starts with a qualitative and highly contextual phase where students, faculty and experts were consulted. It ends up with a psychometric validation where Exploratory and Confirmatory Analyses are undertaken to end up with a robust list of items and factors that assess entrepreneurial skills beyond business creation. Being highly contextual is a limitation of this methodological experience. On the other hand, the contributions of this article are three-folded. First, the strategies and decisions undertaken may shed a light on future efforts to assess the engineering entrepreneurial mindset in different engineering education settings. Second, the validated three-factor instrument can be validated in other contexts that are specific to engineering education. Lastly, data yielded from the application of this instrument can be complemented with other sources of data (i.e., students' trajectory, performance, teaching effectiveness) to answer research questions that are particular to engineering entrepreneurship education.

2 | THEORETICAL FRAMEWORK

Different methods have been used to assess engineering entrepreneurship students. These range from quizzes to project deliverables, surveys, interviews and concept maps (Purzer et al., 2016). Although diversity in assessment is considered positive, most of the evaluation tools used in engineering entrepreneurship education lack a "theoretical framework or research-based argument that guided their design" (Purzer et al., 2016).

Engineering entrepreneurship started by adapting business education into the engineering curricula with the goal of creating new technology-driven startups (Weilerstein and Byers, 2016). Over time, more and more researchers and practitioners have become interested in the significance of entrepreneurship beyond the creation of new enterprises. Anderson (2015) points out that researchers have usually reduced entrepreneurship to generate economic growth while the social, emotional and aspirational aspects of the construct are often underplayed. He calls it the economic reification of entrepreneurship (Anderson, 2015; BLINDED, 2020). There is an argument to be made about the educational benefits of defining entrepreneurship as more than venture creation in the context of formal education (BLINDED, 2020). In engineering, this has meant that the conversation has changed from promoting an entrepreneurial intent for the creation of new businesses to the development of an entrepreneurial mindset (Huang-Saad et al., 2018).

Many of the surveys created to assess engineering entrepreneurship education are based on venture creation. Some examples are the Engineering Entrepreneurship Survey by Duval-Couetil et al. (2011) and the Engineering Mindset Rubric by Shartrand et al. (2008). Beyond these types of business-creation assessments, efforts have been made to provide instruments that eradicate competencies associated with commercialization. KEEN (Kern Entrepreneurial Engineering Network) uses a specific approach to defining the entrepreneurial mindset (EM) with 3C's: *Curiosity, Creating value,* and *Connections*. Some examples for assessment are developed by Li et al. (2016), Schoonmaker et al. (2020), or the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) by Brunhaver et al. (2018). Some of these were validated using psychometric standards and provide enough evidence for reliability as quantitative measures. However, although the KEEN 3C's framework is popular among researchers and is useful as a non-business-oriented guideline, KEEN-created instruments lack the full research underpinning of empirical research (Huang-Saad et al., 2020). For instance, the ESEMA (Brunhaver et al., 2018) did not incorporate any empirical evidence when constructing the instrument items and depended on the theoretical validity of the KEEN framework.

The work of London et al. (2018) shows that, when analyzed through the lens of academic literature, the 3C's transform into 12 themes rather than three. Moreover, when assessed using psychometric analysis from engineering students, those 12 themes then transform into 7 factors (Brunhaver et al., 2018). This shows that the entrepreneurial mindset cannot be reliably assessed using KEEN's 3C and there is reason to believe that researchers should conduct independent research to re-interpret KEEN's mission to instill the EM into engineering education beyond the idea of commercialization (Hylton et al., 2020).

Despite the assessment instruments, interesting literature can be found in the KEEN environment regarding definitions for the entrepreneurial mindset (EM) outside the business-creation paradigm and in the specific context of engineering. One of the major difficulties when evaluating the entrepreneurial mindset is to turn the abstract concept of "mindset" into measurable observations. This means that the mindset concept's abstraction is an obstacle to its operationalization. To address this problem Bekki et al. (2018) proposed a definition for the entrepreneurial mindset as the "set of cognitive behaviors that orient an engineer towards opportunity recognition and value creation in any context, not just that of an entrepreneurial venture" (p.2). Accordingly, KEEN authors found that entrepreneurship literature in engineering is separated into two concepts: mindset outcome (idea or attitude) and behavioral outcome (action) (London et al, 2018). These definitions are valuable to establish behaviors as a way to operationalize the entrepreneurial mindset.

Apart from the economic reification of entrepreneurship and the lack of rigor in the assessment of entrepreneurship, there is evidence that a common mislead when assessing entrepreneurship is the evaluation of the possession or not of the entrepreneurial mindset

(BLINDED, 2020). Instead of a binary category, the entrepreneurial mindset or skills should be assessed as a spectrum. Therefore, this study's conceptual discussion is based on the entrepreneurial mindset's operationalization through observables everyday behaviors.

In summary, there are still major challenges when devising theoretically sound and context-sensitive assessment methods in engineering entrepreneurship education. In particular, three major gaps have been identified while reading through this theoretical framework. In the first place, there is a lack of surveys or instruments that focus on entrepreneurship beyond business creation. Secondly, there is a lack of surveys that are generated without giving emphasis to one particular institutional framework (for instance, the KEEN framework). Finally, there is still a challenge in the operationalization of the entrepreneurial behaviors in a way that is sensitive to the cultural context and the specific domain of engineering (BLINDED, 2020). Therefore, the research questions this study tries to tackle are the following:

RQ1. What are the measurable dimensions of the everyday entrepreneurial behaviors in the context of engineering?
RQ2. How can these dimensions be translated to observable and quantifiable items for instrument assessment?
RQ3. What are the statistical properties of validity and reliability of the instrument?

3 | METHODOLOGY

This research contemplates the use of a sequential exploratory mixed design, which is often used to develop comprehensive instruments (Creswell and Plano Clark, 2008; Tashakkori and Teddlie, 2010). This type of methodological design allows qualitative, contextually rich data to guide item construction for quantitative surveys, producing more solid and grounded instruments (Onwuegbuzie, Bustamante and Nelson, 2010). **Figure 1** portrays the methodological overview of these sequential quantitative and qualitative phases which will be explained in detail.

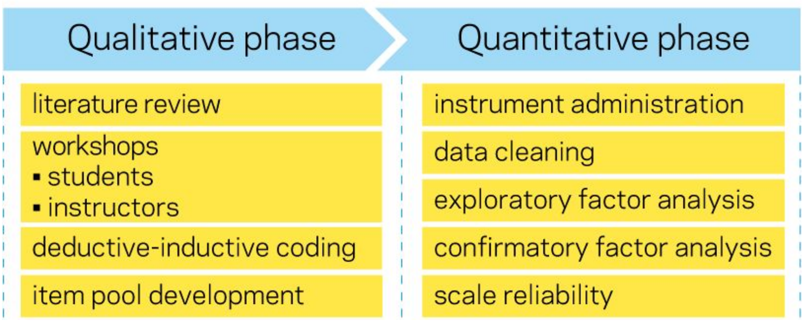

Figure 1. *Methodological overview*

4 | QUALITATIVE PHASE

4.1 | Literature review

The process started by setting up a multidisciplinary team coming from the areas of engineering education and educational psychology. The team conducted a thorough narrative style (Ferrari, 2015) literature review to identify components of the entrepreneurial mindset. **Figure 2** shows, the areas where the review was undertaken. These include a) education or learning theory b) engineering education, and c) business management. Publications from the last ten years were searched in Web of Science and Scopus databases. The main objective was to guide the construction of items and give the theoretical grounding for the overall definition construct of engineering entrepreneurial mindset. The team looked to answer (1) what are the components of the entrepreneurial mindset that cross the different entrepreneurship paradigms beyond business creation? (2) what are the main challenges and theoretical considerations needed when conceptualizing and defining the entrepreneurial mindset in engineering?

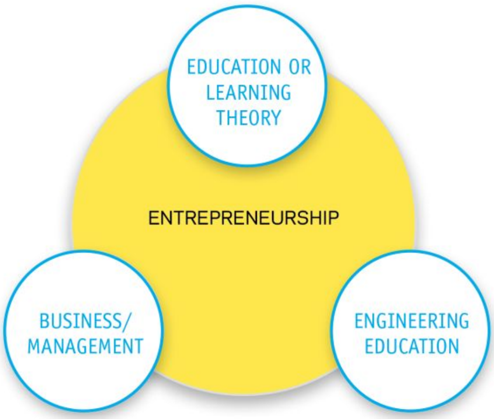

Figure 2. *Disciplinary areas for the literature review*

The keywords used were: “entrepreneurship education”; “entrepreneurial mindset”; “entrepreneurial cognition”; “entrepreneurial skills”; “engineering entrepreneurship education”; “engineering entrepreneurship”. The criteria for inclusion and exclusion of studies were determined by the abstract and date of publication. Articles whose abstract indicated a discussion around the definitions and/or components of entrepreneurship were included. Exclusion criteria involved articles defining entrepreneurship as business-creation or with no clear conceptual discussion of entrepreneurship’s definition and/or delimitation. Emergent themes were identified in the different sources and were discussed by the team to check on their prevalence. These patterns evolved in categories that guided a second focused review to explore and complement that theme.

We were able to find both commonalities and challenges to the task of identifying components of the entrepreneurial mindset. For the commonalities, we were able to find key publications that already revised the components of the entrepreneurial mindset through different types of literature. Clark and Harrison (2019) conducted a multi-perspective and integrated review of the literature to identify patterns in all schools of Entrepreneurship Studies. They concluded that four key elements should be present in an integrated definition of entrepreneurship, namely: (1) Opportunity, (2) Risk, (3) Pro-activity and (4) Innovation. This synthesis provides a broad but sound initial composition.

Many scholars in the 'new venture tradition' (Clark and Harrison, 2019) have focused on the entrepreneur as a lone hero, but this is not representative of the actual entrepreneurial process which is usually carried out in teams (Cooney, 2005). As Warhuus and Jones (2016) put it: 'in reality, developing collaborative competences is more in line with the life of everyday entrepreneurs who have to form networks and learn to draw on the resources of others' (235). This is why (5) Collaboration was also included in the list. Another major component of entrepreneurship is the creation of value for others. The literature revision of Shepherd et. al. (2019) is consistent with the previously mentioned components but focuses more closely on the role of value creation in initiating business endeavors. Shepherd et al. (2019) value can be social, economic or environmental. This is also consistent with Korte et al. (2018) review of empathy as a key component of entrepreneurship. Therefore, (6) Empathy and Value creation for others was also incorporated to the initial list. This final list of components reflects most of the dimensions present in other reviews such as London et al. (2018) or Commarmond (2017). These components are:

1. Identifying opportunities
2. Taking risks and dealing with uncertainty
3. Being proactive
4. Being innovative
5. Collaborating and leading
6. Being empathetic

We concluded that these broad constructs did not provide enough information to drive the creation of items. These constructs were not specific to engineering education and did not relate to the cultural context of the target population. As Figure 3 shows, the team felt the need to triangulate this information sourced in praxis. This included the perception of students, instructors and professors involved in engineering classes. A qualitative inquiry was used to address the following question: How do these broad components translate into the experience of a particular population and their cultural context?

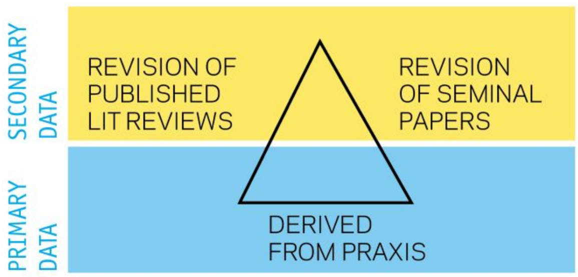

Figure 3: *Triangulation of information by sources*

4.2 | Qualitative data collection

Students were selected using purposive sampling (Patton, 1990) that ended when data saturation was achieved, contingent on the ultimate goals and analytical framework developed (Saunders et al., 2018). Four 1-hour-long workshops and semi-structured interviews were carried out in an engineering school throughout 2019. Three of them were done with engineering students and one of them with engineering professors/instructors. In particular, the instructors and tenured track professors involved were linked to courses that specifically taught entrepreneurship using problem-based learning. The number of students that participated were 16, all from undergraduate programs. Ages ranged from 18 to 25 years old, 11 were men and 5 were women. Their engineering sub disciplines involved: industrial engineering, mechanical engineering, civil engineering, environmental engineering, biomedical engineering, computer sciences, electrical engineering and transportation engineering, among others.

Figure 4 showcases workshops that used cultural probes to engage in activities that would yield specific conversations directed to identifying examples, observable conducts and educational practices related to entrepreneurship in engineering. The questions and protocols were subjected to a first iteration after testing with a few individuals. The research protocol for the workshop implied one moderator and one individual taking notes and recording. All participants were informed about the nature of their participation and signed informed consent documents approved by the IRB. The workshop started with an opening part where the team and the participants introduced themselves. Then, to break the ice, a free-listing (Weller and Romney, 1988) activity where the participants were asked to write down all of the words related to entrepreneurship and explain their choices. This part of the activity also serves to explore the cognitive domain or categories that the individuals attribute to entrepreneurship as a contested concept. Finally, participants were presented with fictional characters and were asked about visible behaviors and practices related to the categories identified in literature like collaboration, empathy and risk taking, among others. All of the workshops were video-recorded and transcribed in order to do qualitative data analysis with their results.

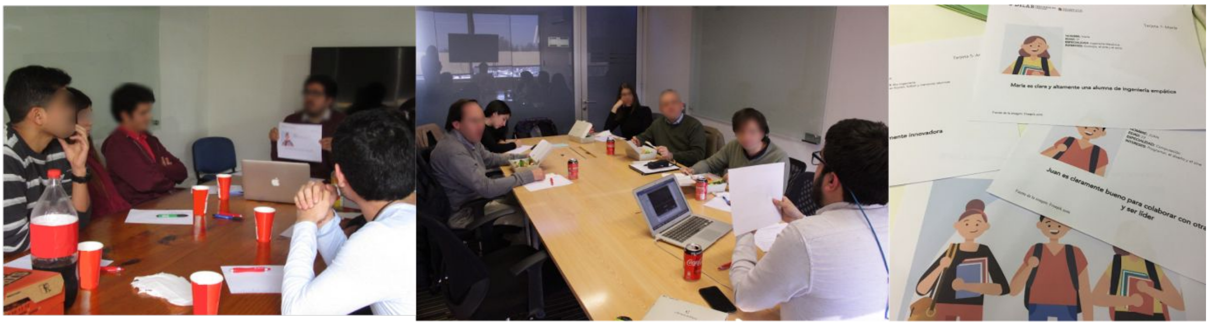

Figure 4. *Pictures of the workshops and probes used.*

4.3 | Qualitative data analysis

Three researchers engaged in a two-phase coding process for the raw qualitative data obtained from the transcriptions. Having the research objectives in mind, each workshop was purposely coded as behaviors/practices and classified under the attribute being asked. They were also classified into three categories: 1) conducts, 2) examples and 3) educational practices. In the second phase, identified behaviors/practices were inductively regrouped into qualitative themes regardless of their initial attribute or data production event. Behaviors and examples were coded independently from educational practices.

The first phase used a deductive approach with theory-driven codes (Fereday and Muir-Cochrane, 2006) to bridge theory with raw data. Non-positivist qualitative researchers often use theory-driven analysis to allow for perspective-taking and critical distance with the final result (Haardörfer, 2019). This strategy intended to connect qualitative data with the review of the literature in order to produce a theoretically strong final survey. Themes were determined *a priori* based on the literature review. The *a priori* themes (or attributes) defined were:

1. Identifying opportunities
2. Taking risks and dealing with uncertainty
3. Being proactive
4. Being innovative
5. Collaborating and leading
6. Being empathetic

All conducts and educational practices that participants associated with these attributes were extracted from the transcripts into a digital table, dividing conducts/examples in one table and educational practices in another. Each data production event was coded independently. The research team observed that many times, codes attributed to one theme were more related to other codes than to the overarching theme and that there were some subtle conceptual differences between the theoretical themes and how the participants perceived them. In order to enhance the internal consistency and content validity of the qualitative findings, the research team decided to re-group the data using an inductive method.

The second coding phase used an inductive approach with data-driven codes using Grounded Theory (Glaser and Strauss, 1967). Theoretical sensitivity (Strauss and Corbin, 1994) was maintained when regrouping codes as a theoretically strong instrument was still an objective for researchers. In this sense, the methodological approach is more aligned with Strauss conceptual approach to Grounded Theory over Glaser's empiricism (Heath and Cowley, 2004).

Themes were created inductively by identifying patterns and similarities across behaviors regardless of the initial attribute and data production event they originated in. Codes were independently grouped by researchers and then collectively negotiated and discussed as to achieve sufficient (1) internal consistency (2) clarity (3) theoretical meaningfulness and (4) groundedness in data. The final result was translated into another unified digital table. Table 1 displays the final themes obtained during the coding process.

Table 1
Qualitative themes

Theme	Description
Proactivity	This theme describes the entrepreneurial mindset as the ability to be creative and proactive (think of engineering ideas, start projects, come up with solutions to engineering challenges, etc.).
Persistence	This theme describes the entrepreneurial mindset as the commitment to educational tasks, personal projects and the ability to learn from mistakes and avoid discouragement.
Collaborative leadership	This theme describes the entrepreneurial mindset as the ability to lead engineering groups by managing group conflict, administrating tasks and being a good listener.
Project Empathy	This theme describes entrepreneurship as concern about and empathy with the world or society problems. This is depicted as being motivated when engineering challenges relate to real-world issues and to be emotionally involved in the engineering projects that involve real people.
Curiosity	This theme describes entrepreneurship as being well-informed about the latest technologies and trends. This, in turn, is perceived to lead to more interest in life-long learning and taking advantage of learning opportunities outside the classroom.
Goal directed	This theme describes entrepreneurship as having achievement goals and being ambitious. This is depicted as aspiring to have your work recognized by others, as aspiring to get good results in your engineering projects and as aspiring to being recognized by your peers and teachers.
Participatory	This theme describes entrepreneurship as participation in different events (social, political, religious) and membership in different organizations (sports, politics, religion, social help, etc.).

4.4 | Instrument development

To transform qualitative themes into items, we conducted a focused review of the literature. We sought to identify guidelines and recommendations to keep in mind when producing items. We followed the general recommendations provided by DeVellis (2017), Krosnick (2018) and Vanette (2018). With these considerations in mind, the team decided to design a five-point (with word labels) unipolar survey to ask behavioral questions (Tourangeau et al., 2000) about the entrepreneurial mindset. Figure 5 displays Rohrmann's (2015) recommendation for frequency scales qualifiers to maximize familiarity and equidistance of results.

Figure 5. *Frequency scale qualifiers adapted from Rohrmann's (2015)*

In order to create and pre-test the instrument, the following five-step process was undertaken:

1. Determine the linguistic structure of a desired item
2. Create a theme-item table to facilitate translation from qualitative information to items
3. Make item pool for every theme
4. Conduct expert validation
5. Conduct cognitive interview

There is no clear step-by-step guidelines on how to write items based on qualitative information were found in the literature, we decided to analyze the structure of exemplary survey items. This analysis was carried out to create a more specific guide to write items based on how other exemplary items were written by observing their underlying linguistic structure. We focused on the type of information present in these items and how this information was put in order when written in a sentence (in linguistic terms, their morphosyntactic structure). Analyzing the morphosyntactic structure of exemplar survey questions from Fries-Britt et. al. (2018), Crede and Borrego (2013) Duval-Couetil et al. (2011) and Brunhaver et. al. (2018) while also considering the theoretical challenges to assess the entrepreneurial mindset (BLINDED, 2020), we produced a tentative structure to guide item writing. Figure 6 displays that structure.

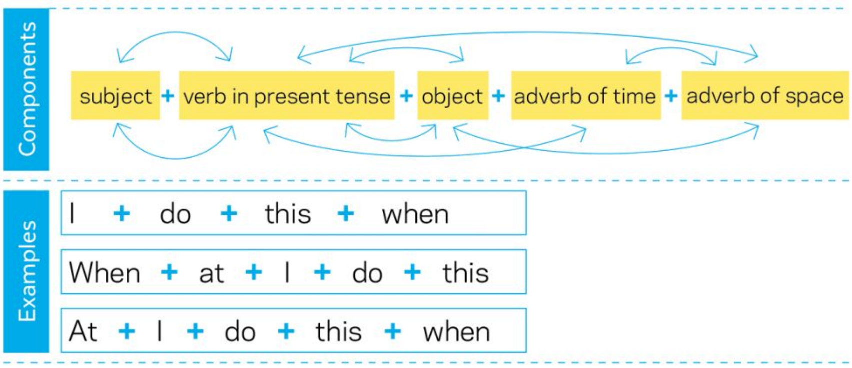

Figure 6. *Components identified for the items' syntax and some examples. It is important to understand that these components can be moved around.*

Example: *I + suggest + taking turns + at group meetings + when we are discussing ideas*
Example: *When we are presenting our results + in the classroom, + I + respond to + the teacher's question*

Using this syntactic structure, members of the research team developed item ideas based on the qualitative findings. Each theme was used by every researcher to produce at least 10 items. Each item was constructed identifying a behavior expressed by the participant as the core verb, “I” as the core subject and identifying objects, and predicative complements from the quotes, context or raw data (in case one or more elements are not found). To facilitate the process a theme-item table was used. Table 2 shows an example of the theme-item table used to generate items.

Table 2
Theme-item table

Themes	Code	Quote	Items ideas
Proactive	In the course, groups go beyond what they've been asked to do	I think that in our course class projects for example, they try to take risks, meaning they are asked for “something” and they go beyond what they’ve been asked to do, they do more advanced work.	1. I do more advanced work when working on class projects in my engineering courses 2. I try to take risks when working on a class project in the university
	Students go further than the achievable	There is a word that a professor uses that sums it up: “audacity”, meaning how bold you are in your project. If the students are actually thinking beyond what someone might think as achievable. They go further. There you have someone really innovative	3. I try to do more than what the teachers demand from us when planning my project at group discussions

After all the items were developed independently for the item pool, the team met to select the final 7 items per theme. For the process of item selection, we used the guiding questions proposed by Blair et al. (2013,153-154). After the selection process was carried out the first pool of items was created containing 90 questions.

To examine the content validity of our survey, these first item pools were sent to be examined by experts in the field (Boateng et. al, 2018). These were individually reviewed by two experts in higher education, on the one hand, and two experts in the specific context of engineering entrepreneurship on the other hand. Four of the experts hold PhDs in Education. The other expert coordinates the division of Innovation and Entrepreneurship of one engineering school.

Experts rated each item based on relevance and interpretability on a 1-3 scale. Questions were: 1. Is the item understandable? (Yes /Not sure /No) and 2. Is the item relevant? (Yes /Not sure /No). Additionally, all expert reviewers shared comments and recommendations to improve individual items.

As an additional step to examine the content validity of our survey we conducted cognitive interviews with the target population. We used a probes approach to cognitive interviewing (Willis, 2018). We used the following probes to assess each individual item:

1. Comprehension probes: What does the term “X” (e.g., “an engineering problem”) mean to you?
2. Paraphrasing: Can you repeat the question in your own words?
3. Confidence judgment: How sure are you that you do this action with X frequency

Through an analysis of both experts’ scores and comments and through a triangulation with data from the cognitive interviews, 27 of 90 items were selected and improved. The second pool had the best scores according to the experts and were properly understood and judged by the participants. All 27 items were distributed among six dimensions. The “goal directed” category and its items were removed following the advice of experts because, although it was notably present in the qualitative data, it reflected a more competitive side of engineering entrepreneurship that an educational-driven survey should not help reproduce.

5 | QUANTITATIVE PHASE

5.1 | Quantitative data collection

The participants of the questionnaire were students from an entrepreneurial course in a Chilean Engineering School. This a mandatory, project-based course for all third-year undergraduate engineering students. The questionnaire was implemented in the first and second semester of 2020. An informed consent approved by the university’s ethics committee was used at the beginning of the survey. Table 3 shows the demographic information of the 2020-1 (March) and 2020-2 (August) samples.

Table 3
Participants demographic information

	2020-1	2020-2
	First sample	Second sample
n	305	414
Gender		
%Female	29	27
%Male	69	71
%Rather not say	2	2
Age		
%24 or more years	11	6
%23 years	20	12

%22 years	30	23
%21 years	34	47
%20 years	5	11
%19 years	0	1

5.2 | Quantitative data analysis

Factor analysis is a statistical procedure that can collect relevant validity evidence and allows the researcher to explore and confirm the relationships of latent variables in a survey. An exploratory factor analysis (EFA) nurtures a confirmatory factor analysis (CFA). The analysis procedures followed Thurstone (1947) parsimony principle for factor analysis, which aims to work towards the simplest explanation consistent with the data.
For the analysis, we changed reversed-negative questions and cleaned the data by deleting missing responses. The first sample had a response rate of 84%, as 256 of the 305 surveys were completed. Similarly, the second sample had a response rate of 84.5%, as 348 of the 414 surveys were completed.

There is no clear agreement on the minimum sample size for factor analysis. According to the rule of thumb, the minimum sample for CFA is 300 (Wilson Van Voorhis and Morgan, 2007). To conduct an EFA, the minimum sample is often considered 50, but even a smaller sample can yield reliable results (Winter et al., 2009). Based on this, we used the first admissible responses database (N=256) for EFA and the second admissible responses database (N=348) for CFA. All data analysis was performed using the RStudio software, version 1.3.1093. For the EFA, we used the psych package (Revelle, 2018) and the nFactors package (Raiche and Magis, 2010). For CFA, we used the lavaan package (Rosseel, 2012).

5.2.1 | Exploratory factor analysis

The goal of exploratory factor analysis (EFA) is to explain the relations among observed variables through a reduced number of non-observed variables (or latent). This technique reveals the underlying structure among items and helps define a set of highly interrelated variables, known as factors, that represent dimensions within the data (Hair et al., 2018). This technique allows to find the factor structure of a newly developed scale (Fabrigar et al., 1999) and therefore is a valuable tool for the researcher. This is achieved using the smallest number of items to explain the maximum amount of common variance in a correlation matrix (Tinsley and Tinsley, 1987). Another popular technique for instrument validation among scholars is principal components analysis (PCA). However, it is frequently confused as an estimation method of common factor analysis (Brown, 2006). PCA does not differentiate common and unique variance; thus, it does not explain the correlations among items. Many authors consistently condemn its use and affirm that the reason for this misconception is that PCA is the default function in many statistical analysis programs (Carpenter, 2018; Osborne and Costello and Osborne, 2005; Matsunaga, 2010).

Before running the EFA, we primarily inspected the first sample data to verify that the items were significantly correlated and suitable for factor analysis. Bartlett's test of sphericity was used, with a result of χ^2=306.9 (df=26, p<.001), corroborating that the sample's correlation matrix was significantly different from an identity matrix. The adequacy of the sample was then analyzed using the Kaiser-Meyer-Olkin (KMO) test. In this test, the semi-partial correlations of an item with the rest of the items are examined. It evidences if the items share sufficient variance with the Measure of Sample Adequacy (MSA) metric, indicating how correlated the items are as the MSA approaches value 1. A total MSA of .81 was obtained with the 27 original items, with a minimum MSA of .66 and a maximum of .89. Based on Kaiser (1974), a total MSA greater than .80 is "meritorious" for proceeding with an EFA (p.35). Other references, such as Kim and Mueller (1978), Hair et al., (1996), confirm that values greater than .80 are considered excellent.

Once the sample's adequacy was confirmed, it was also tested whether there was multivariate normality. Mardia's test was used, where the assumption was not fulfilled since non-item univariate normality was found. According to this finding, the extraction method chosen for exploratory factor analysis was principal axis rather than maximum likelihood. We selected this method because it is recommended when the assumption of multivariate normality is "severely violated" (Fabrigar et al., 1999). According to Costello and Osborne (2005), principal axis factors will give the best results when data are significantly non-normal. Additionally, the principal axis method reveals underlying latent factors based only on the shared item variance, including communalities and excluding unique and error variance (Kim and Mueller, 1978).

Factor rotation is a mathematical transformation that facilitates interpretability; its purpose is to obtain theoretically meaningful factors and look for the simplest structure (Hair et al., 2018). This is achieved by rotating the factors' reference axes and allowing them to get closer to the variables' location. As Brown (2006) states, there are two types of rotation, orthogonal and oblique. Orthogonal rotation constrains the factors to be uncorrelated (90° from each other), while in oblique rotation, the factors correlate (less than 90° from each other).
In most disciplines, constructs tend to be at least marginally correlated with each other, so oblique rotations are mostly recommended (Osborne and Costello and Osborne, 2005; (Fabrigar et al., 1999). Obliques rotations are also more realistic because the theoretical underlying dimensions should always be correlated (Hair et al., 2018). Therefore, we used a type of oblique rotation named direct oblimin (with gamma value zero) because we also expected correlations among factors.

To define the best structure, it is necessary to establish the number of factors to extract. There are several approaches; although some work better than others, none of them is valid for all cases (Lewis-Beck et al., 2012). Therefore, it is needed to use different criteria and look for convergence among them, simultaneously to the solutions' interpretability. Based on this, we used three different criteria. First, we used the Kaiser rule (1974) that proposes that a factor could be worthwhile if its eigenvalue is higher than 1.0. The eigenvalue equals the sum of

each item's squared factor loadings; therefore, eigenvalues above 1.0 are only achieved when there are large factor loadings to square and sum (Costello and Osborne, 2005).
According to Brown (2006), another popular approach is scree plots (Catell, 1966). This method consists of examining the graph with eigenvalues plotted and looking for sections where the curve flattened to determine the number of factors (Netemeyer et al., 2003). It is important to consider that the number of factors is determined by the point where the curve bends and not when the drastic break occurs (Costello and Osborne, 2005). The third criterion is parallel analysis, introduced by Horn (1965). This technique consists of comparing the sample's eigenvalues with eigenvalues from generated random uncorrelated data. The factors that should be retained are those above the line of the simulated eigenvalues. With the 27 items, the suggestion provided by Kaiser rule, scree plot, and parallel analysis were three, four, and four factors, respectively. Therefore, we ran the analysis with three and four factors, aiming to find the precise number of factors that produced the best conceptual sense. However, the four-factor solution was uninterpretable and also involved one factor with two items, that is highly not recommended (Viswanathan, 2010). We chose then to explore a three-factor structure for the first EFA because it displayed conceptual sense and model parsimony.

5.2.2 | Confirmatory factor analysis

As exploratory factor analysis allows to explore underlying factor structures, confirmatory factor analysis (CFA) is used to confirm a hypothesis. In this technique, the researcher has a conceptual foundation about the constructs and their relationship based on empirical work results. It is needed to specify the factors, their associations, and the relations with their indicators. The purpose is to assess which of the hypothesized or imposed models fit a different sample's data (Finch and French, 2015). A CFA is carried on a separate sample to confirm the proposed scale structure resulting from EFA (Kline 1994; Costello and Osborne, 2005). CFA must be used to validate the dimensional structure of a measure in every developed scale, to prevent literature being built on illegitimate instruments as this usually happens (Levine et al., 2006). This procedure is mostly deductive, focusing on the extent to which the hypothetical covariance matrix imitates the observed covariance matrix, adding restrictions to the model.

For the execution of the CFA, the measurement model must be identified. We decided to fix one loading of each factor to 1.0 to estimate the factors' variance freely. We also checked multivariate normality on the second sample with Mardia's test. The assumption that data followed a normal distribution was rejected. Therefore, we used a maximum likelihood estimator with robust Huber-White standard errors (MLR in lavaan).

Once parameters are estimated, it is needed to evaluate if the model fits the data. As Finch and French (2015) state, the question is, "Is the model able to reproduce with accuracy the covariance matrix of the observed variables?" (p. 40) This question can be assessed by three types of indices: absolute fit, comparative or incremental fit, and fit adjusting for model parsimony. The most used absolute fit indices are chi-squared and standardized root mean square residual (SRMR), although the first is rarely used in applied research as a single index of model fit and will almost certainly be rejected when the sample size is sufficiently large (Finch and French, 2015; Brown 2006). The incremental fit indices compare a baseline model that has all indicators covariances fixed to zero. The comparative fit index (CFI) and Tucker-Lewis index (TLI) have demonstrated the best performances of all indices introduced in the literature (Brown, 2006). The most utilized and recommended index which adjusts model parsimony is the root mean square error of approximation (RMSEA) because it incorporates a penalty function for less parsimonious models.

5.3 | Quantitative data results

5.3.1 | Exploratory factor analysis (EFA) results

We performed EFA iteratively and examining the theoretical sense of each structure. Items were removed one at a time and reran the factor determination using the Kaiser criterion on eigenvalues, a scree plot, and parallel analysis. In every decision, parsimony was the goal. The first criterion for item elimination was low loadings. A factor loading represents how meaningfully related is the item with a factor. There is no consensus in the literature on which factor loading cut-off to maintain. There is literature supporting that maintaining loadings above .30 is acceptable (Tinsley and Tisley, 1987; Kachigan, 1986; Pett et al., 2003), and Kline (1994) defines loadings above this threshold as moderately high. Another rule of thumb is setting .32 as a minimum loading for an item, as Tabachnick and Fidell (2001) recommend, as well as Worthington and Whittaker (2006). However, to pursue a more parsimonious structure, we wanted to ensure that each instrument's item represented the construct of each factor. Therefore, we set .40 as the minimum for item retention as several statisticians recommend (Ford et al.,1986; Floyd, 1995; Reinard, 2006; Hair et al., 2018). We removed seven items based on this criterion (20 items remained).

After obtaining a model with loads above .40, we then analyzed cross-loadings. A cross-load is defined as a large factor loading onto multiple factors. Minimizing cross-loadings helps achieve a simpler structure solution where there is only one high loading for each variable in one factor. Although most scholars do not report cross-loading cut-offs, some established an unvarying difference of 0.2 or 0.1 (Howard, 2016). However, we used the guidelines described in Hair et al. (2018) that compare ratio variances instead of loadings and address relative magnitude loading. Based on this principle, we removed items Q12 and Q22 because they had problematic cross-loading (ratio of 1.17 and 1.3 respectively) and Q21 because it was potential cross-loading (ratio of 1.7).

After the removal of the items, 17 items were retained, and all criteria that aim to determine the number of factors (eigenvalues, scree test, and parallel analysis) suggested three factors. One of the factors gathered items regarding curiosity, information seeking, and self-learning. This factor was primarily named "Learning autonomy" (LA). Another factor associated with good team players behaviors such as listening, team collaboration, and project commitment. This factor was named "Committed collaboration" (CC). Finally, the "Creating direct value"

(CDV) factor gathered items about social problems and constant search for meaningful projects. Although each factor's conceptual core was well defined, two items added noise to the interpretation. As Matsunaga (2010) stated, the resultant pool of items should contain only items that tap theoretically meaningful and interpretable factors. In this case, the question Q7 "I assume leadership roles in my courses projects," was not related to its factor "Creating direct value," and Q11, "I work well with people with different academic interests," could be held to confusion. Those items were removed from the scale. The conceptualization of these factors and their descriptions are further discussed in the "Discussion" and "Conclusion" section of this manuscript.

The final structure proposed has 15 items, with loading ranging from 0.4 to 0.78 and communalities ranging from 0.28 to 0.66. Although communalities are low, all fulfill Child's (2006) threshold of 0.2. This can be found in Table 4. All factor eigenvalues are greater than the minimum reference of 1.0. For unrotated factors, the values are 2.83 for the CDV factor, 1.40 for the CC factor, and 1.02 for the LA factor. After rotation, eigenvalues were 2.15, 1.67, and 1.43 respectively. The 15-item instrument explained 35% of the variance in the pattern of relationships among the items.

Table 4

Exploratory factor analysis results, factor loadings, and communalities

Item	LA	CDV	CC	Communality
Q24: I keep up with any new developments and advance within issues that interest me.	0.6			0.33
Q19: I learn tools and knowledge on my own that would help me in the future	0.51			0.26
Q26: I seek to learn about issues unrelated to engineering	0.5			0.28
Q13: On my own time I review complementary material that isn't in the syllabus	0.49			0.23
Q25: I propose diverse solutions to the challenges given to me within my engineering projects	0.42			0.35
Q20: I actively work to connect my engineering knowledge with social problems		0.78		0.66
Q15: I spend part of my time considering how to improve aspects of our society (for example, a more environmentally conscious city, social injustices)		0.67		0.42
Q4: I participate in projects that have an impact on real people.		0.64		0.37
Q2: I am motivated to acquire knowledge that allows me to directly help others when I work		0.54		0.34
Q8: I am emotionally invested in my class projects		0.46		0.28
Q16: I listen to feedback from others without interrupting to explain or justify my decisions			0.69	0.47

Q9: In project meetings, I listen patiently to all my partners.	0.64	0.39
Q17: I work well with individuals who have different work styles than me	0.5	0.28
Q18: I actively listen to my teammates in group projects	0.54	0.36
Q5: I quit projects that become too complicated	0.4	0.22

5.3.2 | Confirmatory factor analysis results

The next step was to fit the second sample with the structure previously found with the first sample. After the CFA execution, it was found that the three-dimension model fits the empirical data well. The robust CFI and robust TLI values were 0.93 and 0.92, respectively, above the 0.9 threshold (Hu and Bentler, 1995). The robust RMSEA was a significant .04, with a 90% confidence interval of .029 and .056, indicating a good fit (MacCallum, Browne and Sugawara, 1996). The robust SRMR was .063 that is below the .08 value proposed by Hu and Bentler (1999) as a good fit. Although all fit indexes indicated a good model fit, the chi-square obtained was 139.5 (df= 87) with a significant p-value ($p<.001$). This indicates that there is a significant difference between the observed covariance matrix and the estimated covariance matrix. However, it is known that statisticians disagree about the utility of this metric for evaluating model fit as it is susceptible to sample sizes greater than 200 (Brown, 2015; Schumacker and Lomax, 2010; Hair et al., 2018). The second sample used in CFA is larger than 200, then it is considered accurate to use the previous fit index reported as they are less sensitive to sample size. Due to the lack of tau-equivalent measurement models, the omega reliability test was used (McDonald, 1999) with an overall value of .83 that indicates good reliability (Nunnally and Bernstein, 1994). Factors indicated acceptable reliability (.75 for CDV, .73 for CC and .63 for LA). The confirmed structure and all their significant standardized loadings (p-value < .01) can be found in Figure 7.

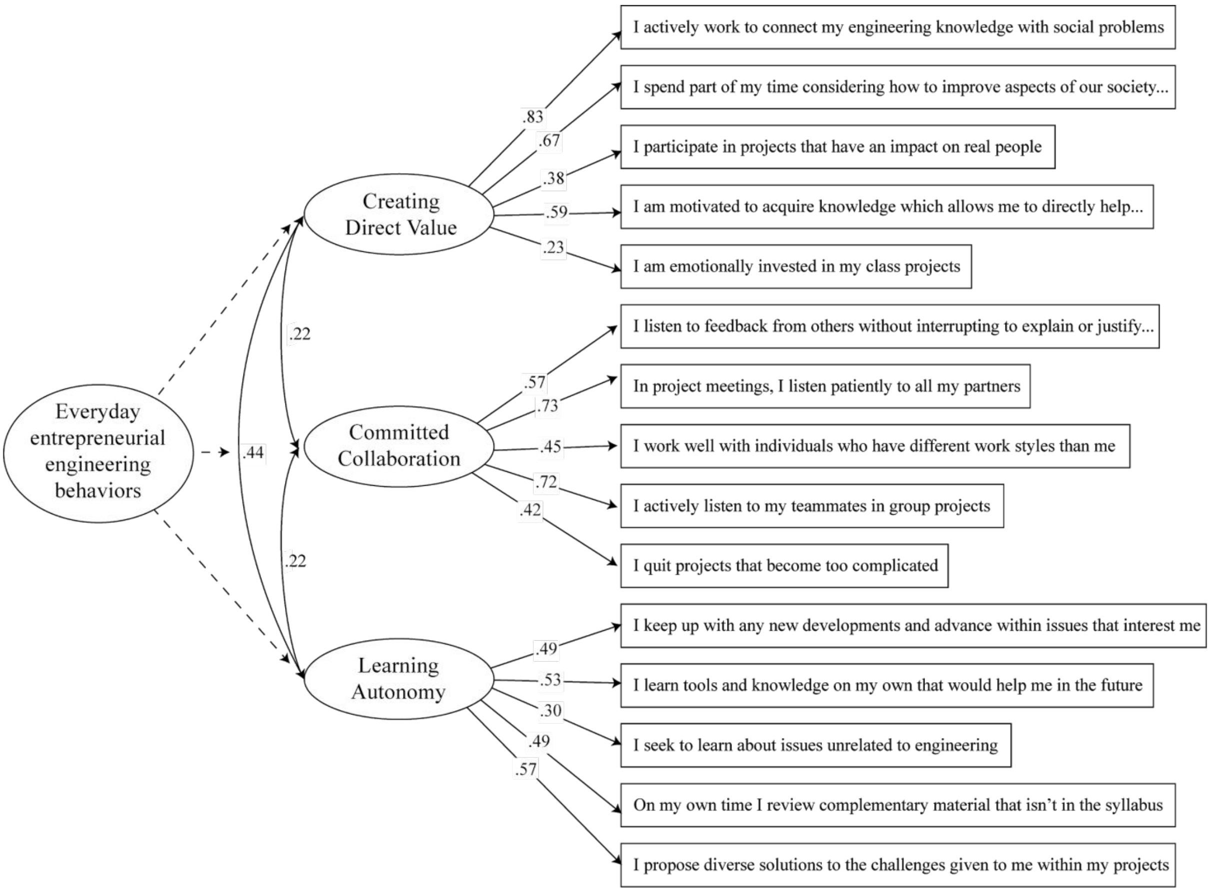

Figure 7. *Measurement model obtained with confirmatory factor analysis*

6 | DISCUSSION

The purpose of this study was to develop an instrument to assess entrepreneurial behaviors within engineering education. This was accomplished through an exploratory research design with a qualitative and subsequent quantitative phase. In the initial stage of the research process, we identified patterns within literature, and we used initial components for qualitative data collection. The information gathered from workshops was analyzed using Grounded Theory, identifying themes among participant responses. These themes were translated into items that assessed entrepreneurial behaviors in a university engineering program setting. 90 items were initially drafted for the instrument, and after expert review, 27 were selected for the first student quantitative data collection. The questionnaire was distributed to two cohorts of an entrepreneurial course, where 256 students voluntarily participated in the first sample, and 348 participated in the second. Upon collection of the survey, factor analysis was executed to achieve construct validity. The structure identified in the EFA has high loadings and few cross-loadings, providing a robust solution that was later verified through CFA. Fit indexes indicated that the model has a good fit and that the three-factor model measures what it is intended to measure.

Throughout this study, three different entrepreneurial mindsets and behavior conceptualizations were identified. Figure 8 displays the process.

Literature COMPONENTS	Qualitative THEMES/codes	Validated FACTORS
I →	II →	III
1. Identifying opportunities 2. Taking risks and dealing with uncertainty 3. Being proactive 4. Being innovative 5. Collaborating and leading 6. Being empathetic	1. Proactivity 2. Persistence 3. Collaborative Leadership 4. Project empathy 5. Curiosity 6. Participatory	1. Creating Direct Value 2. Committed Collaboration 3. Learning Autonomy

Figure 8. Entrepreneurial mindset and behaviors conceptualizations

The conceptualizations changed along with the progression of the study. We identified six entrepreneurial mindset and behavior components from the literature in the initial stage of the process. When those components were utilized to gather qualitative data from students' experiences, the observed themes were considerably different. This finding demonstrates how some literature components are not necessarily relevant for the study subjects, in our case, university students. Data gathered from a real-life context is necessary for a robust theoretical framework. In the final stage of the process, qualitative codes/themes were operationalized through everyday behavioral items. After collecting student responses and undergoing factor analysis, the six entrepreneurial themes previously identified were condensed into three factors. The content of the final identified factors correlates to the initial themes, but only certain items were retained to achieve a more parsimonious structure to provide the simplest scientific explanation that measures entrepreneurial behaviors.

To better understand the validated factors, it is relevant to analyze the transition from themes to factors. The final three validated factors resulted from the combination of the six qualitative themes. The *Persistence* theme merged with the *Collaborative Leadership* theme, becoming the "Committed Collaboration" factor. The *Proactivity* theme merged with the *Curiosity* theme to form "Learning Autonomy." Finally, the *Participatory* and *Project Empathy* themes converged to create the "Creating Direct Value" factor. The factor names were assigned based on entrepreneurship literature terminology and the item contents (Duval-Couetil and Wheadon, 2013; Warhuus et al., 2017; Shir et al., 2019; van Gelderen, 2010; Macke et al., 2018; Auerswald, 2009)

More specifically, the "Committed Collaboration" factor gathered items from the *Collaborative Leadership* theme but excluded all leadership questions. For example, Q9: "In project meetings, I listen patiently to all my partners" and Q18: "I work well with individuals who have different work styles than me" were included. However, items such as "I assume leadership roles in my group projects" and "I avoid taking an active role in my projects because I am afraid it could affect the group result" were removed. Also, a question from the persistence theme was merged into this factor, Q5: "I quit projects that become too complicated." As a result, the "Committed Collaboration" factor gathered items about being an active listener, promoting a positive team environment, and committing to the project without giving special emphasis to leadership.

The "Creating Direct Value" factor grouped questions about tangible actions related to social conscience. Although altruism and humanitarianism may seem abstract, these values are assessed in this factor through questions regarding concrete, everyday activities. For example, some of the *Project Empathy* theme items selected for the “Creating Direct Value” factor were Q2: “I am motivated to acquire knowledge that allows me to directly help others when I work” and Q20: “I actively work to connect my engineering knowledge with social problems.” Also, item Q4, from the *Participatory* theme was included: “I participate in projects that have an impact on real people.” All items gathered translated into direct, concrete value creation; consequently, we chose “Creating Direct Value” as the factor name.

Lastly, the factor "Learning Autonomy" relates to curiosity, multiple interests, and the possession of an autonomous and self-regulated learning process.
For example, it gathered items like Q19: “I learn tools and knowledge on my own that would help me in the future,” Q24: “I keep up with any new developments and advance within issues that interest me,” and Q26: “I seek to learn about issues unrelated to engineering.” Also, this factor gathered an item from the *Participatory* theme, Q25: “I propose diverse solutions to the challenges given to me within my engineering projects” that adds a component of creativity and exploration to the factor.

Interestingly, some similarities can be found in the specific context of engineering education, such as the work of London et al. (2018). To operationalize and align the 3C’s framework of the Kern Foundation with existing literature of entrepreneurial mindset in engineering, London et al. (2018) found twelve mindset outcomes and seventeen behavioral outcomes, which were categorized as Curiosity, Connections, and Creation of Value. The correlation between London’s et al. (2018) outcomes with our everyday behavior factors is noteworthy, especially with the “Learning autonomy” factor, which is similar to their behavioral outcomes “observes trends about the changing world with a future-focused perspective” and “explores multiple solution paths" (2018, p.7). In the case of the other two factors, “Creating Direct Value” is less related to the London et al.’s Creation of Value, mostly because it is centered on the creation of projects or solutions. However, they have a similar mindset outcome, which is “[to be] motivated to make a positive contribution to society” (London et al., 2018, p.7). Finally, our “Committed Collaboration” factor slightly correlates with the Connection behavioral outcome “identifies and works with individuals with complementary skill sets, expertise, etc.” which is similar to our item Q18: "I work well with individuals who have different work styles than me."

These results offer unprecedented evidence to support 3C’s framework because other KEEN studies have not developed a theoretically supported entrepreneurial mindset assessment. In fact, Brunhaver et al. (2018) used London et al. (2018) operationalization model for item generation; however, the final factors determined in the EFA were seven, and neither the 3C's nor the mindsets outcomes were included. Analyzing the similarities between our model and the KEEN framework would be recommended.

The process displayed in this article demonstrates that the entrepreneurial mindset can be operationalized through everyday behaviors and that a good qualitative phase can provide a sufficient foundation to develop an educational assessment. The results have further strengthened our conviction that business subjects are under-emphasized when information is gathered in the specific domain of engineering education.

This particular survey was constructed based on the qualitative information of one particular cultural setting (i.e. Chilean engineering undergraduates). This means that the generalizability of the qualitative results to other populations cannot be directly assumed. The generalizability of this present article is threefold. Firstly, qualitative results here presented can be used to create, complement or re-examine other concepts or theories produced by different methodologies, in other fields or using other populations. This is what is often called analytical generalizability of qualitative data (Chenail, 2010; Smith, 2018). Secondly, the initial theoretical components are derived from the literature and are not specific to our population. These components may be used by other researchers seeking to explore the entrepreneurial mindset. Thirdly, our main contribution is to provide an adapted step-by-step methodology to create entrepreneurial mindset assessment methods in a way that integrates theory and specific cultural settings.

This study is the first step towards providing an assessment of the entrepreneurial behaviors in engineering education. Further work will be conducted to ensure measurement invariance and external validation of the instrument, besides discussing the findings obtained from its application in different cultural settings, including the US. Additionally, it is important to note the relevance of complementing these sort of indicators (i.e. student behaviors) with assessment of educational practices. Ultimately, the goal of engineering entrepreneurship research is to understand how to teach entrepreneurship in engineering, and thus further work can explore the relationship with particular teaching practices with our results that provide standards of learning outcomes.

7 | CONCLUSION

In this paper, we have presented some of the main challenges when assessing the entrepreneurial mindset in engineering education. Prior work has proposed surveys and rubrics based on a business creation paradigm (Duval-Couetil et al., 2011; Shartrand et al., 2008), but the shift from business intent to entrepreneurial intent is here to stay (Huang-Saad et al., 2018; Huang-Saad et al., 2020). In the U.S, researchers have proposed instruments that target an entrepreneurial mindset beyond business skills (Li et al., 2016; Brunhaver et al., 2018), but lacking sufficient empirical evidence (Huang-Saad et al., 2020) to justify the initial selection of factors.

Our study lets these different educational actors operationalize the entrepreneurial mindset themselves, through the identification of everyday behaviors that represent the broad theoretical components that have been associated with the entrepreneurial mindset. In this sense, what we are proposing is the opposite of seeking to validate an institutional framework such as KEEN's with data, but rather, to let the data guide the construction of the framework. Our resulting survey contains 27 items organized into 3 factors (Creating direct value; committed collaboration and learning autonomy) that represent motivational, relational and cognitive/metacognitive dimensions of the entrepreneurial mindset respectively.

In conclusion, this work expands the current understanding of what developing and assessing an entrepreneurial mindset implies. Although this concept is still evolving (Huang Saad, et al. 2020), this study has converged into some factors that have already proven to be measuring one unique construct. Former studies have referred to the importance of developing students' capacities to identify opportunities, deal with uncertainties, collaborate, and be proactive, innovative, and empathetic. In our work, we have been able to verify that teaching staff and students also refer to these capabilities, but through specific everyday behaviors. Staff and students have shared with us concepts that encompass these behaviors, besides proposing ways in which they can be measurable in terms of items. Future work to assess an entrepreneurial mindset could be grounded in our approach to create a shared understanding of engineering entrepreneurship and its outcomes.

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