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THE PROFILE OF INNOVATIVE ENGINEERS AND THE EVALUATION OF ACTIVE LEARNING

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Tese de Doutorado apresentada Programa de Pós-graduação em Engenharia de Produção, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Produção.

Orientador: Édison Renato Pereira da Silva

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TESE SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA (COPPE) DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS EM ENGENHARIA DE PRODUÇÃO.

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Dedicatória

Às três mulheres que moldam a minha vida, cada uma no seu papel e com a sua participação única e inconfundível: minha filha Laura, minha esposa Fernanda e minha mãe Maria José.

Olhando para o futuro, espero que esta tese e a conclusão do doutorado sirvam de inspiração para a minha princesa Laura, norteando os seus passos com a educação como prioridade;

No presente, desejo que minha rainha Fernanda entenda esta tese como a entrega final de uma longa jornada, que seria sobremaneira mais difícil sem a sua companhia e seu amor; e

Em retrospectiva, ofereço esta homenagem à minha mãe Maria José, que me ensinou desde cedo que a educação seria o maior patrimônio que poderíamos ter e a forma mais eficaz de provocar uma mudança significativa em nossas condições sociais, além de ter dedicado muitas horas, ao final de seus cansados dias de trabalho, para acompanhar de perto minhas tarefas escolares.

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Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc.)

THE PROFILE OF INNOVATIVE ENGINEERS AND THE EVALUATION OF ACTIVE LEARNING

Humberto Henriques de Arruda

Novembro/2023

Orientador: Édison Renato Pereira da Silva

Programa: Engenharia de Produção

As transformações ocorridas no último século e as metas de desenvolvimento sustentável mudaram o foco do que a sociedade espera da engenharia. Se décadas atrás a preocupação central era o *act* (a construção, o projeto, a entrega), atualmente o engenheiro precisa ser capaz de analisar o *impact* de suas soluções, nos aspectos técnico, social e ambiental.

A tese é organizada em duas partes, compostas por trabalhos publicados ou submetidos a importantes periódicos durante a trajetória doutoral do autor.

Na primeira parte, o foco é no perfil do engenheiro do século XXI. Esta parte se inicia com debate sobre a perspectiva sul-americana da engenharia, além da preocupação acerca dos aspectos sociais e éticos. Em seguida, é apresentado um método para a identificação de empresas fundadas por egressos no Brasil, chamado BR-AFC. Este método é a pedra fundamental para a medição do impacto empreendedor dos cursos no Brasil. Também é apresentada uma primeira análise da relação entre a atividade empreendedora e o desempenho acadêmico dos alunos.

Na segunda parte, o foco é no processo de educação em engenharia. Inicialmente, existe a proposta do modelo E^2ALM^2 para a avaliação de implementações de aprendizado ativo em um curso. Em seguida, é proposto o índice de auto-consciência do docente (LSAI), que visa mensurar divergências entre as percepções do aluno e do professor. Por fim, o artigo sobre ferramentas para bibliometria desencadeia o debate sobre a adequação dos sistemas de avaliação dos docentes em vigor.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

THE PROFILE OF INNOVATIVE ENGINEERS AND THE EVALUATION OF ACTIVE LEARNING

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The transformations that have taken place in the last century and the goals of sustainable development (SDG) have shifted the focus of what society expects from engineering. While decades ago, the central concern was *act* (construction, design, delivery), today's engineer must be capable of analyzing the *impact* of their solutions in technical, social, and environmental aspects.

The thesis is organized into two parts, consisting of papers published or submitted to prestigious journals during the author's doctoral journey. In the first part, the focus is on the profile of the 21st-century engineer. This section begins with a discussion of the South American perspective on engineering, along with concerns about social and ethical aspects. It then introduces a method for identifying companies founded by alumni in Brazil, known as BR-AFC. This method serves as the cornerstone for measuring the entrepreneurial impact of courses in Brazil. Additionally, it presents an initial analysis of the relationship between entrepreneurial activity and the academic performance of students.

In the second part, the focus shifts to the engineering education process. It begins with the proposal of the E^2ALM^2 model for assessing active learning implementations in a course. Next, it introduces the Lecturer Self-Awareness Index (LSAI), designed to measure discrepancies between students' and professor's perceptions. Finally, the article on bibliometric tools sparks a debate about the adequacy of the existing systems for evaluating educators.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

1. Introduction

1.1 Motivation

Engineering involves the utilization of knowledge, skills and attitude to tackle problems. Over the course of thousands of years, engineering has adapted alongside human development, serving as both a profession and a field of study (UNESCO, 2021).

Since centuries ago, engineers have been pioneers, driving transformation across the world. Their innovations range from the inception of primitive stone tools to the development of basic mechanisms like pulleys and levers, which empowered individuals to raise and transport heavy objects beyond the capability of a single person. The term 'engineer' originates from the Latin word *'Ingenium'*, which also forms the basis of 'ingenuity', highlighting innate attributes, notably mental dexterity (UNESCO, 2021).

Engineering is a very varied profession and provides opportunities in several areas (Weichert, Rauhut, & Schmidt, 2004). Additionally, it is indeed a remarkable and exceptional field that encompasses a multitude of disciplines. These disciplines span from the time-honored practices of military and civil engineering to the more contemporary realms of mechanical, electrical, electronic, and chemical engineering. Moreover, engineering continually evolves to embrace emerging fields like environmental engineering, mechatronics, bio-medical engineering, and bio-chemical engineering. This continuous expansion of horizons is a defining hallmark of engineering, perpetually challenging the limits of what can be accomplished through inventive thinking and clever problem-solving (UNESCO, 2021). Engineering has been instrumental in resolving our everyday challenges and fulfilling our production needs by employing scientific understanding, technical methods, design principles, and effective management (UNESCO, 2021).

The aim of engineering activity is to expand the possibilities available to humanity, achieved through the advancement of technological resources and by making intelligent use of them (Weichert et al., 2004).

In 2015, the 193 members of the United Nations committed to the Sustainable Development Goals (SDGs). These goals are designed to address a wide range of social, economic, and environmental challenges facing the world. They aim to promote sustainable development in various areas, including poverty reduction, gender equality, clean energy, quality education, climate action, and more. The goal is to achieve these objectives by the year 2030 to create a more equitable, sustainable, and prosperous world for all (UNITED NATIONS, 2015).

Indeed, the global challenges require engineers to demonstrate exceptional ingenuity in developing and implementing the solutions necessary to advance these goals. Engineers play a vital role in reshaping the world once more, working towards the creation of a smarter world that is dedicated to sustainable development for the betterment of all (Kanga, 2021). Finally, engineers are situated as potential problem solvers able to work towards achieving the 17 SDGs through the application of an innovative and solution-based approach (UNESCO, 2021).

1.2 New engineers: profile and educational process

Engineering is experiencing a moment of relevant transformation and is facing immense challenges (Ji, 2021). The quality of life almost throughout the world has been impacted by the actions and creativity of engineers. Currently, the world is experiencing the Fourth Industrial Revolution in which data and connections will lead to greater efficiency and innovation (Kanga, 2021). Engineering, scientific advancements, and technology act as the driving force behind economic growth while serving as an abundant wellspring for the advancement of human society (Ji, 2021). Economic growth is positively influenced by significant number of engineers (CEBR, 2015).

1.2.1 Does the world need different engineers?

With this ongoing transformation, a significant question arises: does the world need different engineers? Reflecting on this need and its outcome can completely alter our understanding of the field of engineering education and its movements. Goldberg and Somerville (2014) assert that the changes brought about by technology and the economy impact both the world and the practice of engineering to such an extent that mere curricular adjustments are insufficient to adequately address these needs. Vieira and Haugerud (2021) propose that engineers need to update their competencies to be capable of contributing to a forward-looking environment. Furthermore, an increased emphasis on "real-world" skills is deemed crucial for addressing the challenges of engineering in the future (Rolston & Cox, 2015). The points outlined above inevitably lead to new demands in terms of the education and training of engineers (Weichert et al., 2004).

Learn versus relearn

Despite all the ongoing transformation, engineers continue to need a high level of performance in mathematics and science (Vieira & Haugerud, 2021) and use their knowledge to transform the world (Weichert et al., 2004). The key difference today is that the pace of change is accelerating such that the cumulative technological breakthroughs of the last 100 years have exceeded those of the last few thousand years (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Kanga, 2021; Weichert et al., 2004).

With the increasing pace of change, the challenge for students shifts from *learn* to *relearn*. Decades ago, it was possible for a professional to graduate from university without significant concerns about staying updated, but this is virtually impossible in today's landscape. The technologies available during an engineering undergraduate program are likely to become obsolete just a few years after graduation.

Thus, a significant portion of the importance now lies in relearning. There are current debates about the impact of lifelong and lifewide learning in engineering (Aoki, 2020; David N Aspin, 2007; Reischmann, 2014; Soeiro, Bakker, Chakabarti, & Kretschmann, 2021). This research has a special interest in the impact on the motivation of students in the fact that the knowledge acquired tends to be ephemeral, and that new technologies will replace those studied during bachelor’s degree, especially in areas where there is more intensive technological development - notably computer engineering, in which the author works. Although the principles of basic sciences remain, the fact that technological cycles become shorter affects the intrinsic motivation for study.

In addition, there are contemporary criticisms, which affect especially the current generation, about the feeling of ephemerality and transience caused by social media (Goodyear & Armour, 2019; Kaya & Bicen, 2016) and how this impacts the profile of the student in general, in particular the engineering student. Several publications have focused on characterizing the present generation and elaborating on their significant distinctions from previous generations. Among these notable distinctions, connectivity and impulsivity have been thoroughly studied (Lombardi & Oblinger, 2007).

Then, how can students (classified as impulsive and hyperconnected) repeatedly relearn the same subject? How can this be done without losing motivation? These are questions that stimulate contemplation about the current generation of students' enthusiasm for engineering. It is no coincidence that there are global concerns about the quantity of new engineering graduates (Confederação Nacional da Indústria, 2018; Weichert et al., 2004) and the need to improve diversity and inclusion levels in engineering programs (Meara & Campbell, 2011; Montgomery, 2017; Tatarlar & Turhan, 2021; UNESCO, 2021).

Learn versus think

While *learning* involves the capacity to acquire fundamental knowledge and concepts in various domains (e.g., emotional, psychomotor, and cognitive), *thinking* is the ability to question and ultimately elevate the acquired knowledge to a more advanced level of understanding (Alkhatib, 2019).

Goldberg and Somerville (2014) emphasize that decades ago, there was a significant distinction between information “haves" and "have-nots". Nowadays, with smartphones at everyone's fingertips, information is just seconds away from anyone. Therefore, the major difference no longer lies in having or not having information but rather in knowing how to use it effectively. In other words, the focus has shifted from *learn* to *think* about a particular subject.

In summary, the profile of the 21^{st} century engineer needs to encompass the shift from *learn* to *relearn* and *think*. But is the current engineering education suitable for addressing this need?

1.2.2 *Act* versus *impact*

In the Engineering for a Sustainable World report by UNESCO, Kanga (2021) asserts that engineers are not only expected to possess technical proficiency but must also incorporate imperatives and values associated with the twenty-first century. These imperatives encompass the responsible utilization of resources, an elevated awareness of the potential adverse consequences of their actions on both society and the environment, the obligation to minimize these impacts to the greatest extent possible, and a significant emphasis on promoting inclusive development that caters to the needs of both urban and rural populations, thus ensuring that no individual is excluded from the benefits of progress.

Engineering programs need to instill in students the comprehensive education necessary to comprehend the impact of engineering solutions in a global, economic, environmental, and societal context (ABET, 2019).

In a world that was previously centered around the *act*, current needs have shifted towards the *impact*. The challenges, such as "building a bridge" or "designing a car," have evolved beyond the development of a product, solution, or system. Today's engineer must be concerned with the impact of their actions, including the environmental and social suitability of the car or bridge, as well as the economic consequences for their region.

Act became a commodity and are now taken for granted by society: a growing societal belief in technology makes people think “engineers will provide” and that technology will not be a bottleneck, but an endless frontier. This shifts the center of society’s desire in relation to engineers. In the past, the discussion about what kind of engineers were needed focused on the acts that they were able to perform: whether mechanical, civil, industrial or electronic engineering. Today, they focus on the impact that their acts have on the world: “more innovative”, “more entrepreneurial”, “more sustainable” engineers. This is not a small change, especially when one thinks about the process of educating these professionals. It is not enough, anymore, in this new context, to teach them to produce acts related to their specialties. It is necessary to teach that, with these or other acts that will be learned after graduation, it is necessary to impact society in this or that way. Since controlling the consequences of an act is something much more complex and multifactorial than controlling the act itself, the problem of ‘educating for impact’ becomes much more difficult to control, and also to teach. It is much easier to teach someone to build a bridge than to teach that such a constructive act should be entrepreneurial, innovative, or sustainable. And it is much more difficult to measure whether, in the future, these same impacts will be used by the professional who today delivers a bridge construction work with entrepreneurial characteristics (whatever they may be).

The problem of measurement, as it can be seen, is central to the problem of managing engineering education. Without being able to measure what is taught, as well as its *impacts*, it is impossible to build a management apparatus that can deliver on a large scale, the needs that the 21st century society requests from engineering schools. Therefore, as will be seen, in the face of this great transformation in the profile and process of educating engineers, the thesis focuses on the broader discussion of the profile of professionals that is desired, and regarding the educational process, it focuses on contributing to better measure what is being done in the process of training engineers.

1.2.3 Connecting the pieces: profile and educational process

Since the world needs different engineers, what are the required skills for the current society and its challenges?

The understanding of the various dimensions of their role and their integration into society is now part of the requirements of engineering education (Conférence des Directeurs des Écoles Françaises D’Ingénieurs, 2022).

Many of the studies on employability report on graduates’ lack of relevant skills and competences and a need for higher education to change (Kolmos, Holgaard, & Clausen, 2020). An important literature review about employability was carried out by Abelha, Fernandes *et al.* (2020), what highlights following list: communication, emotional intelligence, teamwork, soft skills in general, digital competence, entrepreneurship, organization, problem solving, and leadership. Furthermore, this systematic review emphasizes the mismatch between university graduates' competences and employers' needs.

In parallel, undergraduate programs pedagogical changes could be an alternative that would make the engineering education to focus on the entrepreneurial skills development, attending market emergent demands and aligning with new technologies (Aranha, dos Santos, & Garcia, 2018; Balan & Metcalfe, 2012).

Therefore, the following concern is "how to". How to advance engineering education to foster these skills?

The field of engineering education has increasingly explored active learning (Lattuca, Terenzini, & Volkwein, 2006; Rui M. Lima, Andersson, & Saalman, 2017; Streveler & Menekse, 2017). Active learning still lacks a single definitive definition, but three stand out as the most popular. Prince (2004) defines it as "any instructional method [used in the classroom] that involves students in the learning process." Roehl (2013) defines it as "an umbrella term for pedagogies that focus on student activity and student engagement in the learning process", and Barkley (2010) as "an umbrella term that now refers to several instructional models, including cooperative and collaborative learning, discovery learning, experiential learning, problem-based learning, and inquiry-based learning". To purposes of this work, the three definitions above are valid and there is no need to choose one specifically.

Problem- and project-based learning (PBL) involves a more complex learning process with students in teams working to identify problems and to select methodologies, while developing prototypes of solutions (Kolmos, 2021). Research literature suggests that Problem-Based Learning (PBL) results in heightened learning motivation, reduced attrition rates, and enhanced competence development (Dochy et al., 2003; Sousa et al., 2023; Strobel & van Barneveld, 2009). PBL has also been seen as a tool to connect engineering education and the transition to professional competency development, serving as a bridge between the two environments (Kolmos et al., 2020; Lamb, Arlett, Dales, Ditchfield, & Wakeham, 2010). Awareness about sustainability is also more relevant among engineering students who have contact with PBL (Duarte, Malheiro, Silva, Ferreira, & Guedes, 2022; Kolmos et al., 2020; Servant-Miklos, Holgaard, & Kolmos, 2020).

Summarizing both sides (profile and educational process), it is possible to make following argument:

<u>ACTIVE LEARNING</u> (promotes) →

<u>AUTONOMY</u> (crucial to) →

<u>LIFELONG LEARNING.</u>

Finally, it is possible to summarize the context of this thesis with two central research questions:

- RQ1: What is the desired profile for the engineer of the 21st century?

and

- RQ2: How can the use of active learning methods underpin the education of this engineer?

Debates concerning the desired profile for the 21st-century engineer and the appropriate educational pathways to achieve this profile are a vast ocean, reaching across various territories and accommodating numerous currents. The aim of this research and thesis is to offer incremental drops to enrich this fascinating ocean.

1.3 Objectives

The German philosopher Friedrich Wilhelm Nietzsche said: “He who has a *why* to live can bear almost any *how*”. With the context detailed in the previous section, this thesis has objectives divided into two independent axes, but which have an important relationship: the first axis is about the *why*, the second axis is about the *how*. In this case, the *why* is interpreted as the desired profile, while the *how* is interpreted as the educational process the engineer.

1.3.1 Axis “The profile: new engineer and the impact on society”

Although engineers are crucial to advancing the SDGs and to meeting the needs of contemporary society, the world is currently experiencing a shortage in both the number of engineers and in the caliber of engineering skills available (Kanga, 2021).

The need to train engineers with different skills than what was done decades ago leads to reflection on the current formation of engineering schools. Therefore, this axis has the following objectives:

- Promote debate about the characteristics of currently trained engineers; and
- Begin debate and measurement about the potential professional paths of engineers after graduation, as a mechanism for evaluating training paths and improving the design and focus of undergraduate courses.

1.3.2 Axis “The process: engineering education and active learning”

The literature in the field of engineering education strongly advocates the use of active learning. Within the context of this thesis, it is possible to emphasize the most relevant motivations: the development of engineers who are more innovative (Aranha et al., 2018; Confederação Nacional da Indústria, 2018; Freeman et al., 2014; Kolmos, 2021; Kolmos et al., 2020; Pereira & Barreto, 2016) and concerned with sustainability, inclusivity, and social impact (Kolmos et al., 2020; Servant-Miklos et al., 2020).

According to Kolmos (2021), one of the most relevant authors in the field: “the question today is not whether PBL works, but rather the quality of PBL implementation”. Extending the interpretation of this statement, it is important to assess the quality of active learning implementation. This way, one of objectives of this research – detailed in next section – is to develop a model to do this assessment.

Despite the relevance and scope of active learning methods, a gap was found in the literature: the absence of an adequate way of measuring the maturity of an institution, or a program, in this regard. Since there is a consensus in academic literature that active learning is a critical success factor in engineering education in the 21st century, it is important to have a way to measure this maturity, as measurement is one of the tools that helps improve any organizational management practice.

In this axis, the main objective is to propose a way to evaluate maturity level in the use of active learning techniques. This objective may be unfolded in two pieces: (i) development of a maturity model to assess active learning implementations with the scope of a course; and (ii) development of an index to measure level of lecturer self-awareness.

These objectives aim to support a more managerial approach that allows the impacts of actions to be assessed objectively. Based on the diagnosis of the current situation, it is possible to plan future actions and assess the results, with the diagnosis to be conducted in the future. For this process, the evaluation method is the initial cornerstone.

Each of the objectives mentioned, in this doctoral journey, was at the same time treated as an isolated part and as a constituent of a broader research trajectory. Therefore, this thesis is a conjunction of scientific articles and book chapters that were produced during the research carried out.

This thesis articulates the texts in their individuality and builds, between them, links and connections that lead to convergence and the response to the more abstract desire mentioned at the beginning of this section: to contribute to advances in the field of engineering education in Brazil and potentially in the world.

1.4 Relevance to Brazilian Education Engineering

In recent years, engineering schools in Brazil have received the new National Curricular Guidelines (Educação, 2019), which are guidelines regarding what is expected of engineers who complete their degree. In these new guidelines, there are characteristics that must make up the profile of an Engineering graduate, of which the following stand out:

- adopt multidisciplinary and transdisciplinary perspectives in your practice;
- consider global, political, economic, social, environmental, cultural and occupational health and safety aspects; and
- act with impartiality and commitment to social responsibility and sustainable development.

Furthermore, the following general competencies must be provided, among others:

- implement, supervise and control engineering solutions;
- know and ethically apply legislation and normative acts within the scope of the profession; and
- learn autonomously and deal with complex situations and contexts.

With this, it is clear that active learning can be a very relevant component in the development of what is expected of new Brazilian engineers, as it promotes student autonomy and engagement. Therefore, when understanding that active learning is linked to engineering education in the 21st century, it is essential to develop a way to evaluate the use of these techniques, to support future analyzes and improvements. Thus, the contribution of the first part of this thesis is justified.

Additionally, the expectation that the engineer is able to consider global, political, economic and social aspects, as well as knowing and ethically applying legislation in the exercise of the profession, increases the relevance of the debate on the contemporary educating process of engineers and how they fit into in society. This is the main point of discussion in the second part of this thesis.

In this way, this thesis makes contributions to engineering education in Brazil in two different, but related, domains.

1.5 Thesis structure

This thesis has this introduction, in the first chapter, followed by a literature review in second chapter, which aims to substantiate the main points of the engineering education, active learning and maturity models.

The thesis core is constructed as a mosaic of six papers written during the research years. The papers were grouped into two parts, each one corresponding to an axis previously described. For each paper, a prologue and an epilogue are provided that explain the paper's motivation, context, and its role in the thesis as a chapter. Hence, each of the following chapters (except for the last one) is composed of a prologue, a full paper, and an epilogue.

In the beginning of Parts I and II, brief notes on the existing literature help set the context to which each chapter seeks to contribute. Table 1 provides a blueprint of each of the thesis' sections.

Table 1 - Thesis core summary

Chapter	Prologue	Main argument	Epilogue
Part I	**Axis "The profile: new engineer and the impact on society"**		
3. The engineer profile we want to deliver to society	Engineering challenges in the Global South; an analysis of economic and political aspects of engineering in Latin America; and engineering from an epistemological, ethical, social and human perspective.	The essence of the engineer's work needs to be recovered	Reflections on the gaps between current educating and existing demands arising from the challenges of the world in the 21st century. This is the first objective of Part I.
4. Identification of alumni-founded companies (AFC)	With the changing world we live in, the university's contribution needs to go beyond scientific publications	Identifying companies founded by university graduates is essential to estimate the impact generated by new businesses and the return given to society	Future works, based on the identification of AFCs, will make it possible to analyze jobs generated and taxes collected, improving the analysis of public

			policies and the direction of institutions. This method is the first step to achieve the second Part I objective.
5. Entrepreneurial activity and academic performance	Entrepreneurship is linked to attributes other than solving questions in a test. Does it correlate with students' academic performance?	Investigating the possible correlation between academic performance and entrepreneurial activity can support changes in course designs	Beyond the entrepreneurial activity, there are many other studies on the engineer's contribution to society. So, this chapter helps to achieve second Part I objective.
Part II	**Axis "The process: engineering education and active learning"**		
6. Engineering Education Active Learning Maturity Model (E^2ALM^2)	The lack of a feasible way to evaluate active learning implementations	A conceptual maturity model can support assessment and future improvements about active learning implementations in a course	Main lessons learned, limitations and future work in building the maturity model. This MM is a piece to achieve the part II objective.
7. Lecturer Self-Awareness Index (LSAI)	The relevance of measuring self-awareness, with the aim of correctly directing energy and resources towards improvements	A suitable index allows to correct divergences between students' and lecturers' perceptions	Need to deepen quantitative studies to better optimize and adjust tools. This index is another piece to achieve the part II objective.
8. Bibliometrix and VOSViewer: tools for bibliometrics	Bibliometrics as a tool for scientific research	Comparisons between the possibilities offered by two leading bibliometric tools	Unassuming Article, Astonishing Outcome

Source: the author

Figure 1 shows thesis structure as a diagram.

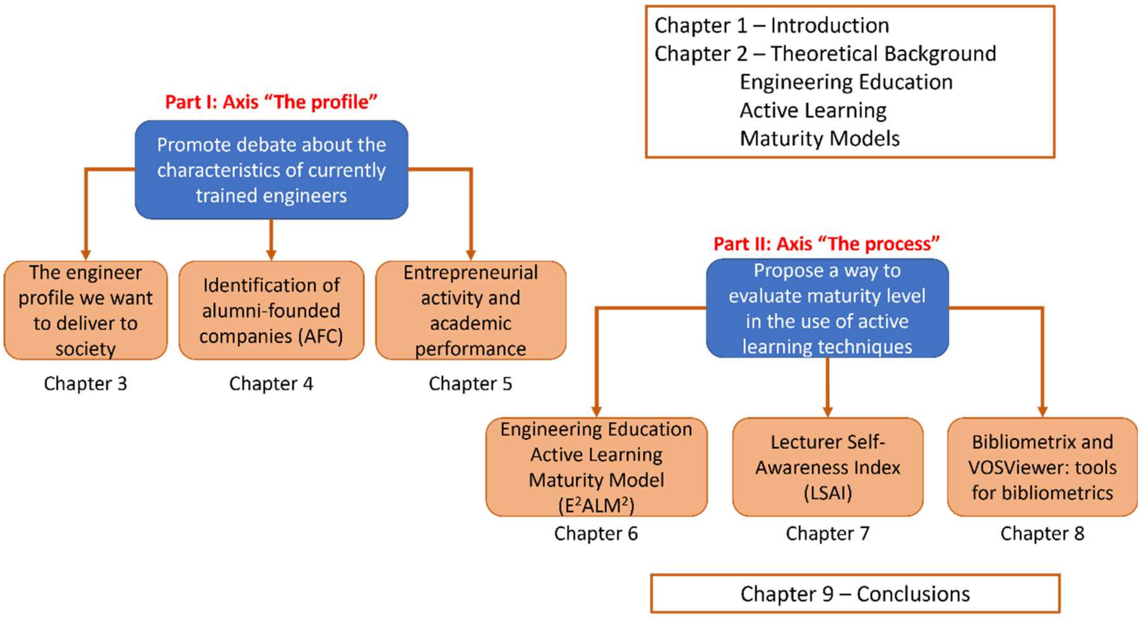

Figure 1 - Thesis structure (Source: the author)

Part I has the engineer participation in the society as the main theme. In chapter 3, there is a discussion about the desired profile of new engineers, who will face challenges of our modern world, and how this profile could and should be developed. Chapter 4 brings the proposal of a method (BR-AFC) to identify companies that have been founded by graduates from a given course or institution. This is an essential step to estimate the impact generated by new businesses and the return given to society. Using the method BR-AFC, chapter 5 shows the investigation whether there is a correlation between academic performance and entrepreneurial activity.

Part II is concentrated in the engineering education and the big umbrella called *active learning*, recommended by the main movements related to the transformation of the field. Although widely studied, there were no objective ways and tools to evaluate the implementation of active learning techniques. This way, chapter 6 presents a conceptual maturity model (E^2ALM^2), built based on success factors previously published in literature, that can support assessment and future improvements. Next, chapter 7 introduces the index (LSAI) to measure divergences between students' and lecturers' perceptions, which allows better direction and use of resources to achieve improvements. Then, chapter 8 provides a comparison of significant bibliometric tools and how the outcome of this comparison can be analyzed from the perspective of Part I, where the measurement of the impact on society is discussed.

Finally, last chapter presents conclusions and future works that rise from the research.

1.6 Thesis originality

As this thesis is structured around publications made along the doctoral journey, each publication brings with it an original contribution to knowledge, validated by peers through the approval of the manuscripts for publication in specialized scientific journals. In this section, the original contribution that each chapter be detailed.

Table 2 synthetizes the composition of each axis and the contribution of its chapters.

Table 2 - Originality in each thesis chapter

Chapter	Manuscript title	Main contribution
Part I - Axis "The profile: new engineer and the impact on society"		
3. The engineer profile we want to deliver to society	What Sort of Engineering Do We Want? How Far Are We From It? A Manifesto for Socially Situated Professional Ethics	Engineering objectives should reflect the demands of a specific population
4. Identification of alumni-founded companies (AFC)	Measuring the Social and Economic Impact of Universities' Entrepreneurial Activity: Introducing the BR-AFC Algorithm to Sort Alumni-Founded Companies	Method to identify companies founded by graduates of a specific program or institution
5. Entrepreneurial activity and academic performance	Is better academic performance in engineering synonymous with more entrepreneurial capacity? A cross-sectional study of the correlation between academic grades and business creation by graduates of Production Engineering at Universidade Federal do Rio de Janeiro	Investigation of a possible relationship between entrepreneurial activity and academic performance
Part II - Axis "The process: engineering education and active learning"		
6. Engineering Education Active Learning Maturity Model (E^2ALM^2)	Assessment and Evaluation in Active Learning Implementations: Introducing the Engineering Education	Maturity model to assess active learning implementations

	Active Learning Maturity Model	
7. Lecturer Self-Awareness Index (LSAI)	Lecturer Self-Awareness Index: measuring the alignment between lecturer and student perception	Index to evaluate lecturer self-awareness and divergences between professor and student perceptions
8. Bibliometrix and VOSViewer: tools for bibliometrics	RESOURCE REVIEWS – VOSviewer and Bibliometrix	Comparison between features of two bibliometric tools

Source: the author

1.6.1 Part I - Axis “The profile: new engineer and the impact on society”

This first axis is structured around three publications.

The first one was published as a book chapter in the prestigious "Philosophy of Engineering and Technology" series by Springer, maintained by the Engineering Philosophy community. In this work, the primary original contribution lies in questioning the traditional and Northern-centric process of engineering education, introducing a South American perspective to the discourse. The uniqueness of this contribution is rooted in the idea that, as engineering serves a particular society, its objectives should not be autonomously defined but rather should reflect the demands of a specific population. Therefore, it is essential to merge global and local demands to produce engineers who can make a difference and create meaningful impacts for the South American peoples.

Additionally, in the education of engineers for the 21st century, it is essential for the university to focus on developing skills more oriented towards entrepreneurship, innovation, ethics, and sustainability (Aranha et al., 2018; Aravena-Reyes, 2021; Balan & Metcalfe, 2012; Confederação Nacional da Indústria, 2018; Duarte et al., 2022; Gibb, 2002; Hundley, 2015; Kolmos, 2021; Lattuca et al., 2006). As a result, the university's assessment needs to go beyond the counting of scientific publications or the number of engineering graduates (Bronstein & Reihlen, 2014; Kolmos et al., 2020; Rolston & Cox, 2015).

The second publication in this axis has been accepted for publication in the "Brazilian Journal of Operations and Production Management" (CiteScore 2022 2.5 and

SJR 2022 0.317) and is likely to be published in 2024, pending the journal's schedule. The original contribution of this manuscript is to present a novel method for identifying companies founded by graduates from a university. Through this method, it becomes possible to assess the impact of university education in general, and engineering education in particular, on entrepreneurial activity. This measurement goes beyond merely quantifying how many companies have been formed by the graduates of a specific program. It also considers the alignment between the company's profile and the desired profile of the program's graduates, allowing us to comprehend whether there is convergence between the educational objectives for entrepreneurship and the actual outcomes achieved. This method was born during the institutional project at UFRJ, that aimed at better understanding the educational journey of its alumni. A pilot study was conducted, with a specific focus on graduates of the industrial engineering program, given that this thesis is affiliated with the COPPE production engineering program.

The third publication in this research axis was presented at the conference PAEE/ALE 2023 in São Paulo (June 2023). In this publication, as a result of applying the BR-AFC method outlined in the previous article, the growth of entrepreneurial activity in the undergraduate Industrial Engineering program at UFRJ over the decades is presented. It is noted that there is alignment between the entrepreneurial activities undertaken and the educational profile of the program, as it is quite comprehensive. This contribution provides mechanisms to move beyond 'anecdotal examples' of well-known and large companies and to understand the entire spectrum of companies established by the program's alumni. Rethinking the curriculum can involve identifying educational profiles ("concentration areas") whose graduates do not establish companies and the impact of specific entrepreneurship courses, as well as the date of offering these courses, on increasing entrepreneurial activities among graduates. Additionally, this original contribution enables the evaluation of potential correlations between academic performance and entrepreneurial activity.

Taking the three original contributions provided in this research axis as a whole, it becomes evident that this work converges to deliver a contribution that assumes that entrepreneurial activity is essential for shaping the new professional profile desired in 21st-century South America. In order to contribute properly to the national development, it is not sufficient to have professionals solely employed in serving foreign socio-economic dynamics. This work places a pronounced emphasis, in its contributions, on measurement. The emphasis on 'measuring to overcome qualitative bias' is the result of an underlying motivation that drives this doctoral research. This emphasis is also observed in the contributions made in the second axis of this work, the engineering education process.

1.6.2 Part II - Axis “The process: engineering education and active learning”

In the second axis, where the suitability of the engineering education process is questioned in light of the previously discussed objectives and the social profile of the current generation entering the university, the original contribution of this thesis is to enhance the ability to measure the quality of active learning and the role of the lecturer in this active learning process. As an educator, this author acknowledges that there are generational changes in the characteristics of students entering engineering today compared to previous decades. Furthermore, there are changes in the demands placed on engineering educators. Measurement, which is, in essence, the primary contribution of this thesis, is a fundamental activity to assess the effectiveness of the changes being introduced in the learning process.

Within this second axis, three additional works contribute to this mosaic of discussions, each delivering its unique original contribution.

The first of these contributions is an article published in the "Educational Sciences" journal (JCR Impact Factor 3.0 and CiteScore 4.0), in which a novel method is introduced for measuring the maturity level of active learning implementations in undergraduate engineering courses. Active learning is one of the most popular recent techniques for enhancing the quality of engineering education, advocating a shift from the focal point of teaching, from the lecturer to the student.

In active learning, the lecturer must relinquish their role as the central figure in the learning process and transfer it to their students through the course content. This is an act of surrendering power. The dethroned lecturer, now handing over the crown of knowledge to the students, becomes the new rulers of the classroom. What is the role of a dethroned lecturer in the learning process? More importantly, how does this lecturer feel, and how aware are they of this shift in authority? Still emphasizing the importance of "measurement", the second article in this section introduces a novel index for assessing the lecturer self-awareness regarding the student learning process.

In this new classroom reality brought about by active learning, where the focus is on the student-content relationship, the instructor's role is that of a facilitator rather than the sole source of knowledge. They should be capable of "reading the minds of the students" and understanding whether the students' interactions with the content are achieving the intended pedagogical impact. In this challenging realm imposed by active learning on instructors, the Lecturer Self-Awareness Index (LSAI) contributes to the teaching process by providing feedback on the alignment of student and lecturer perceptions regarding what is happening in the classroom, based on the Engineering Education Active Learning Maturity Model (E^2ALM^2). The integrated use of E^2ALM^2 and LSAI, therefore, provides two essential management mechanisms for assessing the quality of active learning practices in the classroom (E^2ALM^2) and addressing the fundamental question, "What is the lecturer's role in this narrative?" (LSAI).

In addition to these two contributions, this second axis also includes an article on tools for bibliometric analysis published in the Journal of the Medical Library Association (JCR Impact Factor 3.9 and CiteScore 3.3). The mere existence of this article and its inclusion in this thesis subtly criticizes the current professor evaluation system in place in Brazilian engineering. Hence, this work holds a dual contribution. The first, intrinsic to the article, is to elucidate the role and use of two fundamental tools in the process of connecting an academic paper with the literature that bibliometric analysis provides: VOSviewer and Bibliometrix. Both tools were studied during the thesis development process in the articles. The publication of this bibliometric work is incidental to the primary contribution of the doctoral thesis, although it still aligns with the overarching theme of "measurement". This publication was driven by the pressure to publish, experienced by both the advisor and the student.

The second contribution of this work precisely addresses this pressure, and it is evident in its existence and the results it has achieved when compared with the Engineering Education Active Learning Maturity Model (E^2ALM^2). Although this work holds a less prominent position in the entirety of the thesis, the "VOSviewer and Bibliometrix" article garnered approximately three times more impact in terms of citations than the E^2ALM^2 article. Moreover, the journal impact factor is 30% higher than that of the E^2ALM^2 publication (3.9 as opposed to 3.0). When considering the "citations per page" – dividing the total citations by the number of pages in each article – the article about bibliometrics exhibits a 14-fold higher indicator compared to the E^2ALM^2 article.

Hence, beyond the contributions within the text itself, this work ironically serves to question the central objective of this thesis, "measure better to manage better," by starkly exposing the limits of this correlation. It is, to say the least, intriguing that a "right choice" of research field (medical librarianship) can enable a researcher to achieve a disproportionately higher improvement in their publication and citation metrics compared to what would have been (and was) obtained by choosing the "wrong field" (engineering education). Therefore, this thesis, while reinforcing the adage "you can't manage what you can't measure," simultaneously challenges it by highlighting the absurdity of a purely numerical evaluation system that fails to grasp the intricate web of meanings that numbers cannot fully encapsulate. This wholeness, ultimately, is the greatest contribution of this thesis.

1.7 Method

It is possible to identify that this thesis has two different angles to achieve its objectives: there are reflections and debates, that have a free writing style and use of arguments, and there are proposals of models and indexes to do measurements. Table 3 shows method of each chapter.

Table 3 - Thesis chapters method

Chapter	Method
Part I - Axis "The profile: new engineer and the impact on society"	
3. The engineer profile we want to deliver to society	Free use of arguments
4. Identification of alumni-founded companies (AFC)	Proposal of an interactive and data-based process
5. Entrepreneurial activity and academic performance	BR-AFC application and statistical analysis
Part II - Axis "The process: engineering education and active learning"	
6. Engineering Education Active Learning Maturity Model (E^2ALM^2)	Proposal of a maturity model based on literature review, identification and consolidation of key success factors previously published
7. Lecturer Self-Awareness Index (LSAI)	E^2ALM^2 application, statistical analysis and proposal of an index based on divergences between students' and lecturers' responses
8. Bibliometrix and VOSViewer: tools for bibliometrics	Comparison between features of two bibliometric tools

To propose models and indices, the first research method used was an exploratory search of the field studied, with the aim of identifying the most relevant publications. Then, based on these publications, it was possible to construct ways of measuring what was in focus.

In the Part I of this thesis, the identification of Alumni-Founded Companies (AFC) was the core task to analyze entrepreneurial careers of engineers. To carry out analyzes like this, there was a proposal to create the BR-AFC method, which was based on an interactive and data-based process.

In the Part II, Engineering Education Active Learning Maturity Model (E^2ALM^2) was built based on factors that several previous works showed important to a successful implementation of active learning techniques. Lecturer Self-Awareness Index (LSAI) was derived from some success factors that made up E^2ALM^2. So, two proposals share same theoretic foundations.

The methodology used in each proposal is described in detail in the articles present in the corresponding chapters.

1.8 Limitations

In the first part of the thesis, there are limitations of different natures. In the debate about the current educational process of engineers, an obvious limitation is the personal bias that may exist among the authors of the work. Although they are researchers from different countries and different experiences, there are many aspects that bring them together. Therefore, it is not possible to state that the impressions presented are completely impartial and impersonal. In the BR-AFC method proposal, the most relevant limitation is the dependence on the Brazilian structure for registering business openings. Although the concepts can be transported to other countries, the method is directly linked to the data made available by Brazilian institutions.

In the second part, the main limitation is the lack of large-scale tests for quantitative validation of the models. The conceptual proposal and the application in a limited number of courses allowed qualitative analyzes to be carried out on the E^2ALM^2 and the LSAI, but the application in more courses has the potential to allow optimizations and adjustments to the data collection tools. Additionally, there is an opportunity for improvement, but not exactly a limitation, related to the implementation of good practices in educational institutions, after applying the model. There is no practical guide for the educational institution to improve its indicators in the model. As the next step in a maturity model, it is possible for the proposed model to move from descriptive to prescriptive. Thus, this opportunity can be seized in the future, with new studies.

2. Theoretical background

According to the United Nations, 2030 Agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom (UNITED NATIONS, 2015). António Guterres, the Secretary-General of the United Nations, stated that "every one of the Goals requires solutions rooted in science, technology and engineering" (Guterres, 2018). Gong Ke (2021), the president of World Federation of Engineering Organizations, said that "science, technology and engineering are the heart of sustainable development". Nonetheless, the emergence of innovative technologies, automation, shifts in demographics, and increased job mobility will demand ongoing skill updates within the engineering field. This will call for the development of engineering expertise, alongside a well-organized strategy, quality control, and certification processes for lifelong education (Soeiro et al., 2021).

Currently, the world is going through a transformation whose main characteristic is the speed and intensity of changes. According to Dochy et al (2003), using a statement that remains valid, the complexity of today's society is characterized by an infinite, dynamic and changing mass of information, the massive use of the internet, multimedia and educational technology. Goldberg and Somerville (2014), in their classic book titled "A whole new engineer", affirm the society changed from a world where information was expensive, hard to find, and difficult to integrate, to the current scenario in which it is cheap or free, easy to find, and easy to integrate.

With this ongoing transformation, about 9 per cent of occupations in 2030 will be new and do not exist at present (Bughin et al., 2018). Countries realize that engineering is essential to have a modern economy, and world is impacted specially by six major trends: rapid urbanization and the development of large cities, shifts in global economic power, climate change, changing demographics with ageing populations in the developed world, technological innovations and the rise of a culture of entrepreneurship (Kanga, 2021).

Despite the need of graduate new engineers to address contemporary society problems, employers have recently expressed concerns about the shortage of graduates in STEM subjects. The number of graduate engineers in particular is a long-term concern (Lamb et al., 2010). Although the engineering profession is often viewed quite positively, there is currently an active debate. On one side, there is concern about the shortage of engineering graduates coming from universities and training institutes. On the other side, there's a discussion about the ongoing and fast-paced changes in the expectations and demands placed on the engineering field (Royal Academy of Engineering, 2007).

Furthermore, following patterns are currently prominent and anticipated for the future of engineering employment (Schwartz, Hartfield, Jones, & Anderson, 2019):

- Engineers are now working for more years because people are living longer and working later into their lives. This means that there will be more older adults in the workforce (Jenkins, 2019);
- Engineers are changing jobs within the same company or switching to different organizations more frequently. This means they need to keep learning and improving their skills regularly (WEF and BCG, 2018);
- Knowledge is growing faster than ever, and technology is advancing quickly. Engineers and technologists must stay updated on these changes and new developments to stay relevant in their careers (DeLong, 2004);
- Engineers are now involved in projects that often have a global reach or significant worldwide impacts, even when working for international companies in local environments (WEF, 2016); and
- Although automation can handle numerous human tasks, there are soft skills like interpersonal communication and emotional intelligence that machines are unlikely to replace. Engineers and technologists must acquire and develop these skills to ensure they stay valuable and employable (Bughin et al., 2018).

According to Lamb et al (2010), university courses need to provide more experience in applying theoretical understanding to real problems, and use the knowledge to solve complex problems in an efficient way (Dochy et al., 2003; Engel, 1991). There is the necessity of a shift in engineering education away from a focus on academic technical knowledge towards a much broader interdisciplinary and complex problem-solving approach (Kolmos, 2021).

The final stakeholder group is society, which has its own goals for engineering education (Lamb et al., 2010). As already shown in this section, issues such as sustainable development and globalization need to be addressed by engineering educators.

Following section will present the foundations of engineering education, the changes occurring in this field and how it is being updated to response new challenges.

2.1 Engineering education and its main characteristics

The aim of engineering education is to transmit the knowledge necessary for students to become successful engineers, encompassing technical expertise, social awareness, and an inclination for innovation (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014, p. 1). Modern engineers "are involved in all phases of the life cycle of products, processes and systems that range from the simple to the incredibly complex, but they all have one characteristic in common: they meet a need of a member (or members) of society. Good engineers observe and listen carefully to determine the needs of the member of society for whom the benefit is intended" (Crawley et al., 2014, p. 2).

The main task of higher education in engineering is to transform new students into modern engineers, capable of participating in, and even leading, work on conception, design and implementation of new products and processes (Crawley et al., 2014, p. 2).

Rugarcia and Felder (2000, p. 2) created a delineation of the technological personality of the 21st century that remains valid. There are 7 factors that represent a challenge for current and next generation engineers:

- Proliferated information;
- Multidisciplinary technological development;
- Globalized markets;
- Threatened environment;
- Emerging social responsibility;
- Participatory corporate structures;
- Quick changes.

In addition to the factors that are a challenge for future engineers, authors split this profile into three components:

- Knowledge: items that the individual knows and the concepts that they understand;
- Skills: ways of managing and applying your knowledge, such as computing, experimentation, analysis, synthesis, evaluation, communication, leadership and teamwork; and
- Attitudes: determine the goals toward which your knowledge and skills will be directed.

In short, "knowledge is the engineer's database; Skills are the tools used to manipulate knowledge in order to reach goals determined, or strongly influenced, by attitudes".

During last years, there has been a shift in engineering education, towards a competency-based pedagogy. Competency-based learning (CBL) is an educational approach that focuses on students' achievements and allows them to face more advanced tasks once they've mastered the required foundational content and skills (Henri, Johnson, & Nepal, 2017). A global engineer today needs to have competences in five categories: technical, professional, personal, interpersonal and cross-cultural (Hundley, 2015).

2.1.1 Students' profiles

To be competitive in a global job market, today's students must become comfortable with the complexities of ill-defined real-world problems (Lombardi & Oblinger, 2007). The more students are immersed in real disciplinary communities, the more equipped they will become to handle uncertainty and apply the advanced analytical and intricate communication skills demanded of them in their professional roles.

However, education is about people, and people are different from each other. So, it necessary to investigate different learning styles and how to maximize the outcomes using a variety of method and processes. In summary, it is important to study what kind of activities work best in which situations and for which courses (Streveler & Menekse, 2017).

Felder (1988) stated, three decades ago in a work that remains very relevant, that global learners should be given the freedom to devise their own methods of solving problems rather than being forced to adopt the professor's strategy, and they should be exposed periodically to advanced concepts before these concepts would normally be introduced. The author highlighted mismatch between most of engineering students – visual, sensing, inductive, and active – and most engineering education – auditory, abstract (intuitive), deductive, passive, and sequential.

To minimize this mismatch, Felder proposed a *learning-style* model that classifies students according to where they fit on several scales pertaining to the ways they receive and process information. Besides of *learning-style*, the author proposed a *teaching-style*, which classifies instructional methods according to how well they address the proposed learning style components. These models have been proposed to environment of engineering education.

To define a learning style, there are five main questions:

- What type of information does the student preferentially perceive – sensory or intuitive;

- Through which sensory channel is external information most effectively perceived – visual or auditory;
- With which organization of information is the student most comfortable – inductive or deductive;
- How does the student prefer to process information – actively or reflectively; and
- How does the student progress toward understanding – sequentially or globally.

Similar way can be presented to define teaching style. The questions are:

- What type of information is emphasized by the instructor – concrete or abstract;
- What mode of presentation is stressed – visual or verbal;
- How is the presentation organized – inductively or deductively;
- What mode of student participation is facilitated by the presentation: active or passive; and
- What type of perspective is provided on the information presented – sequential or global.

Based on these definitions, Figure 2 shows the dimensions of learning and teaching styles.

Preferred Learning Style		*Corresponding Teaching Style*	
sensory intuitive	perception	concrete abstract	content
visual auditory	input	visual verbal	presentation
inductive deductive	organization	inductive deductive	organization
active reflective	processing	active passive	student participation
sequential global	understanding	sequential global	perspective

Figure 2 - Dimensions of Learning and Teaching Styles
(Source: (Felder Richard M. & Silverman Linda K., 1988))

More recently, DeMonbrun et al. (2017) presented a compilation of student reactions to different instructional methods, enabling instructors to assess how their students react to these activities and identify any behaviors that could suggest disengagement during the learning process.

2.1.2 Transformation of the field Engineering Education

In addition to what was discussed in the begin of section 2.1, the field of Engineering Education has objective reasons to transform.

During the second half of the 20th century, several humanities courses were included in engineering training, which proved to be ineffective in producing responsible and ethical engineers (Rugarcia et al., 2000, p. 10). Grasso and Burkins (2010) state that our society needs a new kind of engineer, one who can think broadly across disciplines and consider the human dimensions. In other words, narrow engineering thinking will not be enough.

Rugarcia, Felder *et al.* (2000; 2000) published a series of papers about the vision of engineering education in 21st century.

In the first paper, beyond the contextualization and an analysis of the new (at that time) criteria to accreditation of engineering programs in USA, the authors listed obstacles and the critical questions to change:

- revisions in engineering curriculum and course structures;
- implementation of alternative teaching methods and assessment of their effectiveness;
- establishment of instructional development programs for faculty members and graduate students; and
- adoption of measures to raise the status of teaching in society and in institutional hiring, advancement, and reward policies.

Following papers of the series aimed to address these questions. According to the focus of this research, second one – about teaching methods and assessment – is very relevant and related to the discussion presented in the section 2.3.

There is a discrepancy between the two sides of those interested in engineering education and its graduates. Accounts of historical changes in engineering education describe the swinging pendulum over the decades between theoretical knowledge and practical skills (Crawley et al., 2014).

On the one hand, there is a need to transmit the ever-increasing body of technical knowledge that graduating students must master. On the other hand, there is increasing recognition that engineers must possess a wide range of personal and interpersonal skills, as well as the product, process, and system-building knowledge and skills needed to function on real engineering teams to produce real products and systems.

This tension is clear in the apparent difference of opinion between engineering educators and the broader engineering community that ultimately employs engineering graduates. Engineers in universities traditionally emphasize the importance of a body of technical knowledge. However, in recent decades industry representatives have begun to express concern about this interpretation, articulating the need for a broader view that places greater emphasis on personal and interpersonal skills and product, process and system skill building (Crawley et al., 2014, p. 3).

Goldberg and Somerville wrote (2014) that not only engineering education tend to emphasize logical/mathematical intelligence with the exclusion of other ways of knowing, but also it operates with a fixed mind-set.

According to the report "Engineering Education: Transformation and Innovation", published by UNESCO, "Engineering education needs to be adapted to the challenges faced by this essential and highly important profession. However, engineering education did not respond as quickly as needed. The necessary transformation remains to be implemented to enable the next generation of engineers to operate effectively in this ever-changing profession" (Beanland & Hadgraft, 2013, p. 8). Although published in 2013, this concern remains valid and contemporary. UNESCO published another report (2021) in which states that educational change must take place at the institutional level and will involve a shift in culture and an understanding of learning among academic staff. It alerts that "Engineering education needs to move quickly to make progress in these areas, not least because it takes five years to train an engineer. Students starting their engineering education today will put their learning into practice beyond the horizon of the existing SDGs". Moreover, due to the velocity of changes in current world, technology complexity may increase, and it is necessary to adapt learning outcomes for engineering education (Kolmos, 2021).

The Royal Academy of Engineering in the United Kingdom has conducted an extensive and detailed study of subjects related to "Educating Engineers for the 21st Century" (Royal Academy of Engineering, 2007). The major findings of their research include:

- Universities and industry need to find more effective ways to ensure course content reflects real industry requirements and enable students to gain practical industry experience as part of their education;

- The accreditation process for university engineering courses should be proactive in driving the development and updating of course content, rather than being a passive audit exercise;
- Funding and a targeted focus on research at many universities are constraining the development of innovative teaching and learning; and
- Much more needs to be done to ensure that school students perceive engineering as a stimulating and rewarding profession worth pursuing.

Some evidences of the need of the transformation in engineering education is listed below, among others (Beanland & Hadgraft, 2013, p. 62; Crawley et al., 2014; Goldberg & Somerville, 2014; Kolmos et al., 2020; Rolston & Cox, 2015; Royal Academy of Engineering, 2007):

- Insufficient graduate engineers with the knowledge and skills to drive innovation,
- Lack of interest among students in undertaking engineering,
- Inadequate attention to the development of the elements of professional engineering practice,
- Academic team with no experience in engineering practice,
- Inadequate exposure of students to people with practical engineering experience, and
- High failure rate of students in engineering programs.

Shuman et al (2002, p. 7) listed four ways to stimulate changes in the field. They are mentioned below:

1. Not hiring graduates (or causing a credible threat that this will happen) – as the industry is one of the main players complaining about the discrepancy between what students learn and what is needed in the market, it could use its power to influence change;
2. Changing the course accreditation process – since courses are designed to be accredited, changes to the accreditation process would result in readjustment of courses;
3. Fund change in universities – the federal government has funded research for 50 years but has only funded education for 10 years (US information). Even though it is only 10 years old, it is already possible to see progress in educational indicators in general. Thus, it can be assumed that this is a viable way to stimulate change; and

4. Change the reward structure – the criteria for promotion and access to benefits are the result of the research culture built over 50 years mentioned in item 3. Changing these criteria can contribute to changes in courses.

Indeed, at least one of the ways the authors explored is clearly underway. ABET (Accreditation Board for Engineering and Technology) has been the recognized body that accredits engineering courses in the USA since 1932. It currently accredits more than 2000 programs in 350 different institutions. As will be detailed in section 2.1.3.1, ABET changed the criteria for accreditation of engineering courses, with the aim of adapting the indicators observed to the current needs of engineering education.

Some institutions that emerged with the explicit objective of better preparing their students for the 21st century used the implementation of item 4 on the list above as one of their principles, such as Olin College and Insper. More university examples will be explored in section 2.1.4 of this work.

Finally, current world requires engineers on a global scale to push technology forward while aligning it with the progression of society and the desires of its people. It's their duty to use their technical expertise and competence to address the pressing issues our societies confront, such as SDGs. Aligned to this reality, the involvement of women in engineering is a substantial issue that requires immediate attention. This is not only to boost the global engineering workforce but also to make sure that the brightest minds can tackle the challenges of sustainable development (UNESCO, 2021).

In order to successfully achieve diversity and inclusion, the culture of engineering must ensure that all people feel comfortable and included, and that they are able to bring their own identity and their own differences to the sector (UNESCO, 2021). Making engineering more attractive to students with different intelligences sparks hope of increasing the potential of new engineers (Goldberg & Somerville, 2014).

2.1.3 New trends and new movements around the world

It is already possible to notice movements that currently exist, albeit in their early stages. These movements can be divided into two main types: control or inspection entities that updated their standards or recommendations; and initiatives from the community active in engineering education, with new actions and the search for advances in the field. Some examples are detailed below.

2.1.3.1 ABET and new accreditation criteria (EC2000)

As already mentioned in this work, the Accreditation Board for Engineering and Technology (ABET) carries out the accreditation of engineering programs in the USA.

It is a nonprofit, non-governmental organization, ISO 9001 certified quality assurance organization focused on college and university programs in the science, technology, engineering and math (STEM) disciplines (ABET, 2023). Currently, the organization also operates in 41 other countries besides the USA, which totals around 4700 programs and 920 institutions served with accreditation.

ABET accreditation requires, among other things, that engineering programs adhere to a set of quality standards called "Accreditation Criteria". For most of the second half of the 20th century, ABET accreditation criteria dictated all major elements of an accredited engineering program, including curricula, faculty, and facilities. In the mid-1990s, however, the engineering community collectively began to question the validity of such strict accreditation requirements. For example, The Boeing Company organized an effort to influence college engineering education by establishing its list of desired attributes of an engineer, as shown in Figure 3:

- A good understanding of engineering science fundamentals
  - Mathematics (including statistics)
  - Physical and life sciences
  - Information technology (far more than computer literacy)
- A good understanding of design and manufacturing processes
- A multi-disciplinary systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics (including business practices)
  - History
  - The environment
  - Customer and societal needs
- Good communication skills
  - Written, oral, graphic, and listening
- High ethical standards
- An ability to think both critically and creatively—independently and cooperatively
- Flexibility, i.e., the ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

—The Boeing Company

Figure 3 - Desired attributes of an engineer

(Source: Crawley et al (2014, p. 6))

After a year of intense dialogue with the engineering community, ABET has developed new and unique accreditation criteria for engineering programs. These criteria became known as Engineering Criteria 2000 or EC2000 (Lattuca et al., 2006). Currently, United States engineering departments need to demonstrate that, in addition to having a firm grasp of science, mathematics, and engineering fundamentals, their graduates possess communication skills, multidisciplinary teamwork and lifelong learning skills, and an awareness of social and ethical considerations associated with the engineering profession (Rugarcia et al., 2000, p. 2).

Essentially, the change in evaluation brought about by EC2000 was the increased importance given to program results, to the detriment of previously more valued formal issues. This change shows high alignment with competency-based learning, since the focus of assessments is on what is learned by students, and not on what is taught by teachers. Eleven learning outcomes have been defined, which engineering programs need to be able to demonstrate their graduates have:

(a) ability to apply knowledge of mathematics, science and engineering;

(b) ability to design and conduct experiments, as well as analyze and interpret data;

(c) ability to design a system, component, or process to meet desired needs;

(d) ability to work in multidisciplinary teams;

(e) ability to identify, formulate and solve engineering problems;

(f) an understanding of professional and ethical responsibility;

(g) effective communication ability;

(h) the broad training necessary to understand the impact of engineering solutions in a global and social context;

(i) a recognition of the need for and an ability to engage in lifelong learning;

(j) a knowledge of contemporary issues;

(k) ability to use modern engineering techniques, skills and tools necessary for the practice of engineering.

Lattuca et al (2006) provide analysis of EC2000 results. Among the findings, the following stand out:

- High levels of institutional support for continuous improvement;
- Greater personal engagement of students in their learning;
- More student interaction with instructors;
- More feedback from instructors on student work; and
- Greater emphasis on programs open to diversity of ideas and people.

Among the discoveries brought forward in this work, the authors highlight:

- Wide use of active learning methods;
- Greater emphasis on professional skills; and
- Maintenance of technical skills and increase in professional skills.

Furthermore, next figures show industry responses to the changes brought about in EC2000. In Figure 4, it is possible to notice that effective communication is the skill considered most relevant by employers, but the ability to solve problems, the application of exact science concepts and the use of modern engineering tools are also highly valued. Next, teamwork and the ability to understand professional responsibility and ethics are two professional skills that stand out. Figure 5 shows that employer satisfaction levels are high in technical and professional skills, which are good results from the application of EC2000 standards.

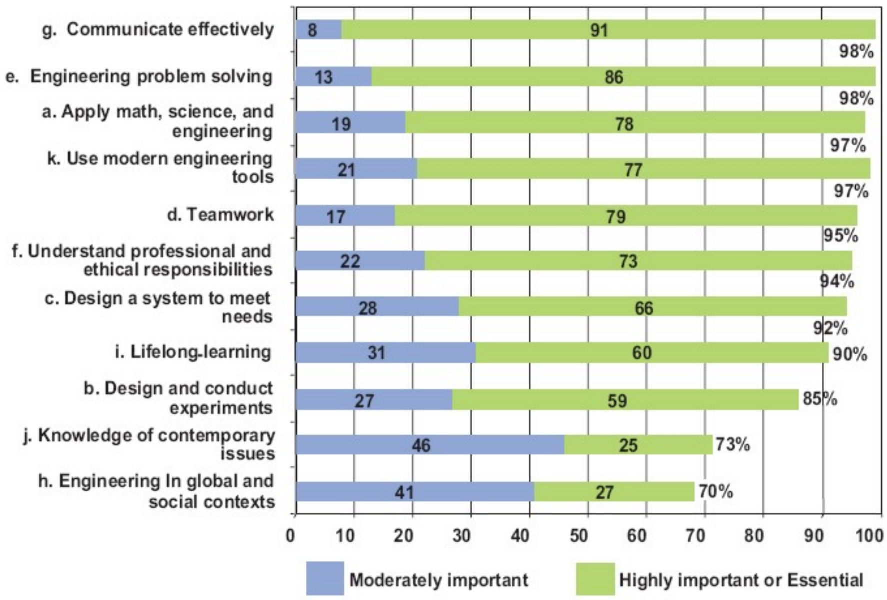

Figure 4 - Assessment of importance given by employers in new hires (results a-k of EC2000)

Source: Lattuca et al. (2006)

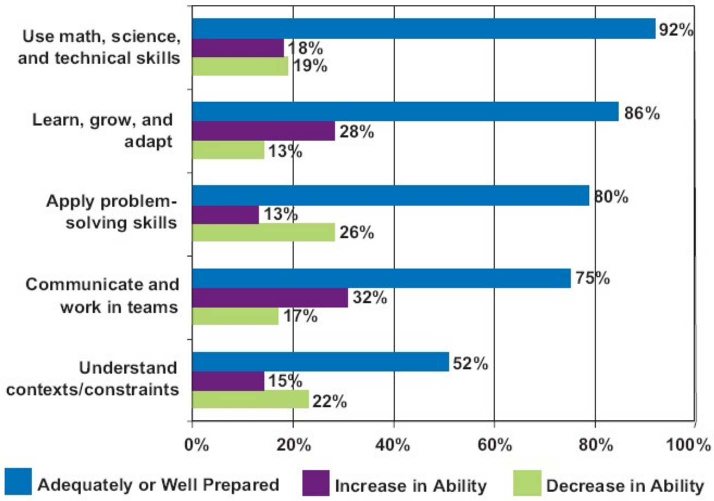

Figure 5 - Employer reporting on engineer preparation and skills changes
(Source: Lattuca et al. (2006))

These results serve as good indications of the problem that we intend to address in this research. One of the common criticisms of the use of active methods is their supposed superficiality (Prince, 2004). These authors fail to consider the interpretation that active methods should be analyzed as if they replaced all traditional methods. In fact, the idea is to use them wherever and whenever it is possible to effectively increase student engagement and improve learning outcomes.

The supposed incompatibility between traditional methods and active methods can be overcome with the balanced use of both approaches, choosing the approaches appropriately for each subject or course to be taught. With this balance, students can be exposed to techniques that enhance their learning, which does not necessarily lead to the same approach all the time. Even so, there could be suspicion that the use of active methods harms depth (technical skills), due to the fact that these methods are also indicated for the development of professional skills. Therefore, knowing that the results achieved generated gains in professional skills without any loss in technical skills is very encouraging.

Recently, ABET published a report that analyzes newest results of EC2000 and confirms previous expectations (ABET, 2019).

2.1.3.2 Royal Academy of Engineering

The Royal Academy of Engineering is the UK's national academy for the engineering profession. The fellows and staff collaborate with various partner organizations, including the Government Office of Science and Innovation, the British

Council, UK research councils, as well as parliamentary and governmental groups. The Academy also plays a key role as a founding member in influential international organizations like the International Council of Engineering and Technological Sciences (CAETS) and the European Council of Applied Sciences and Technologies and Engineering (Euro-CASE), which are significant platforms for shaping global policies.

Due to its strong political role, the Academy can work in government and parliament, providing support to a large number of decision makers, who largely do not have an engineering background.

Another crucial aspect of the Academy's efforts in shaping national policies involves inspiring and guiding the education of young individuals, with a particular emphasis on encouraging them to pursue studies in science, technology, engineering, and mathematics (STEM) fields.

The Academy's outreach to the public is focused on enhancing the organization's visibility and highlighting the role, contributions, accomplishments, and issues confronting engineers. These communication efforts aim to involve individuals of all ages and backgrounds in discussions about engineering and its influence on society, the country, and the world.

Since November 2019, the Academy has led a national awareness day to raise public awareness of how engineers make a difference in the world and celebrate how engineers shape the future. This is called “National Engineering Day” and promotes a competition that is open to all the UK’s kitchen table engineers, with ideas and innovations that could make or are making our daily life more sustainable.

In addition, there is a campaign launched in 2018 and called “This is Engineering” with the aim of encourage more young people, from all backgrounds, to consider engineering careers. According to the official website (Royal Academy of Engineering, 2023b), the main objective is to show more young people what engineering really looks like, and how it could be an exciting and rewarding path for them in the future. It is a top-quality, highly effective multi-channel campaign that aims to inspire 1.5 million young people to become engineers by 2025, with at least half coming from underrepresented groups.

One interesting fact about the Royal Academy is its attention to contemporary problems. Beyond two actions listed above, there is a series of videos about how engineering can support each one of 17 SDGs. Moreover, the Academy has a committee dedicated to diversity and inclusion issues, parallel to the research committee, among others.

In the last two years, two reports must be highlighted:

- Ethics in the engineering profession (Royal Academy of Engineering, 2023a) - The main goal was to create a standard against which the engineering profession in the UK can regularly assess and report on its ethical performance, as well as pinpoint areas where improvements in ethical culture and practices are needed.
- Maintaining society's trust in the engineering profession (Royal Academy of Engineering, 2022) - Proposes a series of actions and appropriate regulation that will achieve a more ethical culture in the UK's engineering profession.

In the report "Educating Engineers for the 21st Century" (2007), the Academy emphasizes the major findings cited in section 2.1.2. These findings were in line with those described by ABET and also with the points raised by Shuman (2002) about the need to modernize engineering education.

2.1.3.3 CDIO (Conceive-Design-Implement-Operate)

The CDIO initiative aims to improve undergraduate engineering education at participating institutions. It began in 2000 with the collaboration of four Swedish universities (The Royal Institute of Technology, Chalmers University of Technology, Goteborg e Linkoping) together with Massachusetts Institute of Technology (Beanland & Hadgraft, 2013, p. 75).

It is based on a few key ideas, the first two being a restatement of the underlying need for reform of engineering education and a set of objectives for engineering education.

The central point of the CDIO approach is a vision for engineering education that includes using the engineering life cycle process as the context for engineering education. A specific pedagogical foundation supports the realization of this vision (Crawley et al., 2014, p. 12).

The CDIO approach has three general objectives. Educate students who are able to:

- Master a deeper practical knowledge of technical fundamentals;
- Lead the creation and operation of new products, processes and systems;

- Understand the importance and strategic impact of research and technological development in society.

Figure 6 shows the evolution of engineering education:

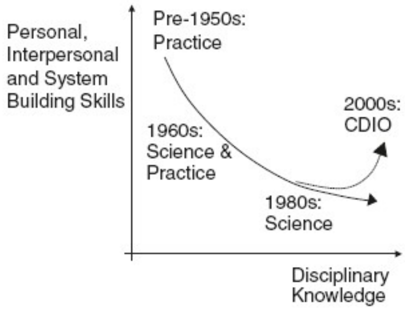

Figure 6 - Engineering education evolution
Source: (Crawley et al., 2014, p. 17)

Currently, the CDIO community has more than 120 engineering schools around the world, organized into 7 regions: Europe, North America, Asia, United Kingdom-Ireland, Latin America, Australia, New Zealand and Africa. In Brazil, Instituto Militar de Engenharia (IME) became an official member of the CDIO community in 2019.

Figure 7 provides a good overview of the implementation of the CDIO approach. In it, it is possible to see that in the center is the CDIO context. It is made up of two large subsets, on the left “how to teach” and on the right “what to teach”.

Regarding the question “what to teach”, the CDIO syllabus and stakeholder surveys lead to the definition of learning objectives, which is also supported by the accreditation criteria and benchmark skills.

Based on the big question “how to teach”, the context of the CDIO community and the best practices that exist in the world lead to the consolidation of 12 standards, which provide guidance for engineering schools that want to align themselves with what is happening in other schools in the community. These standards can be seen as recommendations that support the redesign of programs, which is also supported by comparison with existing teaching and learning methods.

Both the redefinition of programs (left side – “How to teach”) and the definition of learning objectives (right side – “What to teach”) impact the existing degree program, to drive the necessary adjustments.

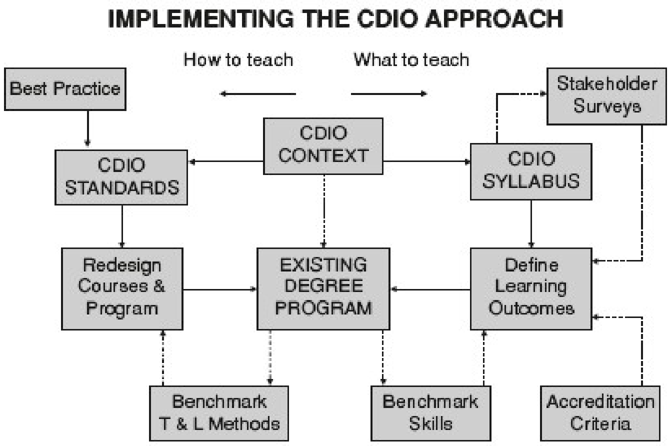

Figure 7 - Implementing the CDIO approach.

Source: (Crawley et al., 2014)

The CDIO approach brings 12 standards, the CDIO Standards, which represent effective principles of practice. They address:

- The fundamental principle of an education lifecycle context (Standard 1).
- Curriculum development (standards 2, 3 and 4).
- Design and workspace implementation experiences (Standards 5 and 6).
- Teaching and learning methods (Standards 7 and 8).
- Faculty development (Standards 9 and 10).
- Assessment and evaluation (Standards 11 and 12).

In particular, standard 8 specifically addresses the use of active learning methods and will be further detailed in section 2.3 of this work.

2.1.3.4 New Engineering Education Transformation (NEET)

The program was launched in 2016 to reimagine engineering education at MIT. An interdepartmental endeavor focusing on integrative and project-centered learning, NEET cultivates the skills, knowledge and qualities essential to meet the formidable challenges posed by the 21st century ("New Engineering Education Transformation - MIT," n.d.).

The NEET vision is built on three pillars (Graham, 2018, p. 2):

- An educational approach that is underpinned by design synthesis and innovation;
- Educational delivery that effectively and appropriately integrates modern pedagogical approaches, supported by a flexible curriculum; and

- An educational framework that reflects the challenges facing engineering in the 21st century.

Additionally, the program has two secondary objectives (Mitra, 2019):

- Reimagine what and how students learn to better prepare them to make important contributions in the 21st century;
- Strengthen MIT's contribution to engineering education around the world.

The program has five main themes of interest, which offer students opportunities to immerse themselves in multidisciplinary projects:

1. Advanced machine materials;
2. Autonomous mechanical systems;
3. Digital cities;
4. Living machines; and
5. Renewable energy machines.

The report titled *The Global State of the Art in Engineering Education* (2018) is a reference in the field of engineering education for seeking answers to five highly relevant questions, especially the fifth:

- Which institutions are considered current leaders in the field?
- Which institutions are considered emerging leaders in the field?
- What characteristics distinguish current leaders from emerging leaders?
- What key challenges are likely to constrain the field's progress in the future?
- What is the future direction of the field?

This survey was based on interviews with 50 global thought leaders in the field, in addition to conducting individual interviews with 178 people with knowledge and experience in globally recognized engineering programs.

In answers to the first two questions, the top 50 experts in the field highlighted ten universities that they consider to be the current global leaders in engineering education, as shown in Figure 8.

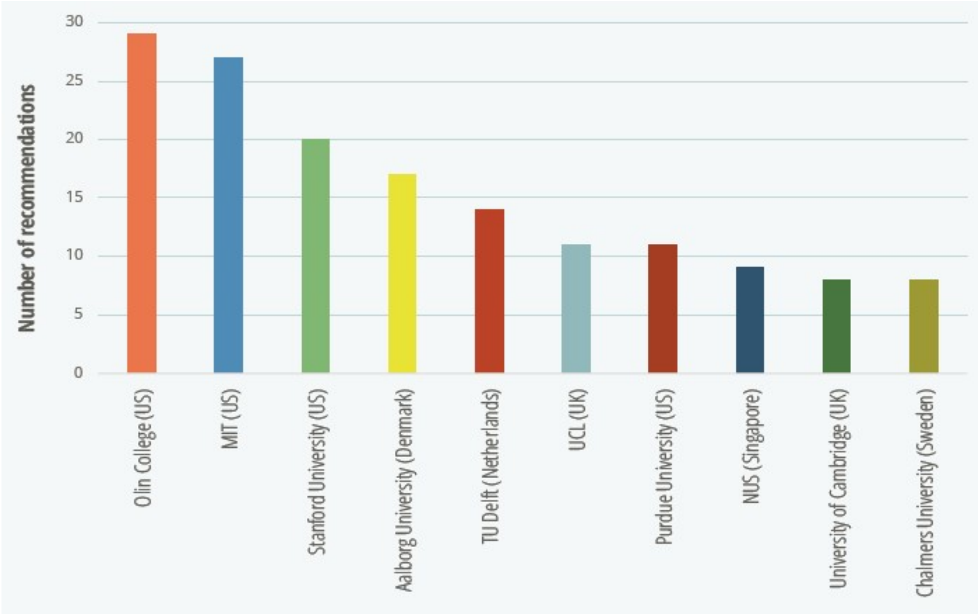

Figure 8 - The 10 institutions most frequently identified as ‘current leaders’ in engineering education.

Source: (Graham, 2018)

Stating that MIT is among the best universities in the world would not be news in itself. However, it is worth highlighting other institutions that are less known to the general public, which will be discussed later in this work (section 2.1.3). They are Olin College, Aalborg University and TU Delft.

Furthermore, the fact that MIT – an institution already considered a world leader – has a movement aimed at reforming the field of Engineering Education is relevant. The work *The Global State of the Art in Engineering Education*, linked to NEET, is one of the main references on the current situation in the field and new challenges.

2.1.3.5 How about Brazil?

Nationally, the National Education Council (CNE) issued an opinion on the approval in 2019 of the National Curricular Guidelines for the Undergraduate Course in Engineering (Engineering DCN’s), in which it emphasizes that this approval “coincides with the expectations of part of the academic community, of the companies that employ this qualified workforce and the sectors that represent the professional activity in the area, as well as the need to update Engineering training in the country, aiming to meet future demands for more and better engineers". Currently, all engineering programs in Brazil need to reformulate their structure and curricula to be aligned with these new guidelines.

The industry's concern with the training of new engineers can be seen in two reports prior to the approval of the new national guidelines. SENAI published the study INOVA Engenharia: Proposals for the Modernization of Engineering Education in Brazil (SENAI, 2006), in which the need to modernize the field in the country is highlighted, in addition to bringing an international contextualization of the field and proposals for this modernization. The need for cultural change among teachers and the updating of secondary school teachers are also highlighted, as a way of "attacking problems at the root". The National Confederation of Industry – CNI, in Portuguese – published the report "Recommendations for the strengthening and modernization of engineering education in Brazil" (Confederação Nacional da Indústria, 2018), in which the needs to modernize teaching methodologies, course evaluation and changes in the hiring pattern and appreciation of teaching staff are highlighted.

The Brazilian Association of Engineering Education (ABENGE, in Portuguese) has taken on the role of promoting debate about the field in the country. Its mission is "To produce necessary changes to improve the quality of undergraduate and postgraduate education in engineering and technology in Brazil, decisively contributing to the training of increasingly qualified and capable professionals who take development and technology to all parts of the country for the benefits that engineering can provide to the entire population" (ABENGE, 2023).

When it comes to topics related to this research, it is worth highlighting that ABENGE maintains two interesting working groups: "Active Learning" and "Entrepreneurial Education". It is also worth highlighting a book that specifically deals with active learning methods for engineering courses, which was supported by ABENGE in its production: "A new classroom is possible: Active Learning in Engineering Education" (Filho, Sauer, Almeida, & Villas-Boas, 2019).

2.1.4 Examples of Universities around the world

In addition to the movements discussed in section 2.1.3, it is also worth going into a little more detail about the universities that have already stood out in the transformation of engineering education. In the study *The Global State of the Art in Engineering Education* (2018), thought leaders had, in addition to identifying the currently leading institutions (as already shown in Figure 8), to point out the five or six universities that they considered to be the 'emerging leaders' in engineering education: the institutions that seem destined to achieve the at the forefront of engineering education around the world in the coming decades. The ten most cited appear in Figure 9.

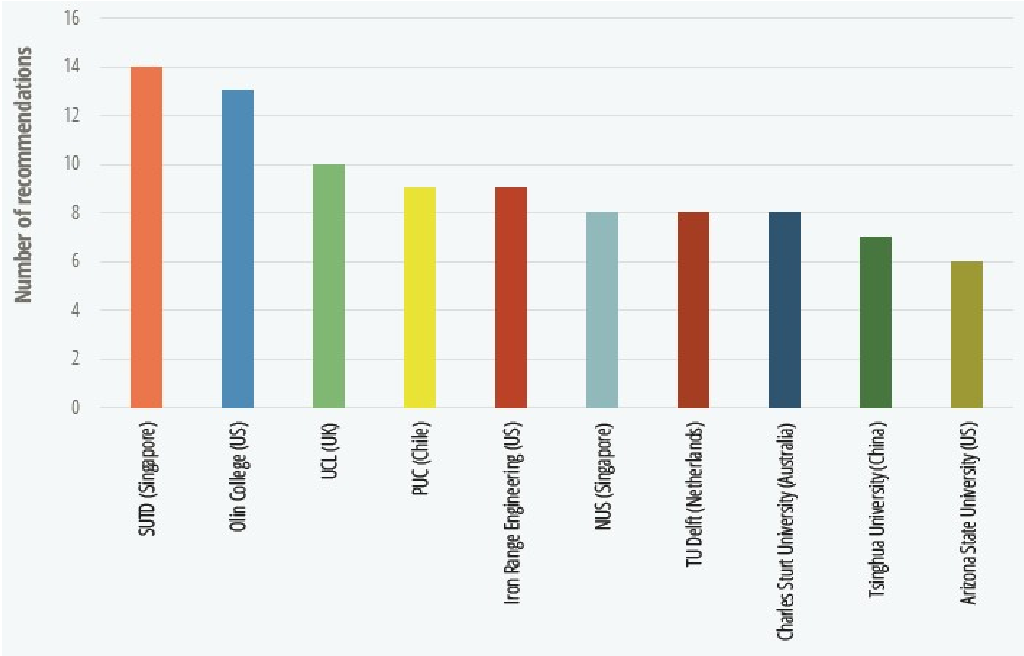

Figure 9 - The 10 institutions most frequently identified as 'emerging leaders' in engineering education.

Source: (Graham, 2018)

Based on the results in figures 8 and 9, it is worth looking more closely at 4 institutions: Olin College of Engineering, Singapore University of Technology and Design (SUTD), UCL Engineering and TU Delft. In addition to them, Insper (Brazil) – for presenting a student-centered curriculum with a hands-on approach – and Aalborg University – for being a leader in using Problem-Based Learning (PBL) as the core of its engineering education programs – will be addressed.

2.1.4.1 Olin College of Engineering

Olin was founded to become an important and constant contributor to the advancement of engineering education in America and throughout the world. In pursuit of this mission, Olin faculty engage in educational research, educational consulting, and the development of innovative, research-based learning opportunities for students (Olin College, 2023).

The institution was founded in 1997 with a total investment of almost US$500 million and a clear objective: to produce a new paradigm for training leaders in the 21st century, "rethinking higher education and creating an entirely new institution with an intense focus centered on the student, no academic departments, no tenure for faculty members, and large merit-based scholarships that reward bright young students who choose to pursue the study of engineering." (Beanland & Hadgraft, 2013, p. 72).

According to Beanland and Hadgraft (2013, p. 71), the Olin College "offers an example of an effective approach to engineering education. It was established to explore the transformation of engineering education and seeks to prioritize the development of the non-technical characteristics required by engineers through an emphasis on innovative projects throughout the program".

The classic book "A Whole New Engineer" (Goldberg & Somerville, 2014) has a direct relationship with Olin College, since Somerville is a member of its faculty and the publication of the book was supported by the institution.

2.1.4.2 Singapore University of Technology and Design (SUTD)

Singapore University of Technology and Design (SUTD) is a research-intensive university established in 2009 in collaboration with MIT and Zhejiang University. Its educational approach and structure are distinct in several aspects. For example, with no departments or schools, SUTD offers a multidisciplinary education that helps students connect and integrate their learning across courses and years of study. (Graham, 2018, p. 65).

According to Graham (2018, p. 87), its success factors are:

- Singapore government investment and commitment to the university;
- Partnership with MIT;
- Quality of university leadership.

In the pedagogical aspect, the structure of the university has the following characteristics (Graham, 2018, p. 20):

- Design-based and maker-based learning;
- Collaborative culture;
- Multidisciplinary approach, without pre-defined blocks of disciplines;

- Wide range of education: research opportunities, industry internships, opportunities to teach during undergraduate studies and subjects in the humanities and social sciences;
- Academic rigor in the fundamentals of engineering.

Those interviewed at SUTD highlighted that intrinsic motivation and the adaptability of the curriculum are fundamental factors for the university to stand out from others.

2.1.4.3 University College London (UCL)

Founded in 1826, University College London (UCL) is located in central London. The university supports a wide range of disciplines, from fine arts to medicine and from astrophysics to anthropology. Recent years have seen significant growth in the size and reputation of the university (Graham, 2018, p. 91).

In 2014, UCL Engineering implemented the Integrated Engineering Program (IEP), a radical reform of the undergraduate curriculum across all engineering departments. The new educational approach has two main components:

- common curriculum framework, adopted by all UCL Engineering degree programs, which is built around a series of authentic engineering projects;
- shared projects from multidisciplinary teams and Minors, bringing together students from across UCL Engineering.

UCL Engineering admission numbers are relatively high - over 950 students joined the student body in 2016/17 - and almost all study on the IEP curriculum. According to Graham (2018, p. 112), its success factors are:

- Quality of college leadership;
- Supportive institutional environment; and
- Empowerment of departments to drive change bottom-up.

2.1.4.4 Delft University of Technology (TU Delft)

Founded in 1842, it is the largest and oldest of the three universities specializing in technology in the Netherlands. TU Delft is made up of eight faculties covering engineering, applied sciences and design. Many interviewees noted the autonomy granted to Faculties, allowing each to follow its own practices and respond quickly to new opportunities. The university was also characterized as “open and accessible, with a flat hierarchy in organization and less bureaucracy than other universities.” Its "problem-solving and socially-relevant" approach to engineering is also reflected in the university's long-standing research collaborations with industry. More than a third of TU Delft's €385 million annual research income comes from industry (Graham, 2018, p. 140).

Key interviewees in the study highlighted “the Delft spirit”, which is a mix of openness and inclusion, which allows new ideas and innovative approaches to emerge from within the university community.

Unlike the cases of SUTD and UCL Engineering, Delft does not offer a core curriculum for engineering courses. Its courses stand out for their diversity: there are 17 bachelor's and 33 master's programs, with independence in conception and delivery. However, they have characteristics in common:

- Deep knowledge of the fundamentals: all interviewees highlighted the technical rigor that students are subjected to in Mathematics, Mechanics and Engineering Fundamentals;
- Design-centered learning;
- Culture of student initiatives for hands-on learning; and
- Pioneering approach to online and blended learning.

The Delft case also differs from previous cases in that it is not based on the creation of a new institution or the profound reform of an old institution. Delft had its strength in achieving incremental changes, maintaining its reputation and being able to open up to educational innovations (Graham, 2018, p. 27).

2.1.4.5 Insper

It is a non-profit higher education and research institution that reverts all operational results to the achievement of its mission, which is to be a reference center for education and knowledge generation in the areas of administration, economics, law and engineering, exploring their complementarities to add value to organizations and society.

Its vision is to be the best Brazilian higher education institution in the areas in which it operates and to be recognized as such (“Insper,” 2023).

Insper began its activities in 1987, with just the MBA in Finance course. It began its career in undergraduate courses (Administration and Economics) in 1999, with the focus on being a different school. Its undergraduate courses in Engineering only began in 2015, which increases the relevance of the work carried out – it was cited just 3 years later by a study that aimed to map the main institutions in the field worldwide.

Apparently, it is inspired by the model of American universities, with strong participation from the alumni community, a high average ticket for students who need to pay for courses and a consistent scholarship program.

In the pedagogical aspect, it has the following pillars ("Insper," 2023):

- Scientific rigor;
- Complete and comprehensive experience;
- Focus, dedication and involvement of the teaching staff;
- Learning through experience;
- Integration; and
- Demanding learning experience.

The last one is described by the institution as "the student is motivated to learn and take an active role in the learning process, both in the classroom and in complementary activities or engagement with student organizations".

2.1.4.6 Aalborg University

Aalborg University has been a leader in using Problem-Based Learning (PBL) as the core of its engineering education programs since 1975. It has deliberately chosen this strategy to transform its program and the results have been carefully researched and prove the merit of its approach (Beanland & Hadgraft, 2013, p. 74). Its programs dedicate up to 50% of available time to PBL and have demonstrated the importance of increasing student motivation and learning effectiveness through the student-centered learning that is created by PBL.

The projects are team-based, of variable scale, are multidisciplinary, tend to be close to professional reality and act in an integrated way with the students' learning. The faculty acts as advisors, but the projects are directed by the students. Projects can be accompanied by relevant support courses. Students are largely self-directed, but their management of the project, their time and available resources are considered in assessments.

2.2 Common points in the different movements analyzed

Regardless of the assumed point of view, there is a consensus that engineering education needs to be transformed. As previously presented in this work, institutions around the world are advancing the transformation process through different paths. In sections 2.1.2 and 2.1.3, there were examples of completely new institutions, created to grow in accordance with the principles of education in the 21st century (cases of Olin College, SUTD and Insper), and examples of very old institutions that needed to readapt (UCL Engineering and TU Delft cases). Furthermore, there were different curricular organization proposals, ranging from a flexible model – but with a common central core (UCL Engineering and SUTD) – to a decentralized model (TU Delft).

However, there are principles that should guide the transformation process (Beanland & Hadgraft, 2013, p. 120). Some of them are listed and commented below:

- Design the curriculum to maximize the development of essential capabilities to operate as a professional engineer – The development of professional capabilities is a subject of particular concern within the contemporary domain. Specifically, it pertains to the desired profile of the modern engineer and the requisite skills, while highlighting the disparity between competencies cultivated in the academic setting and those sought by employers (Abelha et al., 2020; Goldberg & Somerville, 2014);
- The design and implementation of the first-year engineering education program to maximize student motivation – The adoption of engineering projects in the very first year as a means to enhance student motivation is closely aligned with the CDIO standards (std 4). Furthermore, it has already been the subject of the author's thesis experiences (Passos, Arruda, Vasconcelos, & Ferrari, 2019). This study reported the curricular change implemented at the Military Institute of Engineering, which involved the introduction of a course titled "Introduction to Engineering Project". This curricular transformation was spearheaded by Aderson Campos Passos, with substantial involvement from the author of this thesis. The results demonstrated an increase in student satisfaction and a positive perception from the participating faculty members as well, aligned to other studies (Abelha et al., 2020; S. Fernandes, Abelha, Albuquerque, & Sousa, 2020; Moreira et al., 2021; Sousa et al., 2023);

- The expansion of Project-Based Learning in engineering education programs – The adoption of curriculum designs tailored for PBL has yielded various positive outcomes (Terrón-López et al., 2017; Yadav, Subedi, Lundeberg, & Bunting, 2011). This approach fosters the development of professional competencies and enhances awareness of sustainability (Du & Kolmos, 2006; Servant-Miklos et al., 2020; Thomas, 2009);

- Replacing the expository class that transmits information in engineering teaching programs with activities that generate student-centered learning through the active involvement of students that creates thinking aimed at achieving understanding - The adoption of active learning techniques has been extensively discussed in the scientific literature, encompassing both the positive and negative aspects. This is a central theme in the current thesis and will be elaborated upon in the section 2.3; and

- The use of a wide range of Information and Communication Technology systems and resources to facilitate student-centered learning – With the advancement of these technologies and the widespread adoption of their usage, it is crucial for the university to align itself with the current landscape and facilitate the necessary updates to enhance student engagement. The 21st-century student exhibits a distinct profile compared to those of past decades, which intensifies the challenge of maintaining their interest in classroom activities (Anabela C. Alves, Fernandes, & Uebe-Mansur, 2021; S. Fernandes, Alves, & Leão, 2022; Leão, Alves, Soares, & Silva, 2022; Lombardi & Oblinger, 2007).

Today's leading universities have different approaches to addressing the field's transformation, but three factors are common to them (Graham, 2018, p. 29):

- Established international profile: most 'current leaders' are well-established public universities serving relatively large groups of undergraduate engineering students;

- Educational excellence often confined to small pieces of the institution: Many thought leaders interviewed noted that the best practices that helped make a university a world leader in engineering education were rarely institution-wide; and

- Emphasis on external engagement and educational collaborations: Most “current leaders” – particularly the five most frequently cited universities – have been actively engaged in disseminating their ideas and practices throughout the international higher education community.

In relation to the ‘emerging leader’ institutions in the field, there are other common factors. The most relevant are in the list below:

- Strength of academic leadership;
- University and exploratory educational culture;
- Student engagement and understanding of new pedagogical approaches; and
- Internal development of new tools and resources to support and advance educational approaches.

If the general institutional aspects present different approaches, on the other hand, the teaching and learning aspects appear to converge on some points, especially with regard to the importance of stimulating student engagement. This need underpins the importance of studying active learning methods.

2.3 Active learning

Engineering is a problem-solving profession and requires a problem-based approach to learning. Engineering students must acquire the skills to analyze and address the challenges society is encountering. They also need to work on developing technologies that can enhance sustainable living (Kolmos, 2021).

People acquire knowledge and skills through practice and reflection, not by watching and listening to others telling them how to do something. While traditional lecturing might effectively enhance short-term memorization of facts, active methods have consistently proven more effective in fostering long-term memory retention, understanding, problem-solving abilities, enthusiasm for learning, and a lasting interest in the subject matter (Richard M. Felder et al., 2000).

As already explained in section 1.2, there is no single consensus definition of the expression "active learning". It is a wide concept, most often referring to student-centered and activating instructional methods and instructor-led activities (Bonwell & Eison, 1991; DeMonbrun et al., 2017; Richard M. Felder et al., 2000; Hernández-de-Menéndez, Vallejo Guevara, Tudón Martínez, Hernández Alcántara, & Morales-Menendez, 2019; Prince, 2004). However, there are three most popular definitions: Prince (2004), Roehl (2013) and Barkley (2010). In addition to these, Hartikainen (2019) presents 66 definitions, grouped into three main categories: (1) defined and seen as an instructional approach; (2) not defined, but seen as an instructional approach; and (3) not defined, but seen as an approach to learning.

2.3.1 Active learning techniques

Among the main active learning techniques, three listed below stand out:

- Problem-Based Learning (PBL) (Edström & Kolmos, 2014; Richard M. Felder & Silverman, 1988; Richard M. Felder et al., 2000; Hoidn & Kärkkäinen, 2014; Lee Chong & Benza, 2015; Mohd-yusof, Arsat, Borhan, Graaff, & Kolmos, 2013; Prince, 2004; Spronken-Smith & Harland, 2009; Yadav et al., 2011);
- Project-Based Learning (PBL or PjBL) (De Los Ríos-Carmenado, López, & García, 2015; Edström & Kolmos, 2014; S. Fernandes, Abelha, Fernandes, & Albuquerque, 2018; Jaeger, 2016; Ríos, Cazorla, Díaz-Puente, & Yagüe, 2010);
- Cooperative e Collaborative Learning (Bolton, Saalman, Christie, Ingerman, & Linder, 2008; Bonwell & Eison, 1991; Carr, Palmer, & Hagel, 2015;

Chapman, 2003; Holbert & Karady, 2009; Prince, 2004; Rodriguez-Triana, Prieto, Holzer, & Gillet, 2020; Salaber, 2014); and

- Flipped classroom (Burke & Fedorek, 2017; Howell, 2021; McLaughlin et al., 2014; Mori, 2017; van Alten, Phielix, Janssen, & Kester, 2019).

2.3.2 Positive effects

According to existing literature, active learning has positive impacts on student engagement (Barkley, 2010; Carini, Kuh, & Klein, 2006; Dochy et al., 2003; Freeman et al., 2014; Ito & Kawazoe, 2015; Prince, 2004; Strobel & van Barneveld, 2009; Yadav et al., 2011) and competence development (Dochy et al., 2003; Duarte et al., 2022; Hartikainen et al., 2019; Hernández-de-Menéndez et al., 2019; Sousa et al., 2023; Strobel & van Barneveld, 2009).

This development may act as the bridge between education and professional career, what increases the motivation to apply active learning techniques to promote working life expectations (B. Chen, Bastedo, & Howard, 2018; Hartikainen et al., 2019; Hernández-de-Menéndez et al., 2019; Ito & Kawazoe, 2015; Kolmos et al., 2020; Lamb et al., 2010; Passos et al., 2019; Royal Academy of Engineering, 2007).

Furthermore, the pedagogical results and effectiveness of active learning are also widely documented, especially with regard to long-term retention (Baepler, Walker, & Driessen, 2014; De Los Ríos-Carmenado et al., 2015; Dochy et al., 2003; Freeman et al., 2014; Hegarty & Thompson, 2019; Hernández-de-Menéndez et al., 2019; Ito & Kawazoe, 2015; Lizzio & Wilson, 2004; Prince, 2004; Strobel & van Barneveld, 2009; Van Amburgh, Devlin, Kirwin, & Qualters, 2007).

To effectively support development to achieve each SDG, engineering problems are more complex than decades ago. The Cynefin framework serves as a valuable tool for grasping the integration of teaching and learning approaches within the growing necessity to comprehend complex scenarios (Snowden & Boone, 2007). This framework classifies situations as:

- Simple: where system behavior is well understood, and best practice is implemented;
- Complicated: requires expert behavior where there are multiple right answers (ex.: design of a bridge);

- Complex: emerging new competencies where the nature of the problem or the kind of solutions to be applied is unclear (sustainability problems are in this domain); and
- Chaotic: situations as a result of disaster, whether natural or human-induced. Immediate actions are needed to stabilize the situation before applying methods from the complex, complicated and simple domains.

Currently, most of engineering programs curricula are concentrated in simple and complicated domains. Kolmos (2021) states that challenges of sustainable development, the Fourth Industrial Revolution and employability call for possible learning competencies within all four domains: i) chaotic; ii) complexity and emergence; iii) complicated; and iv) obvious. Figure 10 suggests how to combine elements in curriculum development, considering degrees of complexity.

	Type of problem	Knowledge and competencies	Curriculum structure	Teaching and learning methods
Obvious	Known problem Known solution e.g. statics	Disciplines	Subjects/courses	Lectures, active learning and flipped classroom
Complicated	Known problem Unknown solution e.g. zero carbon house	Multi-disciplinary	Collaboration among several disciplines	Academic problem-based projects across disciplines
Complex	Unknown problems Unknown solution e.g. energy zero buildings in energy zero cities New IoT, AI, Bio technologies and sustainability challenges	Inter-disciplinary	Re-organization of the curriculum and development of new student-centred and blended learning models	Complex problem analyses and problem-based projects across disciplines and together with stakeholders Mega-projects
Chaotic	**Disasters beyond complexity**	**Training in immediate action by bringing experiences/ problems from chaotic situations into education**		

Figure 10 - Combining elements in curriculum development with degrees of complexity. (Source: (Kolmos, 2021))

Finally, students from active learning experience evaluate themselves more confident in sustainability and social responsibility, even with no more courses about this issues (Kolmos et al., 2020; Servant-Miklos et al., 2020).

2.3.3 Limitations

However, there are problems in both the research and implementation of active learning. Prince (2004) points out that comprehensive assessment of active learning is difficult due to the limited range of learning outcomes and the different possible interpretations of these outcomes. Streveler and Menekse (2017) note that “active learning is not a panacea that is a blanket remedy for all teaching inadequacies. Rather, it is a collective term for a group of instructional strategies that produce different results and require different degrees of time to design, implement, and evaluate”. Fernandes (2014) reports that “students identify the heavy workload that the project entails as one of the main obstacles to the PBL approach”. When it comes to more traditional and domain-specific skills related to natural sciences, students in PBL courses report feeling less confident than others (Kolmos et al., 2020). There are also the less researched, but much mentioned, barriers of resistance to novelty on the part of teachers and students (A. Alves et al., 2016; Andrews et al., 2021; Bicknell-Holmes & Seth Hoffman, 2000; Borrego et al., 2019; DeMonbrun et al., 2017; Ito & Kawazoe, 2015). However, the way colleges and universities reward their faculty has a big impact on how much they focus on teaching. It can either motivate them to pay more attention to teaching or make them less interested in it (Lattuca et al., 2006).

2.3.4 Analysis

As already shown in this work, active learning has been widely applied in engineering and STEM. Moreover, those techniques are very popular in other fields, such as Management and Health (De Los Ríos-Carmenado et al., 2015).

Students’ affective responses to active learning in STEM courses were systematically reviewed, from 1990 to 2018 (Borrego et al., 2019). Those responses were overwhelmingly positive, with 84% of studies reporting positive or mostly positive results (346/412 studies), despite vast majority (80%) of the studies earned less than half the possible points on our scoring rubric.

Analyzing the geographic scope of active learning, especially in high-level institutions, reports about MIT (Kolmos et al., 2020), Olin College (Goldberg & Somerville, 2014; Grasso & Burkins, 2010), University College London (Kolmos et al., 2020), Aalborg University (Hernández-de-Menéndez et al., 2019; Kolmos, Hadgraft, & Holgaard, 2016; Kolmos et al., 2020), The University of Queensland – Australia (Hernández-de-Menéndez et al., 2019), and Singapore University of Technology and Design (Graham, 2018) stand out.

Despite the limitations and particularities, it remains clear that active learning works as an important tool to improve student engagement, lifelong learning and development of critical and problem-solve thinking. However, a search of the literature failed to quantify and characterize the use of active-learning techniques by faculty members (Van Amburgh et al., 2007). Kolmos (2021) stated about Project-Based Learning, but it is possible to extend the same logic to active learning as a whole: The question today is not whether active learning works, but rather the quality of active learning implementation.

In order to fill this gap, the proposal of this work is to employ the concept of maturity model, detailed in the next section.

2.4 Maturity models

As companies constantly deal with the need to stay ahead and keep their edge in the market, it's becoming more and more crucial to find ways to reduce expenses, enhance quality, and speed up the product development process. To aid in these efforts, maturity models have been created to help organizations.

The concept of maturity has seen widespread attention in several academic fields. Maier (2012) lists three approaches of this concept:

- Process maturity – The idea of process maturity originates from Total Quality Management (TQM), where the use of statistical process control methods demonstrated that enhancing the maturity of any technical or business process ideally results in reducing the inherent variability in that process. Consequently, this leads to an enhancement in the average performance of the process.
- Organizational Maturity – widely used in software development. It is based on the interpretation of organizations advance through a series of five stages or levels of maturity: from an initial level to a repeatable, defined, managed, and an optimizing level. These levels describe an evolutionary path from ad hoc, chaotic processes to mature, disciplined software processes, and define the degree to which a process is institutionalized and effective; and
- Process Capability - measures process capability directly and organizational capability with a process capability profile.

Szakonyi (1994) states that maturity seems to be an increase in knowledge about skills, methods, and responsibilities. A commonly accepted principle involves depicting maturity as a sequence of cumulative stages, with each higher stage building upon the requirements of the lower stages. In this practice, a higher number signifies a high level of maturity, while a lower number represents lower maturity, and this approach is widely embraced in practical applications (Maier et al., 2012).

Maturity models have been designed to assess the maturity (i.e. competency, capability, level of sophistication) of a selected domain based on a more or less comprehensive set of criteria (de Bruin, Rosemann, Freeze, & Kulkarni, 2005). Maturity modeling is a generic approach that outlines the evolution of an organization over time through optimal levels leading to a final state (Klimko, 2001). A maturity model, in essence, illustrates various stages of growth and development in terms of both quantity and quality, aiming to evaluate progress in specific areas of focus (Kohlegger, Maier, & Thalmann, 2009).

These models can be used as an evaluative and comparative basis for improvement (Fisher, 2004; Spanyi, 2004). Categorizing the tiers, or phases, of any process often facilitates analysis and understanding (Jabbour, 2010; Maier et al., 2012). The great contribution of a maturity model is the process of evolution and cause-effect analysis that can support organizations to improve their maturity level in a scale (Ormazabal, Rich, Sarriegi, & Viles, 2017).

Among the prominent maturity models across various domains, the following stand out:

- CMM (Capability Maturity Model) – widely employed for organizational process improvement (Humphrey, 1989; Paulk, Curtis, Chrissis, & Weber, 1993);
- OPM3 (Organizational Project Management Maturity Model) – from the field of project management (PMI, 2003);
- BPM (Business Process Management) – popular for assessing capabilities in business process (Fisher, 2004; Rosemann & De Bruin, 2005); and
- ECO-MI – significant model for evaluating eco-innovation practices in organizations (Xavier, 2017; Xavier, Reyes, Aoussat, Luiz, & Souza, 2020).

According to de Bruin et al. (2005), a maturity model may be classified as:

- Descriptive – evaluates the situation *as is*, but does not provide suggestions to improve the level;
- Prescriptive – emphasizes the relationship between process and performance, and is able to offer a guide to increase maturity level; and
- Comparative – allows comparative analysis between different industries or regions and make comparisons between procedures in the organizations.

It is possible to understand these three types of models as evolutionary phases of a maturity model lifecycle. First, the model diagnoses (descriptive) the situation to increase the comprehension about the area. After that, the model can advance to prescriptive stage, through improvement proposals that may be repeated. Finally, the model needs to be applied to a large sample of organizations and/or regions, to collect data that supports a valid comparison (comparative).

Finally, there is an acceptance that business processes are beneficial and necessary (Maier et al., 2012). However, the fundamental concept of "cause and effect" may be fallacious since the processes being evaluated often involve social dynamics that do not follow simple cause-and-effect patterns (Pfleeger, Fenton, & Page, 1994). Then, careful analysis is needed to evaluate whether relationships between processes and results are reliable.

PART I – AXIS “The profile: new engineer and the impact on society”

Engineers are positioned as potential problem solvers who can contribute to the achievement of the 17 Sustainable Development Goals by applying innovative and solution-based methods (UNITED NATIONS, 2020).

It's important to acknowledge that the essential skills demanded of engineers are undergoing a noticeable transformation as technology advances. With the rise of Artificial Intelligence, machine learning, and the integration of robotics, the connection between humans and the traditional "hands-on" engineering skills of the past is being reduced. Then, competencies formerly categorized as "soft skills" are now increasingly recognized as the pivotal skills for the future (UNESCO, 2021). Competencies like resilience, flexibility, the ability to acquire new information, collaboration, and effective communication will soon be just as crucial, if not more so, than the extensive technical expertise that was historically highly regarded in the field of engineering (Jackson & Mellors-Bourne, 2018). Consequently, this will require a new type of engineer, one in which diverse traits are highly prized (WEF, 2016).

This need of an engineer trained with new skills and concerns is the main motivation of first axis of this thesis.

Initially, there is a book chapter titled “What sort of engineering do we want? How far are we from it? A manifesto for socially situated professional ethics”, focused in two points: (i) choices made by south American countries in terms of developing national engineering capability; and (ii) the training of engineers, who are now eminently concerned with the technical aspects of design solutions, but is leaving out the most important part of the civilizing process today: the human question.

In sequence, following two papers are inclined to entrepreneurship and its relationship with the university. Chapter 4 presents an authorial method to identify alumni-founded companies, called BR-AFC, which is the first step to measure the entrepreneurial impact of university to the society. Using BR-AFC, it will be possible to evaluate whether the entrepreneurial result is aligned to the program objectives. Finally, chapter 5 investigates whether there is correlation between entrepreneurial activity and academic performance. There is a consensus that employability is linked to students results during the course, but now the research is about entrepreneurial activity.

3. The engineer profile we want to deliver to society

3.1 Prologue

Over last decades, some topics that were not treated as priorities in engineering have gained relevance, such as inclusion, diversity, communication, and sustainability (UNESCO, 2021).

Because of that, engineering education has been faced with many different societal challenges that have required change in the curriculum, especially with emphasis on embracing more critical thinking and community-driven modes (Kolmos et al., 2020).

In the realm of engineering education, numerous experts have contended that one of the most effective methods for enhancing awareness of sustainability and fostering engagement among engineering students is by active learning, specially problem-based and project-based learning (Coral, 2009; Guerra, 2014). Furthermore, PBL provides sustainability skills improvement or development (Dochy et al., 2003; Kolmos et al., 2020).

Particularly, Lattuca *et al.* (2006) analyzed impacts of new ABET set of accreditation criteria EC2000 on engineering graduates from 1994 to 2004 and reported relevant gain in awareness of societal and global issues, group skills and awareness of issues relating to ethics and professionalism. In the same period, there was an important increase of the use of active learning methods. One of the main findings of this study is about the gain of professional skills, besides a maintenance of technical skills.

Several publications focused on the social, soft, and professional skills (Anabela C. Alves, Leão, Moreira, & Teixeira, 2018; Araujo & Manninen, 2022; De Los Ríos-Carmenado et al., 2015; Karabulut-Ilgu, Madson, Miner, Shane, & Burzette, 2023; Marinho et al., 2022). Moreover, most cited skills are listed below, with additional references:

- Sustainability (Kolmos, 2021; Kolmos et al., 2016, 2020; Lattuca et al., 2006)
- Leadership (Aranha et al., 2018; Confederação Nacional da Indústria, 2018; Hundley, 2015)
- Teamwork (Aranha et al., 2018; Confederação Nacional da Indústria, 2018; Duarte et al., 2022; Hundley, 2015; Kolmos et al., 2020; Lattuca et al., 2006)
- Communication (Conférence des Directeurs des Écoles Françaises D’Ingénieurs, 2022; Duarte et al., 2022; Hundley, 2015; Kolmos et al., 2020; Lattuca et al., 2006; Lombardi & Oblinger, 2007)

- Entrepreneurship (Confederação Nacional da Indústria, 2018; Etzkowitz, Webster, Gebhardt, & Terra, 2000; Kolmos, 2021; Linton & Klinton, 2019; Täks, Tynjälä, Toding, Kukemelk, & Venesaar, 2014)
- Innovation (Aranha et al., 2018; Confederação Nacional da Indústria, 2018; Etzkowitz et al., 2000; Vefago, Trierweiller, & de Paula, 2020)
- Problem-solving ability (Alkhatib, 2019; Confederação Nacional da Indústria, 2018; Dochy et al., 2003; Duarte et al., 2022; Kolmos, 2021; Kolmos et al., 2020; Lattuca et al., 2006)
- Interdisciplinarity (Confederação Nacional da Indústria, 2018; Duarte et al., 2022; Grasso & Burkins, 2010; Hundley, 2015; Lattuca et al., 2006)
- Creative thinking (Alkhatib, 2019; Confederação Nacional da Indústria, 2018; Duarte et al., 2022; Hundley, 2015; Lombardi & Oblinger, 2007)
- Critical thinking (Duarte et al., 2022; Hundley, 2015; Kolmos et al., 2020)

According to Felder (1988), Borrego (2019) and Kolmos (2020), teaching methods and contemporary subjects (like ethics, inclusion, diversity, and professionalism) have some degree of relationship, although they could be seen as two environments completely separated. This bridge is the trigger that motivated the teamwork whose result is this book chapter (Aguilar Molina et al., 2023).

This book chapter started from the participation in Forum in Philosophy, Engineering and Technology 2020. The initial discussions about the plausibility of a maturity model to assess active learning implementations fit in with other three works at the conference that focused on the broader and contemporary training of engineers. The four articles examined the ideal characteristics of emerging engineers and how these traits can and should be developed.

Additionally, the chapter explores related topics regarding the education of engineers, including ethics, the process of engineering design, and the responsibilities of engineers in a world facing imminent crises, largely due to their work in the field.

Main result was this chapter, published in the book called “Rethinking technology and engineering”. The chapter discusses the profile of the 21st-century engineer, particularly in terms of technical, human, and social aspects. Furthermore, this discussion encompasses the constraints imposed by society on engineering goals, from a South American perspective.

3.2 Full text

Chapter “What sort of engineering do we want? How far are we from it? A manifesto for socially situated professional ethics” in book “Rethinking technology and engineering” (Fritzsche, 2020).

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Chapter 3
What Sort of Engineering Do We Want? How Far Are We From It? A Manifesto for Socially Situated Professional Ethics

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> *"The real problem for the engineer is where to place what he designs or builds and this does not come from engineering, but from the relationship of engineers with the world they inhabit, and that what they are designing makes sense and is desirable"*
>
> *Humberto Maturana Romecin, Chilean neurobiologist, creator of the theory of autopoiesis and the biology of knowing (1928–2021).*

Abstract This chapter seeks to discuss the directions in which engineering should evolve, with emphasis on the case of South America, in two dimensions. The first, at the national level, refers to the choices made by these countries in terms of developing national engineering capability. We maintain that these choices must prioritize, under all circumstances, the minimization of social and human inequality. And the second, at the individual level, is the training of engineers, who are currently eminently concerned with the technical aspects of design solutions. We believe this

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training leaves out what, in our view, is perhaps the most important part of the civilizing process today: the human question. For this purpose, the following will be discussed: (1) Engineering challenges in the Global South; (2) an analysis of economic and political aspects of Engineering in Latin America; and (3) Engineering from an epistemological, ethical, social and human perspective. This chapter is an argument to recover what we take as the essence of the engineer's work: having a broad view of the field of possibilities, in order to make a comprehensive reading of a given situation and, from that, formulate a problem to be solved, through a project solution in which the technical, the human and the social variables can be reconciled. We argue that current engineers' work in Latin America is far from embodying this essence and thus we discuss how education can play a privileged role in approaching a future generation of engineers to this ideal.

Keywords Engineering challenges · Human question · Global south · Engineering ethics · Engineering education

3.1 Introduction

This chapter is a synthesis of four papers presented at the Forum on Philosophy, Engineering and Technology, an event held in November 2020. The four papers discuss the desired profile of new engineers and how this profile could and should be developed. The chapter further explores this issue and touches transversal themes to the training of engineers, such as ethics, engineering design and the role of engineers in a world on the brink of collapse, mainly as a result of their professional practice.

The beginning of the twentieth century was characterized by the development and consolidation of fundamental industries for humanity, such as the automobile, aviation, synthetic materials and pharmaceutical industries. The development of science and technology was fundamental in both World Wars, boosting applications that opened the "pandora's box", placing ethical, social, human and environmental issues on the agenda of discussions regarding the future of humanity – given the evident corruption and subordination from technology and engineering to prevailing political agendas, reflected in the horrors of war. In this line, Van De Poel (2020) outlines three perspectives that delineate concerns with the implications of technology. The first of them – Technology as autonomous and determinate force – sees technology as an inexorable transforming vector of society, with its risks and benefits. The second – technology as a human construct shaped by human interests and values – is guided by the teleological aspect of technologies, seen now not just from the singular and abstract point of view, warning about the impact that cultural, political and value visions embedded in new technologies we may have in society. The third perspective – coevolution of technology and society – shows a concern with the difficulties of dealing with the unpredictability and unintentionality of technologies, where 'values, needs and expectations of society', while not immutable, evolve along with technologies in a circularity that can generate space for experimentation, creating new dilemmas and risks. Indeed, a series of discussions in the science and technology community focused at delimiting ethically controversial applications, especially in the context of nuclear weapons and the chemical industry. In the US, the discussion about the protection of the environment originated in 1962, with the publication of the book Silent Spring, by Rachel Carson – a denunciation of the indiscriminate use of pesticides and their consequences on air and water pollution (Carson, 2002). Such concerns were based on a series of disasters with millions of gallons of oil spilling onto California's beaches or chemical contamination of Ohio's Cuyahoga River, which spontaneously burst into flames. Astronauts began to show evidence of these disasters by photographing the Earth from space, with the consequent increase in awareness of the rapid depletion of its finite resources (EPA, n.d.) and the acceleration of planetary degradation processes.

In the last three decades of the twentieth century, the development of electronics and computing, in addition to biotechnology and nanotechnology fostered disciplinary hybridization, enabling the emergence of new areas such as genetic engineering and nanoengineering. Today, it is understood that most of the technologies of the so-called "Present Future" (Perelmuter, 2021), the near future that takes us to the middle of the twenty-first century, come from at least one of these areas, and above all from their cross intersections (Marr, 2020a; Diamandis & Kotler, 2015). However, if all these advances are bringing great expectations to humanity, they also brought significant impacts and influences on a wide spectrum, including economic, cultural, legal and political. New forms of production and consumption have changed the relationship between human beings and technology and required the development of different regulations at the governmental level.

After all these concerns, we find several ethical-cultural issues not yet resolved, which lead engineers to have to make decisions that can, in the long run, change the history of humanity for the worse – intentionally or not. This is the potential of emerging technologies, which have caused, however paradoxical it may seem, the immense increase in inequality in contemporary civilization. Such changes, roughly speaking, concern, for example:

- The place artificial intelligences (AI) will occupy in society and the rights they will have – whether AI will have rights comparable to those of objects (hence no rights), of animals or of humans. AI are currently seen as a sort of object, but the question is: for how long?
- The entire ethical-moral debate and the consequent regulatory framework related to implants in the human body. Internal devices that monitor the behavior of the human body, and that can even complement or replace organic organs are a tendency. What is not clear is whether this is desirable and ethical, and in what contexts it should be allowed or prohibited – a heart implant that can substitute a malfunctioning organ is more easily acceptable, but what about an artificial lung, eye, or something completely new that can counter human limitations? Artificial wings? Artificial gill?

- The entire debate on genetic editing of living beings, particularly humans, in favor of eliminating diseases and "enhancing" desired characteristics (height, strength, reproduction capacity, body shape, intelligence).

In addition to this global concern regarding the future of engineering, there is another concern with the National Engineering Capacity (Silva et al., 2015) of specific countries, especially countries in the global South. With small budgets available for technological development and, above all, social development, they need to make difficult choices in order to prioritize investments in one area over others. The more technology development accelerates, the more difficult it becomes for countries with less investment to keep pace without having to depend on evolutionary acceleration leaps (Ribeiro, 1969). It should be noted that access to technology cannot and should not be restricted to issues previously defined by hegemonic countries because, in many cases, these definitions increase geopolitical asymmetries. In the case of the global South, engineering must have the capacity to promote the reduction of inequality.

Therefore, as a main focus, this work seeks to discuss the directions of engineering, with emphasis on the case of South America, in two dimensions. The first, at the national level, refers to the choices made by these countries in terms of developing national engineering capability, which must prioritize, under all circumstances, the minimization of social and human inequality. And the second, at the individual level, is the training of engineers, who are currently eminently concerned with the technical aspects of design solutions. We believe that this training leaves out what, in our view, is perhaps the most important part of the civilizing process today: the human question (Bazzo, 2019). For this purpose, the following will be discussed: (1) Engineering challenges in the Global South; (2) an analysis of economic and political aspects of Engineering in Latin America; and (3) Engineering from an epistemological, ethical, social and human perspective.

3.2 Engineering Challenges in the Global South

Engineering in the Global South needs to cope with challenges emerging from a growing population experiencing fast urbanization: exploring new energy sources, democratizing water distribution and sewage treatment, waste management, massive transportation. For its part, the growth of extractive economic activities, with high environmental risk, has resulted in an increase in catastrophes – whether due to the action of nature or the collapse of large-scale works such as dams, nuclear plants, viaducts or buildings, all of them with serious environmental consequences, are events that raise fundamental questions about the role and responsibility of engineers, as the consequences of their decisions impact society and the environment.

The Covid-19 pandemic has greatly affected Latin America, in terms of health, demographics and economics. Infections and deaths were higher compared to the other parts of the world. In facing the pandemic with health technologies, engineering has an important role in building medical equipment. What was seen in the crisis is that having national engineering capability (Silva et al., 2015) is essential to remedy import dependency of equipment with an overpriced, questionable quality and extended delivery times, as was the case of Brazil. From an economic point of view, the national engineering capacity also refers to the capacity to (a) produce global technological innovations and sell them internationally and (b) introduce technologies currently available in other countries to national markets. An example of the second kind of engineering capability is the need to transform the entire chain of education, tourism and food-away-from-home (FAFH) in the face of a reality of prolonged social distance. In the specific case of education in many Latin American countries, there are still significant bottlenecks in access to technologies such as cell phones, computers and the internet (a problem with economic roots, not only technological ones), difficulties in assimilating new technologies (online classes, online tests, online books) and difficulties in innovating (creating new companies, business models and products that enable online education with quality equal to or greater than in-person). According to Costa (2020), in the Brazilian reality, the percentage of teachers who use collaborative activities with students does not reach 7%. In addition, one-third of students are unable to participate in any online activities.

In addition, during the pandemic, several multinationals that had branches in Brazil (Ford, Sony, Roche and Mitutoyo, for example) left the country, causing a wave of deindustrialization. This reduced the engineering labor market, and, coupled with currency devaluation, caused brain drain, particularly in areas where global demand is high (mainly information technology-related jobs such as software engineering). In the Chilean case, companies like Maersk, Nivea, Unilever and Lansa closed their factories in 2020 due to the loss of competitive capacity. According to the vice president of the National Competitiveness Commission, this is mainly due to the stagnation in the quality of higher education and the lack of competition generated by the concentration of wealth (small economy and many oligopolies) (La Tercera, 2020). In Mexico, deindustrialization is a phenomenon observed since the 1980s, with a significant advance of the tertiary sector over the industrial one (El Economista, 2017). Such a change in the employment profile is due, in large part, to the fact that many of the inputs used by the industry are imported, with the consequent decrease in value added in their processing, which is transferred to foreign companies. In Argentina, deindustrialization is the result of political processes that coincide with a cycle of accumulation and reproduction of an increasingly diversified and trans-nationalized capital (Schorr, 2012). Similar processes can be observed in other countries in the region, such as Colombia (Echavarría & Villamizar, 2005). In all cases, globalization is the common denominator, which has definitively affected the development of the industrial sector, by prioritizing natural resources and commodities.

3.3 Engineering and Society in Latin America: Economic and Political Aspects

In economic and market terms, engineering serves two different purposes: it is simultaneously a driver of economic indicators' long-term trends, and a necessary condition for present economic results. This reflects a dual role of engineers in society from an economic point of view: (a) developing new technologies and products and (b) generating production capacity for goods and services. The latter directly influences a country's GDP, while the former affects the long-term GDP and can be measured by other indices.

In recent years, Brazil has had economic results below the necessary to grow on the international stage. After the positive results in the beginning of 2010, a much more difficult reality came about, represented, among other things, by the small share of industry in the Brazilian GDP (less than 10%). Between 2006 and 2016, industry productivity dropped by more than 7%; in the Global Manufacturing Competitiveness Index, Brazil dropped from 5th position in 2010 to 29th position in 2016. Brazil ranks 62nd in the Global Innovation Index. According to WIPO (Soumitra Dutta & Wunsch-Vincent, 2020), Brazil and Chile produce less results in innovation than expected for the level of investment.

These numbers show the difficulty of Brazilian engineering in achieving both roles in the economy. Brazil's position in the Global Innovation Index highlights the country's backwardness in its ability to internalize and develop cutting-edge technologies embedded in products and services. Even when compared to emerging countries, the Brazilian performance leaves something to be desired. Figure 3.1 below, with data available on the World Bank portal, shows how the GDP per capita (in international prices) of the BRICS and Chile evolved in the last three decades.

Fig. 3.1 GDP per capita. (Data from World Bank portal)

It is possible to notice that Brazil and South Africa are the countries that did not show an upward trend in recent decades, and it is also worth noting the drop in Brazil's performance as of 2014. On the other hand, Chile has shown consistent growth, especially from 2008 onwards. A question emerges from such comparison between Brazil, Chile, and the other BRICS: can the way in which engineering is taught and practiced in Brazil help explain the poor economic and innovation results the country is having? Neely et al. (2018) argue that engineering tends to lose its disciplinary importance by increasing its involvement with the use of technical artifacts and value-creating economic issues rather than the development of technologies themselves. To regain their professional importance, engineers need new content in terms of design, business, and management.

According to the World Economic Forum's "Jobs of Tomorrow" survey (Ratcheva et al., 2020), it will be necessary to promote a global reskilling revolution, preparing the workforce for information technology jobs. In general terms, the first three industrial revolutions raised production levels, evolved assembly lines, electricity and information technology. The so-called 4th Industrial Revolution is mainly characterized by the importance of technologies that allow the fusion of different worlds: the metric physical world, the nano world, the digital world and the biological world (de Almeida & Cagnin, 2019). Building an exhaustive list of technologies that guide this process is an impossible exercise, not least because new technologies are always generated. On the other hand, there are some that are already mapped as being fundamental in this movement. Some of these technologies (Marr, 2020b) are, for example: Artificial Intelligence and Machine Learning; Internet of Things; Autonomous Vehicles; 3D and 4D printing and additive manufacturing; and Nanotechnology and Materials Sciences.

From the identification of these technologies as central to technological development in the coming decades, it becomes even clearer that engineering courses in Brazil need to be updated now. There is no growing trend in the number of engineers trained with mastery of these areas. It is still possible to notice in Brazil a high number of graduates in older courses, such as Mechanical and Civil Engineering, and a smaller number of graduates in courses closer to the 4th Industrial Revolution, such as Computer Engineering, Mechatronics or Control and Automation. This necessary reskilling of the global workforce is facing difficulties to be implemented in Brazil. Historically, engineering in Brazilian society is understood as one of the three imperial professions, together with medicine and law (Coelho, 1999). However, the last two are different in that they are generally at the service of specific individuals or companies, while engineering has a broader scope and, consequently, its responsibility is more often related to benefit society as a whole than specific people (Habash, 2018).

The demand for engineering majors faces cultural barriers related to difficulties in basic mathematics and science education in Brazil. Indeed, all of South America suffers from poor performance on the Program for International Student Assessment (PISA) (Schleicher, 2019) exam. These difficulties reflect a lower demand for engineering and technology courses, negatively affecting the already deficient availability of professionals in the sector. The Brazilian Association of Information and

Communication Technology Companies (Brasscom) estimates a need to train 420 thousand technology professionals between 2018 and 2024 (Brasscom, 2020), 70 thousand per year. Considering that the country trains 46 thousand people with a technological profile each year, this mismatch between labor supply and demand represents an opportunity to develop national capability in this area.

In addition, despite its importance to socio-economic development, engineering never shared the same social prestige medicine and law have in Brazilian society (Telles, 2014). The lack of prestige of Engineering in the group of three imperial professions deserves a careful analysis. The first question that needs to be answered, and that should be part of engineering training, is: engineering for whom? For society, for engineers, or for investors?

The current educational system discourages students' capacity for innovation and invention by focusing on problem solving rather than problem formulation. This causes them to be molded into an obedient way of reasoning, subservient to those who actually formulate the problems engineers will solve, characteristic of today's global production systems. Their obedient behavior makes engineers unaware of complex societal issues and of the adverse consequences of their works. Engineering cannot be merely operational and functionalist: it needs to be socially and ethically responsible. As engineers are the main drivers of both the development and application of technologies, Aslaksen (2015) understands that it is necessary to provide students with a proper understanding of the structure and functioning of society and its interfaces with engineering, in order to make a critical evaluation of its consequences. It involves dealing with hidden curricula and their implicit messages about the value of ethics and professionalism (Doorn et al., 2021), a discussion that has the virtue of awakening a critical vision of the society in which engineering is embedded, which can make students less prone to simply accept, as professionals, ethically dubious demands.

In fact, in Brazil, there is a clear observation of the little or almost non-existent participation of engineer's associations in public discussions that, in many cases, affect – sometimes drastically – engineering itself. From the choice to privilege road transportation to the detriment of the rail network in the 1950s, to the demand for investments in energy and infrastructure in the 2000s, their involvement on the political debate is practically nonexistent. The same cannot be said of the legal and medical professional associations, which actively participate in public discussions with a high impact on society. This is because in these professions – medicine and law – there is a direct interface between the profession and society, which does not happen with engineering (Aslaksen, 2015), as it has a broader scope and is inserted in a productive process whose target is broader than specific people. Thus, it is not possible to consider the value of engineering, or any other effect of engineering on society, without considering the associated production process.

Costa (2005) and Bazzo and Costa (2019) present some examples of this omission of Engineering and also the case of the participation of the OAB (Brazil's National Bar Association) in an episode with the Minister of Education. After a meeting between OAB's president and the Minister, the latter gave in to the entity's request regarding the creation of new Law courses. The absence of engineering from political debate can be seen in two ways: as a result of an alienation about social problems, resulting from an eminently technical training, or as a deliberate action, in the sense of keeping production processes under the exclusive protection of investors, to the detriment of the participation of engineers and other relevant social groups and voices. What can be inferred, in this context, is an evident discredit of Engineering as merely professional training, and not a full-fledged profession.

3.4 A Human, Social, Ethical and Epistemological Analysis of Engineering

According to the previous analysis of the current situation in the global South, now we turn our attention to the challenges that engineering must address in order to recover what we take as its essence.

Engineering is defined by the Accreditation Board for Engineering and Technology (ABET, 1977) as "the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind." The basic elements of this definition can be found in different geographical contexts and point only to the functional aspect of the profession, without contemplating any ethical consideration regarding the conditions for the use of "natural resources and forces for the benefit of humanity". In fact, as van de Poel (2009) and Luegenbiehl (2009) show, the discussion about the definition of engineering remains open. More specifically, whether such a definition should include normative-teleological elements (e.g., "for the benefit of humanity") or should it be free of any connotation of values. Davis (1991) emphasizes the importance of understanding engineering as a profession, which means having its members organized to serve *others*. That is, the profession is organized for public service. According to ABET (1977), engineers must "uphold and advance the integrity, honor and dignity of the engineering profession using their knowledge and skill for the enhancement of human welfare". For us, more than ever, due to the consequences presented and detailed in this work, values must be present. Engineering cannot be value-free, it must be ethically situated. If we consider that it is essential to include the human, social and ethical dimension in the definition of engineering, it is up to engineers themselves to change the order of priority in the intricacies of the profession, which is the motto of this chapter.

3.5 From Ethics to Epistemology

Professional ethics has a direct implication on the professional's responsibility regarding the effects and consequences of the projects carried out. Defining professional ethics depends upon professional knowledge and practice. According to Davis (1991), in engineering, a professional code of ethics is essential to advise individual engineers on how to behave, to judge their conduct and, ultimately, to understand engineering as a profession. All over the world, different normative instruments embody the engineer's social responsibility through the concept of professional ethics, which, as a set of principles or standards that guide human conduct, needs to underlie the daily practice of engineering.

Along these lines, the professional engineering glossary has incorporated a new term in recent decades, closely linked to the concept of professional ethics. Taken from the Anglo-American legal system, the term "compliance" (from the verb to comply, which means to act in accordance with a rule, an internal or external instruction) places ethics and professional responsibility in direct relation to compliance with legislation and contractual requirements. Thus, the adoption of compliance practices is a fundamental agenda for corporations, which must develop and incorporate codes and practices in terms of effective ethical conduct. Codes of ethics for engineers describe principles, objectives, attributes, obligations, prohibitions and rights that guide the exercise of the profession (CONFEA, 2019; CECH, 2012; ASCE, 2020; NSPE, 2019), addressing the duties and conduct that are prohibited and qualifying possible infringements. However, they are silent on the definition of ethics and fail to provide any useful framework for thinking about how ethical and professional responsibility can be taught in engineering schools and practiced in engineering projects. This limited view of official bodies regarding the role of engineering constitutes an obstacle in the training of engineers, whose professional attributions are defined precisely by the systems that govern the profession, as is the case of the CONFEA-CREA system.

This concern becomes more relevant if we consider the decrease in the participation of engineers in the formulation of major societal problems or their subordination to private interests, which contrasts with the view of the engineer as a project professional (in the context of design) aiming to serve society as a whole, as defined in classical literature (Bazzo & Pereira, 2011; Krick, 1969) and also by the different currents within the philosophy of engineering and technology addressed by Aravena-Reyes (2019). Problems engineers deal with are often poorly defined. According to Rittel and Webber (1984), they can be described as wicked problems, characterized by their unique and non-recurring character, and whose formulation evolves in parallel with their solution throughout the solving process. Often, a solution will be adopted more because of a deadline to solve the problem than because it is actually an optimal solution. Hence, the definition of engineering problems and their consequent solutions are clearly permeated with underlying ethical considerations, which cannot be simply ignored in favor of some sort of technological solution.

The emergence of projects of increasing complexity and order of magnitude demand multidisciplinary teams, which makes the role of engineering in projects go far beyond technical interchanges between colleagues familiar with professional jargon and knowledge. There are a number of additional goals that must be achieved long before drawings and engineering specifications are completed, or even started. It is the engineer's responsibility to design project goals, to anticipate and to be accountable for their consequences, especially the unintended ones. For this, they must be able to anticipate the effects of a given project proposal, as well as specify the actions necessary for such results to be achieved and to counter risks for the project's beneficiaries and the rest of the society. Therefore, the engineer must be strongly committed to the needs of society, as well as the acceptance and effects of his works.

The history of engineering records major catastrophic events, as widely reported by the press around the world, which the same media often label as accidents or tragedies. However, on closer inspection, it is clear that many of these events have highly deterministic characteristics and, as a consequence, could have been anticipated and avoided, taking away from them that aura of misfortune associated with the label of tragedy. Since 2015, two natural disasters of large proportions related to mining dams have occurred in Brazil: Mariana (O Globo, 2015), which cost 19 lives, in addition to the devastation of the Rio Doce by a sea of mud that reached the Atlantic Ocean, in Espírito Santo, and the rupture of the Brumadinho dam (Agência Brasil, 2019) caused the death of more than 270 people and the disappearance of an entire village. In the investigations of these disasters, evidence show the responsibility of engineers. From the design of dams using the "upstream raising" technique, considered outdated (although cheaper), to the issue of periodic opinions unduly attesting that there were no risks in the dams, the work of engineers is closely related to the subsequent catastrophic results. This has led to the accountability of engineers in ongoing criminal cases. Additionally, it is possible to reflect on the question posed by Davis (1991): even if an engineer could individually object and refuse to do a specific job, he could be replaced by another engineer who would not object. It is impossible not to question oneself, then, about the ethical and social debates that should take place in engineering courses. Is it enough to teach engineering techniques without this being accompanied by the development of ethical attributes?

3.6 Engineering Education

The need to reframe engineering education is evident, as, unlike scientists, who discover the world that exists, engineers create worlds that never existed, develop new ideas and concepts, invent and build devices and structures (Crawley et al., 2014) and – more than anything – engineers identify, formulate and solve problems in society (Krick, 1969; Bazzo & Pereira, 2011). Engineering design is the essence of the work of engineers and, according to van Gorp and van de Poel (2001), it constitutes an interesting starting point for ethical issues in engineering for educational purposes. van Gorp and van de Poel (2001) show that ethical issues can be posed in engineering design processes in two important steps: (1) in formulating problems (requirements, specifications, and design criteria), and (2) in evaluating trade-offs between criteria and making decisions about what are acceptable trade-offs. Investigations into the catastrophes of Mariana and Brumadinho precisely show that engineering as a whole failed in these two aspects, a conclusion that can easily be extended to many other catastrophes. Not only the responsible engineers failed: engineering professional association and engineering schools are also ultimately part of the tragedy.

These questions lead us to observe the various movements around the world that have addressed the modernization of engineering education, especially due to the technological transformation experienced since the second half of the twentieth century. With the transformations experienced in recent decades, today's higher education students, particularly in engineering schools, were born surrounded by many technological resources. Computers with internet, smartphones, on-demand videos in the palm of their hands, among other things, have been part of their lives since early childhood, which makes them very different from previous generations. Young people today have the power to discover things on their own, are more flexible and therefore have a greater capacity to adapt to changes. They are more immediate and, therefore, long-term projects are of little interest to them. Basically, as everything is on Google, society is going through the decrease of importance of the "how-to" question and the increase of importance of the "what-do-I-do-with-this" question. David Goldberg argues in his book "A Whole New Engineer" that the educational environment today is totally different from the Sputnik era, but the culture of engineering education has not changed: "For example, we need to attract more, and more diverse, engineering students today. But women, more than 50% of the world population, are still underrepresented in engineering courses" (Goldberg, 2014).

This global trend of transformation of engineering education presents itself with several approaches, which converge in the recommendations for the teaching-learning process to be changed, no longer being centered on the teacher – who transmit knowledge to students who receive it passively, for a model centered on the student – who start to participate actively (Moloney et al., 2018). With this, active learning methods gain increasing importance in the field (Humberto Arruda & Silva, 2021). Among the movements to modernize engineering education, particular emphasis can be placed in the reformulation of the standards for accreditation of engineering courses in the USA (called EC2000) (Lattuca et al., 2006), the CDIO approach (Crawley et al., 2014) and, in the particular case of Brazil, the new National Curriculum Guidelines for Engineering courses (called the new Engineering DCN) (Brasil, 2019). In the Brazilian case, however, awakening interest in engineering is not easy. Such educational difficulty manifests itself at all levels: science teaching in elementary and high school is centered on the repetition of scientific concepts, rather than on the familiarization of students with the process of observation and discovery that characterizes scientific activity, including social science. Higher education, especially engineering, suffers from the same deficiency. In a world where everything is on Google, except what has not yet been discovered, it makes sense to emphasize the process of discovering, creating and understanding the civilizing process (Bazzo & Costa, 2019).

In addition to the pedagogical change itself, the expansion of the use of active learning aims to develop students' critical thinking and analytical skills. When trying to answer the question "what engineering do we want?", it is inevitable to emphasize that engineers need to be connected to the needs of the society around them, and not just apply technically adequate solutions to solve problems that they have not thought about or formulated. Thus, it is possible to see that active learning methods have a relevant role in the transformation of the field but are the only change necessary toward the sort of engineering we want.

3.7 From the Social to the Human: The Need for a New Civilization Equation

Studies on Science, Technology and Society (STS) argue for the need to develop more than simply piling up more technologies to maximize wellbeing: humanity needs a new civilizing equation (Bazzo & Pereira, 2019). The more technologies increase human productivity and optimize time, people feel the exact opposite: that they have less time. Society is increasingly dependent on companies whose assets are user data provided for free by them (Lanier, 2018). Although we seem to have the world in our hands, we are not happier (Twenge, 2018). In Brazil, engineering culture has been restrictive to critical views, always placing itself on the side of hegemonic power. This option is, in many cases, naturalized, as if it were a contingency of reality and there was nothing else to do (de Souza, 2017, 2018). The consequences of the current civilizing process are already being observed: separatist movement in Spain; BREXIT; construction of a wall between the US and Mexico; and, in Brazil, the proliferation of an ideologically constructed hatred for different worldviews that hampers coexistence between political left and right and that can lead to extreme consequences in the 2022 presidential elections.

We are reaching levels of inequality from the so-called Belle Époque period (Piketty, 2013), with stark implications for developing countries. While in the 1960s to 1980s the direct interference of the great powers, in particular the US, was necessary through the support of the dictatorships that were implemented in Latin America, the same was not necessary from the 1990s on. The Washington Consensus agenda promoted a cultural revolution whose main and immediate focus was the end of the USSR, but which actually contributed to starting the downfall of social democracy, especially in Europe. This reality has important repercussions for engineering, and for the role that councils, class associations and engineering schools have played in the face of some historical facts that had a high impact on engineering, such as the "Oil is Ours" movement back in the 1960s, EMBRAER's privatization (1994) and the pre-salt oilfield discovery (2006). In these three important historical moments, despite the contribution engineers could bring, there was no mobilization of national engineering, even in the face of a broad and polarized discussion carried out in society. The same can be seen in the recent privatization of EMBRAER, a Brazilian company considered the third largest producer of aviation jets in the world. The silence of the Engineering class in the face of this operation was embarrassing. Last but not least, the discovery of the Pre-Salt oil reserve was on the agenda of a recent impeachment process for Brazilian President Dilma Roussef. Once the process was consolidated, the market for the exploration of the Pre-Salt was internationalized and the national monopoly for exploration was eliminated, showing how much the discussions about "Oil is Ours" were still latent.

3.8 Conclusion

It is widely recognized that there is a lack of political, human and social studies in engineering education, and especially of reflections that can lead us towards a less cruel and individualistic civilization process. We risk having engineering students and professors solve technical problems only through technique and no longer considering that engineering problems are human problems. From here it can be seen that the current engineering training is in general outdated, with the aggravating factor of seeing, from past experience, that, even with clear curricular guidelines, academia does not apply them. Additionally, many engineering professors do not express a genuine concern for the direction of the country and do not engage in political debate. This is a worrying fact, as it shows that this "neutral" view of engineering education can have disastrous consequences. In Brazil, this neutrality is reflected in the omission of engineering, as an interest group, in different situations, from the time of the "Oil is ours" campaign to the delivery of the Pre-Salt to foreign companies, where engineers were quiet despite the collapse of national engineering and the great loss of technical jobs, in domestic industry in general, and engineering in particular, most of which went abroad.

In contrast to the lack of reflection, it is clear that students are eager for a new vision of engineering and the need to go beyond standardized technical training. It is necessary to lead them to philosophical reflection, to discuss the philosophy of technology and ethics and related topics, but not from a merely contemplative perspective, but an active one. According to Abaté (2011), training engineers to be moral individuals is an unfeasible task, although it is possible to stimulate the cognitive and practical process, with the use of case studies involving situations, which, even with some limitations, contributes to see the ethical dimension of engineering problems and extract realistic solutions. According to Kanemitsu (2018), the philosophy of technology can provide a new framework for engineering ethics; especially, Peter-Paul Verbeek's theory of mediation (Verbeek, 2005), apud (Kanemitsu, 2018), which proposes to "follow" technological development, not merely aiming to reject or accept new technologies. Kanemitsu (2018) believes that it is necessary to teach future engineers not only about conventional issues, but also about issues of philosophy of technology, as a fundamental basis of the engineering ethics of the future.

The importance of considering the epistemological formation of the professor is evident, in order to strengthen the idea that engineering problems are not just technical problems. On the other hand, they show that there is no magic formula to solve them based on defined variables without having as a background an essential control volume, which is planet Earth, where contemporary civilization is inserted. And, in this sense, there it is possible to talk about any methodology without understanding and defining an engineering design problem. However, it is possible to help students to discover how most moral dilemmas focus on certain patterns. Additionally, discovering that recognizing these patterns and knowing how to act in these situations increases the chances of adequately solving real problems when they occur. The use of philosophical problem-solving techniques and appropriate case studies can encourage students to develop the conceptual tools necessary for this process (Abaté, 2011). In the globalized world we live in, it is important to highlight the importance of communication in the construction of these conceptual tools for ethical judgment. Kroesen and van der Zwaag (2009) point out that decisions are more a result of a group process than determined solely by individual reflective reasoning. Thus, they are strongly affected by the quality of communication. Luegenbiehl (2009) argues that this debate on ethical principles needs to emphasize two important elements: (i) the connection of engineering to the business environment and (ii) the need to understand the variety of cultural value systems in the world.

In the context of this discussion, there is evidence that in Brazil professionals are being trained to be “obedient engineers” – engineers who work from previously formulated problems and serve a specific function in an unchanging grand scheme of things, mainly because it is based on the promise of a favorable political and economic insertion, as a legacy of the scheme of the imperial professions (Coelho, 1999). This, in fact, is the denial of engineering as a profession. The essence of the engineer’s work consists precisely in having a broad view of the field of possibilities, in order to make a comprehensive reading of the situation and, from that, formulate the problem to be solved, through a project solution in which a greater number of variables can be reconciled – technical, human and social –, as the classical literature clearly recommends (Bazzo & Pereira, 2011; Krick, 1969). Therefore, it is clear that it is necessary to broaden the discussion on engineering education as a whole, in addition to the fact that a code of ethics is not in itself sufficient to prevent the formation of “obedient engineers”. Herkert (2001) has already pointed out the importance of professional societies in supporting the success of the existence of a code of ethics, but he also identified the great influence that corporations have on such societies as a risk.

In this sense, there is an explicit demand from the Brazilian productive sector, articulated around the movement “Business Mobilization for Innovation” (MEI, n.d.) which, in a series of meetings over the past few years, has discussed engineering education in Brazil (MEI, n.d.), having as main motivation the need to train “more and better engineers” (ABENGE, 2018). Such demands call for a different vision by engineering schools, in addition to the need for significant changes to break down the watertight walls of the traditional disciplinary vision. More than knowing it as an abstract theoretical concept, it is necessary for the engineer to incorporate ethics as a way of life. To achieve this, students must be provided with elements that enable the development of a more sophisticated and not just intuitive moral reasoning, in order to make them competent engineers from both a professional and citizen point of view.

There is no condition to think of a solution without considering all the contemporary variables in engineering education. The omission of the engineer class was evident in the context of the current Brazilian political and economic degradation, which saw high technology, internationalized Brazilian engineering companies being decimated and dragging with them a huge number of high-quality jobs. This shows that the solution to the problems in the training of new engineers is not simply a methodological issue, but an epistemological and ideological attitude of the professors who work in the area.

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3.3 Epilogue

This book chapter contributes to the first objective of Part I of this thesis. It makes a case for rediscovering what authors see as the core of an engineer's work: having a broad perspective on the range of possibilities to thoroughly understand a particular situation and, based on that, defining a problem to solve through a project solution that can harmonize technical, human, and social factors. The authors argue that the current work of engineers in Latin America falls short of embracing this essence and, thus, discuss how education can play a crucial role in bringing the next generation of engineers closer to this ideal.

Due to the time gap between the production of the book chapter and the completion of this thesis, the GDP per capita graph presented (figure 3.1 in book chapter published) may be subject to update. Figure 11 shows current configuration, in which red line highlights the original end.

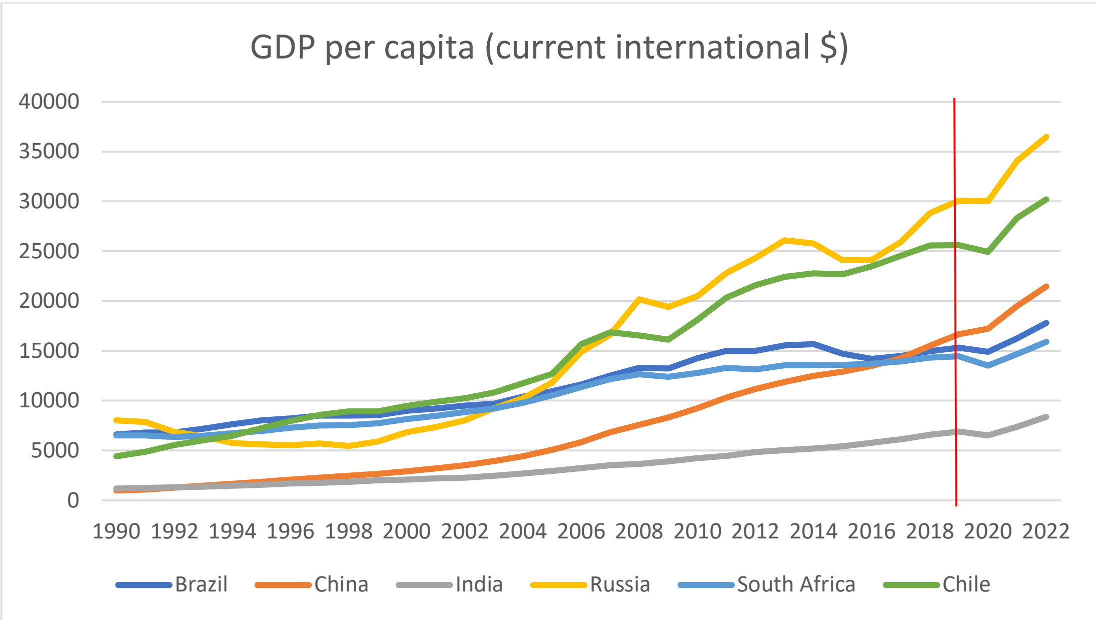

Figure 11 - Current GDP per capita (BRICS and Chile)

It can be observed that all the countries under analysis, except for China, experienced a decline in the indicator in 2020, primarily due to the COVID-19 pandemic. It is noteworthy that the decline is more pronounced in countries with lower initial values, such as India and South Africa. Subsequently, there was a recovery in all cases, with particular emphasis on Russia and Chile, which already exhibited favorable outcomes, demonstrating a higher acceleration than the others in the post-2020 period.

Collaboration developed during the process to write this work was very relevant to this doctoral trajectory, once it was the first international teamwork and opened a wide range to future works, such as the deepening of debates about ethics in engineering education and the role of professors in the necessary change.

4. Identification of Alumni-Founded Companies (AFC)

4.1 Prologue

According to Etzkowitz (1983), university has its role changed from the traditional teaching function (1st mission) to become an Entrepreneurial University, which encompasses active research (2nd mission) and the market (3rd mission). As university increasingly engaged in the innovation process, it evolves by adopting an entrepreneurial approach that goes beyond and integrates its traditional roles in teaching and research (Compagnucci & Spigarelli, 2020).

An entrepreneurial university can be understood as an active institution, which promotes changes in its structure and in the way it responds to internal and external demands (Ferreira, Soria, & Closs, 2012). It is the result of a next step in the development of a single institution, a third mission for economic, social and regional development (Etzkowitz, 2013; Lai & Vonortas, 2019; Urbano & Guerrero, 2013; Vefago et al., 2020).

In fact, the collaboration between universities and industry became more intense during last three decades (Schaeffer, Fischer, Moraes, Queiroz, & Salati, 2023). This interaction has gained relevance as theme of research and public policy (Crescenzi, Filippetti, & Iammarino, 2017).

Aligned to this evolution, universities play important role in debates related to technological generation and transfer and in dynamics of innovative endeavors (Etzkowitz & Klofsten, 2005). The university's competitive edge is tied to the ongoing influx of its students, fostering a perpetual exchange of fresh ideas, a challenge not easily replicated by other knowledge-producing institutions (Etzkowitz & Zhou, 2017).

Although universities engage in various activities, their primary assessment typically revolves around their scientific output and its influence. Metrics such as the quantity of research papers published, the volume of citations received, and the impact factors of the journals they contribute to can be readily accessed through publishing platforms.

Considering the relevance of the university's third mission and the need to measure the impact to the society beyond scientific publications, the number of spinoffs is an important indicator that can be used. The term 'spin-off' is usual in literature to refer to capital companies whose intellectual capital has originated at the university, in some way (Callan, 2001). According to the Organization for Economic Cooperation and Development (OECD) (Hogan & Zhou, 2010), an intellectual property-based spinoff from a publicly funded research organization is defined as "a new firm whose start-up includes a substantial contribution of knowledge recently developed in a public research organization; and this knowledge is protected by intellectual property rights that are either licensed or transferred to the firm".

Then, an essential step is to identify the companies that have relationship with the university. That was the motivation to an institutional project in the Universidade Federal do Rio de Janeiro. The basic criterion for this identification was that the company had at least one university graduate among its founders. Using data provided by Internal Revenue Service (IRS) in Brazil, the first outcome of this project should be a list of companies that have been founded with participation by graduates from UFRJ. These companies are titled Alumni-Founded Companies (AFC).

Beginning with unstructured data from IRS and student data from the university, there was a proposal of an intensively data-driven method, called BR-AFC. This method proposal was the subject of a paper accepted to publication in the Brazilian Journal of Operations and Production Management (BJOPM), presented as follows.

The BR-AFC method serves as the cornerstone for the development of a new way to assess the outcomes delivered by the university to society. Clearly, the establishment of businesses is not the sole means of evaluating university performance. However, the BR-AFC method enables a more precise evaluation of *impact*. Rather than considering scientific output, it assesses the tangible effect on entrepreneurial activity.

4.2 Full text

Accepted but not yet published full text in Brazilian Journal of Operations and Production Management (BJOPM) (Arruda, Silva, & Uziel, 2023b).

Measuring the Social and Economic Impact of Universities' Entrepreneurial Activity: Introducing the BR-AFC Algorithm to Sort Alumni-Founded Companies

Abstract

Goal: This study introduces an algorithm to sort alumni-founded companies from the public Brazilian Internal Revenue Service (IRS) database.

Design/Methodology/Approach: Departing from IRS data and student data from the university, sequential filters are applied to arrive at a final list of alumni-founded companies.

Results: The main result of this study is the establishment of the algorithm itself, which emerged after cycles of iterations of analysis and rewriting. To test its reliability, a sample of 1625 alumni was used. The algorithm successfully identified 140 founders of 159 AFC. Founders were heterogeneously distributed throughout the decades analyzed. Companies belonged to different industry sectors and were classified according to their technological intensity, with predominance of middle-low and low intensity.

Research limitations/implications: Although the BR-AFC algorithm is applicable to any Brazilian institution, generalization to other countries depends on access to country-specific databases containing data about companies and its partners. Additionally, the final result depends on the reliability of input data and of user decisions about the rigor of its premises.

Practical implications: The BR-AFC algorithm can improve measurements of the socioeconomic impact of educational institutions. It points to the formation of entrepreneurs and, as a consequence, institutions can evaluate courses and educational programs and improve curricula. Policymakers and sponsoring institutions can measure return over investment, outcomes of policies to encourage entrepreneurship and rank universities according to novel criteria.

Originality/Value: The main contribution to the literature is exploring novel approaches to measuring university-industry relationship. More specifically, it proposes an algorithm to identify the alumni-founded companies of a given university from large country-based databases.

1. Introduction

Universities in Brazil are established upon a foundation of teaching, research, and outreach endeavors. In global academic discourse, the latter is commonly termed the "third mission" of a university, which is broadly defined as a "contribution to society." This encompasses a diverse array of activities that entail contributions to the social, economic, and cultural development of not only the state, region, but also the entire nation. In a recent review, Compagnucci and Spigarelli (2020) cite the work of contemporary authors as evidence showcasing the impact of knowledge and technology transfer on both industry and society, as integral components of the university's third mission. Universities around the world are looking to update their curricula to promote greater interdisciplinarity (Klein, 2015; Marins, Ramos, Ferreira, Costa, & Costa, 2019) and stimulate innovative behaviors (Hoidn & Kärkkäinen, 2014; Täks, Tynjälä, Toding, Kukemelk, & Venesaar, 2014; Ten Caten, Silva, de Aguiar, Filho, & Huerta, 2019).

The scope of university entrepreneurial activity is encompassed within this "third mission" (Li, Yang, & Cai, 2021; Vefago, Trierweiller, & de Paula, 2020), encompassing actions such as patenting, licensing, establishing incubators, science parks, and spinoffs. There is clear empirical evidence indicating an uptick in such activities in developed countries (Mowery, Nelson, Sampat, & Ziedonis, 2004; Phan & Siegel, 2006; Rothaermel, Agung, & Jiang, 2007). This phenomenon has also gained traction in developing nations, evident in cases like Brazil (Freitas, Gonçalves, Cheng, & Muniz, 2011), even preceding the promulgation of the Science, Technology, and Innovation Act (Código Nacional de Ciência, Tecnologia e Inovação, 2016).

While universities engage in a multitude of activities, they are primarily assessed based on their scientific output and its influence. Metrics such as the quantity of published papers, citation counts, and journal impact factors are accessible on publishing platforms, fostering a self-reinforcing cycle that bolsters research. However, contemporary literature emphasizes the necessity of quantifying the university's "third mission" (Compagnucci & Spigarelli, 2020) and proposes pertinent indicators (Uziel & Allonso, 2022). One vital aspect of the university-industry relationship is evaluating the number of spinoffs, which serves as a significant dimension in this context.

The literature in the field often refers to companies whose origin of intellectual capital is tied to a university or public research institution as "spinoffs" (Callan, 2001). Shane (2004) defines a spinoff as "a new company founded to exploit a piece of intellectual property created in an academic institution." Similarly, the Organization for Economic Cooperation and Development (OECD) characterizes an intellectual property-based spinoff from a publicly funded research organization as "a new firm whose startup incorporates a significant contribution of knowledge recently developed in a public research organization, with this knowledge being protected by intellectual property rights that are either licensed or transferred to the firm". While there is some variation in the definition of the term, there is a degree of convergence that academic spinoffs are established by individuals originating from universities or research institutions, who then seek to commercially exploit the intellectual property created there.

Quantitative studies adopt diverse measures to assess spinoff creation. North American researchers often utilize Association of University Technology Managers (AUTM) surveys to quantify the number of spinoff companies originating from universities or research institutes (O'shea, Allen, Chevalier, & Roche, 2005). AUTM exclusively tallies companies that have licensed intellectual property from a university or research institution. European scholars, on the other hand, create their own databases, identifying spinoffs through publicly accessible sources (Conceição, Faria, & Fontes, 2017) or official spinoff lists provided by universities and public research centers (Meoli, Pierucci, & Vismara, 2018).

Employing intellectual property-based spinoffs as a measure for a university's new venture creation and its subsequent economic impact can yield results that are ambiguous and incomplete. The ambiguity arises due to the disputable nature of quantifying the extent to which intellectual capital contributes to the inception of a new business. Incompleteness stems from the fact that not all knowledge generated within universities and research institutes conforms to the criteria for formal protection. Consequently, knowledge originating from a university might give rise to new companies that do not meet the classification of spinoffs, leading to the exclusion of numerous economic activities from the tally.

In pursuit of alternatives, institutions like Stanford and MIT have focused on companies founded by alumni to delineate their economic impact, based on factors such as domain of activity, employment rates, revenue, income, and market capital (Lebret, 2017; Roberts, Murray, & Kim, 2019). The University of Campinas (Unicamp) has introduced the term "daughter companies" to encompass those founded by individuals with affiliations to Unicamp, including students, former students, professors, former professors, employees, former employees, and those previously incubated or graduated from the institution's incubator (Unicamp, 2020). This study delves further into the definition of daughter companies and presents a logical algorithm for calculating companies established by alumni of a given institution, exploring their economic impact.

The approach taken in this study quantifies entrepreneurial activity at the Federal University of Rio de Janeiro (UFRJ) and employs its Industrial Engineering course alumni as an initial step in a demographic study of UFRJ's alumni-founded companies. The methodology's resultant data already encompasses companies' economic activities and can be combined with data from other sources (e.g., the technology transfer office) to analyze its societal and economic developmental impact more comprehensively.

2. Method

With the aim of formulating an algorithm for categorizing companies founded by alumni, this project utilized two databases. The first database is an anonymized open dataset sourced from the Brazilian Internal Revenue Service (equivalent to the American Internal Revenue Service), updated monthly on a government online open data platform (Brasil, 2023). The second database is derived from UFRJ's internal student registration system. Since student data is personally identifiable, special permission was secured for this study. Data handling adheres to the principles of the Brazilian General Data Protection Regulation, affording the institution the right to conduct research for public policy development. All outcomes are presented in aggregated form, ensuring individual identification remains unfeasible.

2.1. Definition of the term 'alumni-founded company'

In this project, an "alumni-founded company" is defined as any entity listed in the Brazilian Internal Revenue Service database that was established by at least one UFRJ graduate or postgraduate alumnus, regardless of its economic activity. It's important to underscore that the collection of companies identified through present methodology encompasses those utilizing intellectual property from the university (and would, accordingly, meet the classification of spinoffs, as per Shein, 2014), yet is not constrained solely by this criterion. Our pool of companies also includes a subset that might be categorized as "daughter companies" according to Unicamp's standards. However, it's noteworthy that Unicamp designates companies as daughters when they respond to their call and provide data on their platform. In contrast, our chosen terminology differs, as the companies authors identified did not actively enroll as university "daughters," and our focus deliberately excludes companies initiated by staff.

In the Portuguese context, the term "company" can yield a dual interpretation: it could pertain to a legal entity name (Razão Social) or a Corporate Taxpayer Identification Number (CTIN), derived from the Portuguese expression Cadastro Nacional de Pessoa Jurídica - CNPJ. Given that companies can generate additional CTIN entries (as branches) for expansion or other purposes, it's conceivable that a single legal entity name could be linked to multiple CTINs. Thus, this work rests upon the following premises: (1) Each company corresponds to a distinct legal entity name; and (2) A CTIN is singularly associated with a unique legal entity name. Henceforth, when referencing a company, this is a specific reference to a legal entity name.

2.2. The nature of the method

It is essential to highlight the empiric nature of the method established to identify alumni-founded companies (AFC). The algorithm emerged after cycles of iterations, in which the following steps were repeated:

- Establish criteria for selecting AFC;
- Implement the criteria on the database;
- Analyze the results;
- Identify results that are incompatible (examples below);
- Restart the process.

In the first attempt to sort AFC, our results included multinational corporations and state-owned companies, which was incompatible with reality. This was the first clue to design an algorithm that sorts companies based on alumni as founders and to deal with companies that have a legal entity as a partner as a special subset of data. To be classified as AFC, two main criteria were followed: (1) When the company does not have a legal entity as a partner, an alumni must have joined the company as a partner up to day 30 from the company's starting date; and (2) If the company does have a legal entity as a partner, it must have joined the company after day 30, counting from the company's starting date. Limitations and possible variations of these criteria will be addressed in further topics of the Method and in the Discussion section "Limitations on the algorithm settings".

Our method can be divided in three main steps, as presented in Figure 1: pre-processing, processing and post-processing. The conceived algorithm (box in Figure 1) permeates the Pre-processing and the Processing phases.

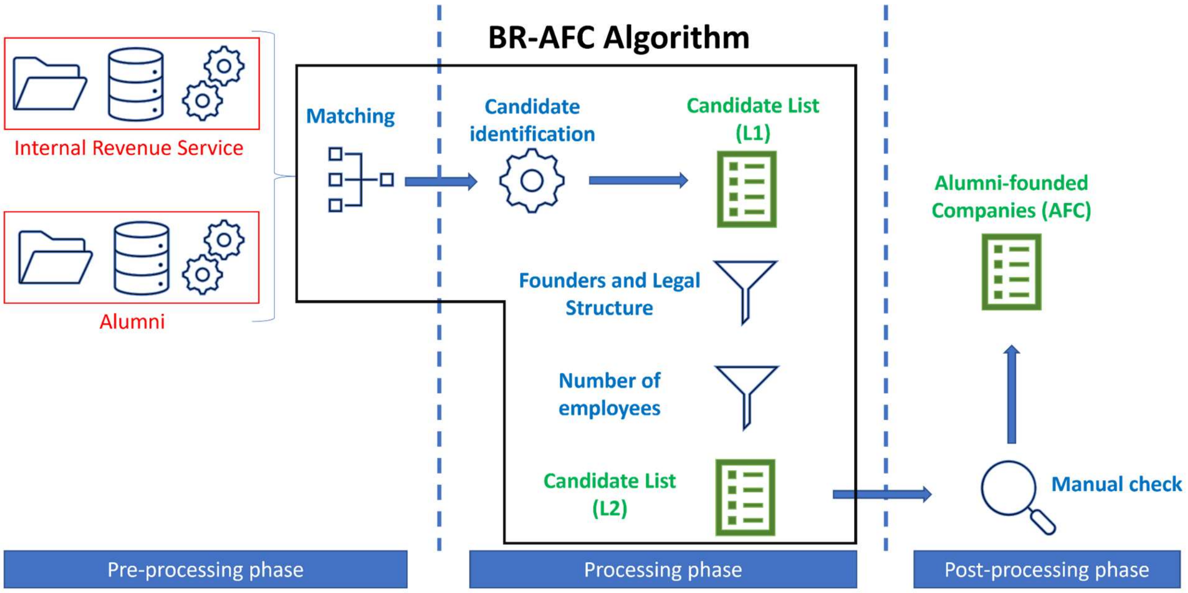

Figure 1. Overview of the proposed method of sorting alumni-founded companies.

Source: authors own elaboration

Briefly, the pre-processing phase aims at preparing the data, since the original data from the Internal Revenue Service (IRS) and from UFRJ presents different types of inconsistency (use of special characters, abbreviations, missing zeros etc.). The processing phase focuses on generating the AFC list (L2) closest to the final result, based on the application of two successive filters to the initial list of candidate companies (L1). Filters are based on the algorithm detailed in the next section. Finally, in the post-processing phase inconsistencies that may have passed through the processing algorithm are eliminated and data reliability indicators are calculated. The final result is the list of AFC from the studied institution.

2.2.1. The Algorithm: A Synthesis

The processing phase of the algorithm is composed of the following steps, that will be detailed in the next subsections.

A. Identify all companies in which alumni are partners (list L1);
B. Apply first filter to companies in L1: founding partners and legal structure:
   a. Calculate the founding date of every company in L1 using two different criteria;
   b. Identify founding partners;
   c. Exclude companies in which alumni were not founding partners;
   d. Exclude companies in which legal entities were founding partners;
   e. Classify companies according to the presence of legal entity as non-founding partners;

C. Apply second filter to resulting companies: number of employees over time:
   a. Calculate the number of employees of each company per year, since its founding date;
   b. Classify companies as "CTIN as a service provider for another company" (also known in Brazil as "pjotização", when a worker is hired as a legal entity) or as regular company.

D. Arrive at the L2 list of AFC, to be post-processed.

2.3. Pre-processing phase

In this phase, a first step of extraction, transformation and loading of IRS and UFRJ data took place, followed by a step of matching of the databases.

The first step carried out was to upload data using a Relational Database Management System, which allows efficient manipulation of large volumes of the data containing all companies in the country.

For the matching, only the Unique National ID (UNID, derived from the Portuguese term *Cadastro de Pessoa Física - CPF*) and Full Name fields were used from the IRS data. It is important to note that the IRS makes UNID data available truncated to 6 digits. That is, the data is displayed in the form XXX.NNN.NNN-XX, where N stands for available digits and X for unavailable digits. In the case of alumni data, the full UNID and full name were available.

The initial difficulty to be overcome was to make the appropriate matching between the same individual in both databases. For this it was necessary to:

1. Cross the truncated UNID data from the IRS with the full UNID data: Only entries in which all available digits were equal were kept as matching candidates;
2. Cross the Full Name data from both databases: When the UNIDs matched, the names were verified. If the first and last name were the same, the entry was accepted.

When matching and understanding the reliability of the results, the pre-processing stage of the data was completed, making them ready for the beginning of the processing phase.

Limitations and possible variations of these criteria will be addressed in the Discussion section "Limitations on the algorithm settings".

2.4. Processing phase

Data processing took place in three stages: identification of candidate companies; filter based on founding partners and legal structure; and filter based on the number of employees over time. Initially, all candidate companies were identified, which were those that are linked to alumni in the IRS database, leading to an initial list of candidates (L1). From there, filters were applied and a more restrictive list of companies (L2) emerged. For all the steps in the processing phase, specific attributes of the IRS database were used, as follows.

2.4.1. Identification of candidates

This stage is designed to comprehensively identify all companies that hold the potential to qualify as "Alumni-Founded Companies" (AFCs) through a meticulous comparison of IRS and university databases. The initial step involved extracting all companies from the IRS dataset that exhibited any form of connection to alumni. This formed the foundational L1 candidate list. This preliminary roster encompassed companies genuinely established by alumni as well as instances of discrepancies. The discrepancies stemmed from companies where an alumnus was attributed any form of social responsibility, such as holding directorial or presidential roles, or even serving as shareholders within corporations. These discrepancies materialize at this phase due to the IRS database's inclusion of all entries—including both natural persons and legal entities—that maintain partnerships with a given company.

2.4.2. Filter based on founding partners and legal structure

This step aims to select from L1 companies only those founded by alumni.

Precisely, founding partners of a given company are those that join it since it legally comes into existence (founding date or starting date). In practice, however, authors noticed from data sample that there was a dissociation between the company's starting date (a column in the IRS dataset named "activity starting date") and the date assigned as the earliest entry of a partner in the partnership (calculated by comparing all the entries of partners for a given CTIN). No clear cause was identified: it could be attributable to bureaucratic procedures regarding the CTIN creation or other reason. To account for this, all partners (natural persons and legal entities) who joined within 30 days from the company's starting date were considered founders. Aiming at more accurate results, for each CTIN, there was a verification whether a partner could be considered a founder (within the 30-day lag after the starting date) using two criteria (attributes from the IRS database): the "activity starting date" of a company and the earliest "date of entry into society". For instance, if a company's "activity starting date" was January 1st but the first partner joined the society on February 15th ("date of entry into society" field), everyone entering the society from January 1st to January 30th was considered a founder by criterion 1 and 2. From January 31st to March 17th (D+30) it would be considered a founder only on the basis of criterion 2. Each criteria was tracked individually, to measure the degree of certainty that a given person was indeed a founder.

In terms of the specific procedures to filter L1, as mentioned before, more than one CTIN can be associated with the same company. Thus, the first step was to obtain the date the company legally came into existence, based on the earliest founding date of all CTIN linked to a given legal entity name ("razão social"). This can be done step-by-step, as follows:

i. Scan the database to identify the earliest start date for each CTIN linked to a given legal entity name. This is the first criterion to obtain the founding date of each company.
ii. Scan the database to identify the earliest date among all the dates assigned as a partner joining the company for all the CTIN numbers associated with that given legal entity name. This is the second criterion to obtain the founding date of each company.
iii. List all partners that could be considered founders by criteria 1 and 2 and check whether they are alumni: search for alumni becoming partners within 30 days since the founding date of that

company. All companies in which the alumni entered after 30 days from the founding date (calculated by criteria 1 or 2) are excluded as AFC candidates.

iv. List all other founding entries in the previous step to check for companies that might be AFC candidates after the previous step. List all other founders' entries and check if there are legal entities or only natural persons listed as founders. This is a classificatory step that allows the method to account for differing uncertainties regarding whether a person was indeed a founder of an entirely new company or of a spinoff or branch of another company that holds a different company name from the parent company.

Based on this procedure, companies can be classified into three groups:

1. Companies that have only natural persons as partners;
2. Companies that have a mix of natural persons and legal entities as partners:
    a. Those that were founded by a mix of natural persons and legal entities; and
    b. Those that were founded only by natural persons (and in which legal entities entered after the 30-day lag).

Acceptance Criteria: Based on the outcome from step iv, each company is classified in one of the three categories listed above. Companies classified as 1 or 2b show a higher probability of being an AFC, whereas those classified as 2a show a higher risk of false positives.

Limitations and possible variations of these criteria will be addressed in the Discussion section "Limitations on the nature of the IRS database".

2.4.3. Filter based on the number of employees over time

During this stage, companies that continue to meet the eligibility criteria went through an assessment based on their recorded employee count over a span of time. This stage serves the purpose of distinguishing entities engaged in authentic productive operations from those established primarily to function as "CTIN service providers" for other companies (a phenomenon colloquially referred to as "pjotização" in Brazil, wherein an individual is hired as a legal entity).

To verify the number of employees hired by AFC from their starting date, the Annual List of Social Information (ALSI, derived from the term in Portuguese *Relação Anual de Informações Sociais - RAIS*) of the Ministry of Labor was used. For the analysis described in the Results section, RAIS data from 1985 to 2017 were used. Based on companies' CTIN, the database was scanned, and the number of employees was registered yearly. Companies were then classified according to their hiring pattern. AFC were classified according to their number of employees, number of partners, existence of legal entities as partners, number of branches, existence of an assumed business name ("nome fantasia"). Those companies that matched all the following criteria were classified as an "CTIN as a service provider for another company" (its creation is probably attributed to an event of hiring workers as entities): hired no employees along their lives, have up to two partners that are both natural persons, does not have legal entities as partners, does not have branches and did not register any assumed business name.

At the end of this stage, a list of companies (L2) came out. It contained all the data from IRS - including founders' entries dates and company start date, that were the basis of the sorting - and the number of employees along time (from the Annual List of Social Information). The list was further refined in the post-processing phase.

2.5. Post-processing phase

From all the parameters previously calculated, the algorithm generates an AFC list (L2). This list L2 can still not be considered the final and definitive one, and it is recommended that during the post-processing phase this list of AFC is manually checked to verify inconsistencies that may have passed throughout processing, due to the inherent uncertainties of the imprecise matching of UNIDs between the bases, the quality of founders' entries dates and company starting date. A final sorting of the data based on its analysis is considered very important (see Discussion section “Limitations on the nature of the IRS database”).

3. Results and Discussion

The main result of this study was the establishment of an algorithm to extract a list of alumni-founded companies from a large IRS database that includes all companies and partners available in Brazil.

For the proposal of the method and for its validation, a pilot study was carried out with alumni from the Industrial Engineering course of the Federal University of Rio de Janeiro.

First, initial population consisted of 2849 alumni who graduated between 1970 and February 2021. From 1970 to 2000, 33% of alumni had either missing or invalid UNIDs registered in the database, since only by 2001 the university created a unified institutional data system, gathering data from different and independent internal sources. Then, only 1625 individuals from the original list were used in the search.

Among the 1625 alumni analyzed, there were 140 founders of 159 AFC companies. Founders were heterogeneously distributed throughout the decades analyzed: 5 in the 1970’s (out of 17 alumni), 10 in the 1980’s (out of 270 alumni), 15 in the 1990’s (out of 867 alumni), 40 in the 2000’s (out of 774 alumni), 70 in the 2010’s (out of 690 alumni) and none in 2020/2021 (out of 32 alumni).

Alumni combined themselves as partners to found companies that had the following temporal distribution: 2 in the 1970’s, 1 in the 1980’s, 21 in the 1990’s, 39 in the 2000’s, 88 in the 2010’s and 8 in 2020/2021. The range of alumni-founders per company varied from 1 to 4 in 97% of the companies analyzed. Ten percent of the companies, however, showed a high number of partners. Among those, one company presented 116 partners.

From the 159 AFC companies identified, 116 did not have any employees since their founding date. Regarding companies’ economic activity, these 116 companies were initially considered small businesses with no employees, which may characterize early stage-startups, IT companies, consultancy partnerships or other business arrangements that, although highly active, are not typical employers. Among the 116 companies, 34 of them fulfilled a profile of “CTIN as a service provider for another company”: did not employ any individuals since their date of creation, had up to two partners (and none of them were legal entities), had no branches or had no assumed business name.

Another 25 companies were small businesses that had up to 10 employees. Their economic activity based on ISIC classification (section) were distributed as follows: 47 (Retail trade, except of motor vehicles and motorcycles, n = 4), 46 (Wholesale trade, except of motor vehicles and motorcycles, n = 3), 82 (Office administrative, office support and other business support activities, n = 3) and 70 (Activities of head offices; management consultancy activities, n = 3). There was a large variability of economic activities among the other 12 companies.

A second group of AFC (n = 18) was characterized by an increasing number of employees (always more than 10 employees) throughout the period analyzed. Among those, three companies had “Retail trade, except motor vehicles and motorcycles” (ISIC section 47) as their primary economic activity. Three companies were in "Wholesale trade, except of motor vehicles and motorcycles activities” (ISIC section 46), two other companies in ISIC section 66 (Activities auxiliary to financial service and insurance activities), two in ISIC section 62 (Computer programming, consultancy and related activities), two in ISIC section 68 (Real estate activities) and two in ISIC section 85 (Education). Four remaining companies were sparsely distributed among other economic activities.

All companies were also classified according to their technological intensity, based on the OECD taxonomy (Galindo-Rueda & Verger, 2016). Most of the companies were classified either as middle-low intensity (n=45) or low intensity (n=78). Only few companies (n=18) were middle-high or high intensity companies, as exemplified by those in ISIC section 72 of economic activity (Scientific research and development).

In respect to their spatial distribution, most of the companies were situated in the state of Rio de Janeiro (n=134), mainly in the cities of Rio de Janeiro (n = 116) and Niteroi (n = 6). Sixteen companies were located in the state of Sao Paulo and the remaining were in other Brazilian states.

Although not described in this paper, it is also possible to correlate the academic performance levels of alumni or their quota status with their entrepreneurial aptitude or to other attributes available in the institution's database.

3.1 Methodological framework and limitations of the method

It is important to emphasize that a simple association of an alumni UNID and a company CTIN within the Internal Revenue Service database will not strictly bring a list of companies that were founded by alumni. It would rather bring all cases in which UNID and CTIN are associated, including those cases where alumni are allocated as director or president of a company or where they are shareholders, among other situations which are not of interest here. This methodological framework faced diverse possibilities and obtained a list of companies founded by alumni by subtracting cases that are not of interest and selecting companies where alumni can be identified since their creation. Parameters adopted in the algorithm can lead to more restrictive or to wider results, depending on how they are calibrated (see further discussion).

Limitations of the method can be related to the algorithm itself, to the quality of the data provided by the university or downloaded from the Internal Revenue Service platform or to how strict were the criteria adopted throughout the algorithm. Here, there is a discussion about some issues that may affect the quality of the final output.

Limitations on the algorithm settings

In the pursuit of identifying founding partners, the algorithm scans the database in two different ways: (1) to identify the earliest starting date for each CTIN linked to a given legal entity name and (2) to identify the earliest date among all the dates assigned as a partner joining the company. If the time interval between the founding date and the date of entry into the society of the graduate is null, it is possible to be fully confident that given alumnus is a founder. In the Revenue Service database, however, the date assigned as the starting date of the company frequently precedes the date of any partner joining it. Therefore, one must define an acceptable time interval between these two events, in which a partner is considered a founder.
The creation of new companies involves several steps, from building a business model, getting funded and developing the solution until selling it. No evidence was found in the current literature that having a team of co-founders from the very beginning is a factor related to business success. Literature points to characteristics of the partners (passion, openness, ethic etc) (Forbes, 2021) and of the partnership (mutual accountability, true commitment, shared goal etc) (Forbes, 2018) rather than to the time lag of joining the company. Nonetheless, it was necessary to design a solution to exclude from our dataset companies where the participation of alumni does not involve founding it. Authors then admitted that the closest to 30 days the time lag is, the highest is the probability of a new partner being a founder. Other shorter or larger periods can be used by other authors. The larger this parameter, the wider the results from the algorithm will be. Further research can propose a specific rule or logic that could help determine the best rigorousness for each dataset.

It is important to emphasize the empirical and data-based nature of the method proposed in this work. Analyzing the method in a simplified way, filters are applied to a list of companies to classify each one of them at the end of the sequence of selections. The quality of classifying a given company as an AFC is highly related to the rigorousness of the parameters used. There is always a risk of false positives or false negatives, depending on this setup.

If a company was founded by a legal entity, it does not fit in the definition of an AFC, even if one of its founders is an alumnus. This corporate composition can be attributable for purposes other than the company's productive activity, such as avoiding tax or labor issues, or because of a spinoff or joint venture. For instance, venture capital (VC) firms usually create new companies under a business structure called "society of specific purpose" (SPE in the Portuguese acronym) to carry out investments. Executives from the VC become founding partners of the SPE, but that doesn't imply they are entrepreneurs: this is only part of their attribution as executives of the original company.

On the other hand, if a certain company is composed only of natural persons, it is very unlikely that it was created as a spinoff of another company, for example. A company whose partners are only natural persons and meets the selection criteria described above will have a very high probability of actually being an AFC.

As a result, it is possible to notice that there are two extremes in the paragraphs above. On one hand, companies that have a legal entity founder. On the other hand, companies that only have natural persons as partners. But there are companies lying between these two extremes: companies that have a non-founding legal entity as partner – startups that received investments later, for example. If a 30-day window between foundation and entry of a legal entity is adopted, any legal entity that becomes partner after that period will be considered non-founding, and the company may be classified as AFC. As the matter is never clear-cut, the post-processing procedure is necessary to check for false positives and false negatives.

Therefore, the choice was to divide the analyzed companies into:

i. Companies that do not have a legal entity as a partner: if they meet the other criteria, will be classified as AFC.

ii. Companies that have a legal entity partner: it is necessary to analyze whether the legal entity partner is a founder or not.

For case (ii) above, the greater the time interval between the entry of the legal entity partner and the founding of a given company, the greater the chance that this legal entity partner will not be a founder.

Limitations on the nature of the Internal Revenue Service database

The Brazilian IRS makes available large amounts of data partitioned in sequential files in the governmental open data platform. The database contains only public data that is adequate for the analysis proposed here but does not provide information regarding employees or revenues (which are private information) for deeper analysis. In Brazil, Unicamp use alumni-directed surveys to gather data from “daughter companies” and track their financial performance (“Unicamp companies,” n.d.).

An Application Programming Interface (API) of IRS data is not yet available: files must rather be downloaded as csv and processed as desired. Such data is ideal for cross-sectional studies, such as the one described here. Although it allows a bulge of results, they are limited in time. For example, a merge or an acquisition of a former AFC will not be detected by a cross-sectional analysis such as the one proposed here, if the alumni UNID is no longer related to the present CTIN. Progress, improvements, and modifications of CTIN along the years would only be possible based on a temporal analysis of the data. It however implies downloading and storing of files by researchers when made available by the IRS, since monthly updates replace former files.

After preprocessing the pilot industrial engineering database, authors noticed that some companies were named "ACME 1", "ACME 2", "ACME 3". According to our premise, each company has only one legal entity name and, therefore, ACMEs 1, 2 and 3 were displayed as three different companies after running our computational algorithm. However, any human would notice that they are in fact the same company, since they share the same characteristics, but it is a limitation for the algorithm. Future research could develop an improved version of the algorithm that would not adopt the premise and would expand the approach to business groups that have more than one company name. Petrobras Corporation (which is not an AFC for obvious reasons), for instance, has about 40 different company names. An algorithm that identifies business groups given a list of company names could be used before the processing stage and potentially improve the solution our algorithm arrives at.

Limitation on the UNID and its uses

Data availability from the alumni institution plays an important role in the results obtained from the proposed algorithm. As mentioned before, 33% of alumni from the Federal University of Rio de Janeiro had either missing or invalid UNIDs registered in the database, and most of the missing data belong to students registered before 2001. Reliability of the results can also be affected by other aspects related to data quality. Until the end of the 1990s, UFRJ allowed students to enroll to the university using their parents' UNID, when they were minors and were not legally obliged to have an UNID of their own. This fact plus the lack of identified UNID numbers forced us to do the matching between databases based not only on the UNID, but also on the person's name. Matching of names could only be skipped if the university database has high data quality and access to entire UNID numbers is provided by the IRS.

Another common practice in the Brazilian labor market that brings inaccurate, incomplete, or inconsistent data to the algorithm is what is commonly referred to in Brazil as “PJotização” and is referred throughout the text as a “CTIN as a service provider for another company”. Its creation is attributed to an event of hiring workers as entities, thus escaping from protective labor regulation. Therefore, such companies are a special case and might not be considered an AFC. Identifying this practice among other companies is a hard task. Authors proposed a way that can lead both to false positives and false negatives but which, in their evaluation, is better than leaving the data as is and considering all companies approved by the L2 filter as AFC. Since the changing of the Brazilian Labor Law in 2002, there is a rise in the number of “CTIN as a service provider for another company” and the analysis deserves a more specific study to identify further ways and criteria to differentiate between companies per se and this workaround.

In a second group of cases, the alumni UNID is used in founding a new company that is not related to his/her field of knowledge. This happens either because the person herself found an opportunity for a franchising or another business unrelated to her former studies, or a relative or a friend needs a partner for a new business. This latter situation was more frequent until 2011, since it was not possible to establish a single-partner company. The creation of the category “Empresa Individual de Responsabilidade Limitada” (EIRELI), “Empresário Individual” and “Sociedade Limitada Unipessoal” allowed opening of new companies in several economic areas with no need of a partner.

Finally, the last group of cases can be described as a variation of the former one. Authors observed that an alumni UNID takes part in founding a company and eventually becomes its administrator, when the other person involved in the founding team is a public agent. This special case happens because Law 8112/90 allows public agents to be partners in private companies but forbids them from being the manager of the business. Therefore, for the same reason, when an alumnus becomes a public agent, he/she must partner with a non-public agent in founding a new company (a case that was also observed in our sample).

4. Conclusion

Brazilian universities, especially public institutions, bear the responsibility to demonstrate their contribution to the collective welfare. University's influence can be evaluated both directly - through the quantity and caliber of their alumni, as well as traditional research benchmarks - and indirectly, such as gauging the economic endeavors ignited by their graduates worldwide. This paper introduces an algorithm designed to be adaptable for any Brazilian academic establishment, with potential adaptations in datasets for use in other countries. The algorithm serves to quantify the economic and societal influence of academic entrepreneurs. Its applicability is versatile. Initially, it can bolster undertakings aimed at evaluating the returns on universities' investments. Furthermore, it can guide internal efforts to reshape curricula by contrasting intended and actual entrepreneurial engagement in different courses. Lastly, through analyzing logically improbable yet frequently occurring scenarios, universities can assess the secondary effects of education and professional practice. For instance, cases wherein professionals who graduated from saturated market segments evolve into small business entrepreneurs or analogous roles.

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4.3 Epilogue

The method BR-AFC, proposed to identify alumni-founded companies, is the first step to measure entrepreneurial activity of graduates and, this way, estimate the impact generated by new businesses and the return given to society. This is the first piece (1 of 2) to achieve the second objective of Part I of this thesis.

BR-AFC uses a criterion to classify a company as alumni-founded based on the presence, between its founders, of a graduate from the university. This choice is different of the chosen by the University of Campinas (Unicamp), for example. Unicamp created the term 'daughter companies' to classify those founded by individuals with affiliations to Unicamp, including students, former students, professors, former professors, employees, former employees, and those previously incubated or graduated from the institution's incubator (Unicamp, 2020).

Institutions like Stanford and MIT have focused on companies founded by alumni to delineate their economic impact, based on factors such as domain of activity, employment rates, revenue, income, and market capital (Lebret, 2017; Roberts, Murray, & Kim, 2019).

In the institutional project of UFRJ, inputs are student data and IRS companies database. This approach is different of the one assumed by the most universities in this theme. For example, MIT uses a survey spontaneously responded by alumni, which turns the process very dependent on the graduates willing and availability to fill out the questionnaires (Roberts et al., 2019).

Identifying the alumni-founded companies is simultaneously only the first and the most fundamental step to measure the university impact on the society by the entrepreneurial activity. Of course, the formation of new enterprises does not necessarily indicate or ensure their contributions to economic growth. Based on the AFC list, it is possible to estimate number of employees and analyze geographical distribution of new business, for example. With additional data about employment, it would be possible to estimate total salaries involved and taxes collected by the government. It is also possible to track investments made by accelerators, joint ventures, and private equity funds. For instance, 56 startups founded by graduates from Insper captured R$ 6.4 billion (around US$ 1.3 billion) between 2021 and 2023 (Inside University, 2023).

This kind of information is already available about MIT, for example. And the indicators are very impressive. According to Roberts *et al.* (2019), the number of new firms formed each year by MIT alumni is growing. During first decade of the 2000s, there were 12000 new companies. In the following decade, this number raised to

18000 and 25% of the alumni in the survey (and 35% of follow-up telephone survey respondents) report having started one or more companies. The number of active companies is estimated as 30000 firms, which employ 4.6 million individuals and generate annual revenues of US$ 1.9 trillion, amount similar to the Gross Domestic Product (GDP) of 10^{th} largest economy in the world.

After the consolidation of the method BR-AFC, it will be possible to conduct studies to obtain information like those about Brazilian universities. Furthermore, programs managers will be able to analyze whether entrepreneurial results of graduates are aligned to program objectives.

Finally, future research should explore whether the main economic activity of a company is related to the major area of the founder, design founder networks seeking the formation of economic groups, analyze profile and diversity in the set of founders, identify serial entrepreneurs or investigate the relationship between the rate of opening new businesses and macroeconomic periods.

5. Entrepreneurial activity and academic performance

5.1 Prologue

Building upon the previously discussed understanding of the necessity to assess the university's impact on society and the role of new engineers in this impact, this chapter represents the first outcome of the BR-AFC method proposed in the preceding chapter.

Analyzing the entrepreneurial profile of graduates from a specific program can serve as a foundation for new guidelines for the program, supporting curriculum changes aimed at achieving the desired outcomes.

The literature has long debated that high salaries and high job performance are directly linked to academic performance (Bartol & Martin, 1987; Roth, BeVier, Switzer III, & Schippmann, 1996; Vinchur, Schippmann, Switzer III, & Roth, 1998). Furthermore, better educated workers face a lower risk of unemployment (Gautier, 2002; Stern, Paik, Catterali, & Nakata, 1989).

But an open question is about the inclination to entrepreneurship. Are entrepreneurs usually the highest performing students? To begin finding answers to this question, an initial analysis was carried out and presented in PAEE/ALE 2023.

In this study, BR-AFC method was used to identify the alumni-founded companies of a particular course. The pilot sample was the Industrial Engineering program at UFRJ, between 1990 and 2020. Despite the limitations of this sample, this study produced initial evidence to build an answer to that open question.

Finally, the more precise analysis between academic performance and entrepreneurial activity, the more undergraduate programs will be able to plan better courses and activities to students. This analysis is the first tangible outcome in this thesis of the shift from *act* to *impact*. Through the utilization of BR-AFC, it was possible to discern the initial indications of the results achieved in the education of entrepreneurial engineers. Consequently, a vast gateway opens up for further, increasingly intricate and pertinent studies on *impact* in real-life scenarios.

5.2 Full text

Paper published in PAEE/ALE 2023 Proceedings (Arruda, Silva, & Uziel, 2023a).

Is better academic performance in engineering synonymous with more entrepreneurial capacity? A cross-sectional study of the correlation between academic grades and business creation by graduates of Production Engineering at Universidade Federal do Rio de Janeiro

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Abstract

Some universities, especially in the United States and Europe, rank their graduates according to a weighted average of the grades obtained in academic activities – Grade Point Average (GPA), or Cumulative Performance Coefficient (derived from Coeficiente de Rendimento Acumulado – CRA in portuguese) in Brazil. It is common for companies to prefer better-ranked students for job openings, as well as in selective processes for master's or doctoral degrees. But what about entrepreneurial activity? Are entrepreneurs concentrated at the top of each class, or spread across the entire grade range? This work explores whether there is a correlation between entrepreneurial activity, measured by the creation of companies, and the academic performance of graduates, measured by the annual ranking in cohorts of each course. The sample used refers to all production engineering students who graduated from the Universidade Federal do Rio de Janeiro (UFRJ) over about 30 years, measuring their business activity through the anonymized database of the Brazilian Federal Revenue Service. The results have the potential to question whether the academic curriculum collaborates to form entrepreneurs and the role of academic excellence in entrepreneurial activity.

Keywords: Entrepreneurship; entrepreneurial activity; academic excellence.

1 Introduction

During last decades, entrepreneurship has gained attention in some developing countries, in addition to being seen as a possible solution to economic problems, due to its central role in the economic growth of developed countries (Nwankwo, Kanu, Marire, Balogun, & Uhiara, 2012). It is now seen as an engine room for economic growth, including its impact in several indicators, such as revenue generation, poverty alleviation and wealth creation (Adekiya & Ibrahim, 2016). Additionally, entrepreneurship has been considered as a key driver to employment and innovation (Urbano & Guerrero, 2013). Finally, Organization of Economic Cooperation and Development – OECD (2003) describes entrepreneurship as a process through which entrepreneurs create and grow enterprises to provide new products/services, or add value to products or services. From the above points, it is possible to deduce entrepreneurs are enterprising individuals who has the intention of creating and adding value to meet human needs (Adekiya & Ibrahim, 2016).

Additionally, entrepreneurial society refers to a society where entrepreneurship serves as the critical force driving economic growth, employment creation and competitiveness in global markets, and where institutions and policy have a focus on facilitating and generating entrepreneurial activity (Audretsch, 2009). In this society, the university is a key institution that catalyses regional economic and social development because it is a natural incubator that create new ideas and technologies (Urbano & Guerrero, 2013). However, not only generating new knowledge, but also facilitating spill overs that spur innovation, economic growth, job creation and competitiveness in global markets (Audretsch, 2009). The main outcome is to provide to the society graduates who become both job seekers and job creators (Schulte, 2004).

This study aims to analyse whether there is a correlation between entrepreneurial activity, measured by the creation of companies, and the academic performance of graduates, measured by the annual ranking in cohorts of each course.

2 Background

This section presents a literature review about principles related to main subject of the study: academic entrepreneurship and academic performance.

2.1 Academic entrepreneurship

Etzkowitz (2013) classifies the entrepreneurial university as an emergent phenomenon resulting from the working out of an 'inner logic' of academic development that previously expanded the academic enterprise from a conservator to an originator of knowledge. Furthermore, the entrepreneurial academic transition is the next stage in the development of a unique institution that incorporates and amplifies previous objectives.

Urbano and Guerrero (2013) show that several studies have tried to define academic entrepreneurship, but without consensus on the use of one specific definition. Since 1980, there has been a substantial rise in the commercialization of science and other forms of university technology transfer, both in USA and many countries in Europe and Asia (Siegel & Wright, 2015). These commercialization activities began to be known as "academic entrepreneurship" in some areas. This fact reinforces the relevance of a robust university ecosystem.

Because of this, the emergent view is based on to provide a wider social and economic benefit to the university ecosystem (Tatarlar & Turhan, 2021). As example, Roberts, Murray and Kim (2019) updated report about entrepreneurship and innovation at Massachusetts Institute of Technology (MIT). In this study, the authors highlight a wide range of infrastructure to support innovation broadly, but particularly entrepreneurship, has grown along a continuum from the earliest stages of commercialization and proof of concept to prototyping and venture creation at MIT over the past decade.

According to Siegel and Wright (2015), key elements of the broadened entrepreneurial university ecosystem include: (1) the rise of property-based institutions, such as incubators and accelerators; (2) substantial increase in the number of entrepreneurship courses; (3) establishment and growth of entrepreneurship centers; (4) a rise in the number of beginner entrepreneurs to stimulate commercialization and startup creation; and (5) a rapid increase in alumni support of this entrepreneurial ecosystem, including student business plan competitions.

Tatarlar and Turhan (2021) include diversity as another important factor to improve innovation performance of universities. These authors claim that there is a significant average correlation between overseas educational background and entrepreneurship aspects in universities. At MIT, foreign-born students play a relevant role as entrepreneurs and innovators as well as key trends in the alumni-founded ventures' industry composition, firm performance, and economic impact through job creation and sales (Roberts et al., 2019).

It is also important highlight that social and cultural approval by the society can contribute to the growth of entrepreneurial activity when the values of a given society reward entrepreneurship while disapproval impedes it (Adekiya & Ibrahim, 2016). When risk taking and supportive of uncertainty are cultural values, they are expected foster the creativity and innovation that underlies entrepreneurial activities (Hayton & Cacciotti, 2013). Further, for starting a new business many factors influence entrepreneurial intention, such as perceived desirability, feasibility, and entrepreneurial experience (Mitchell et al., 2002).

2.2 Academic performance

Academic performance can be seen as a result of several inputs. Usually, some factors are considered as important to a good student performance, such as student engagement, learning styles, learning environment and teaching activities.

Learning in a structured educational setting may be thought of as a two-step process involving the reception and processing of information. A learning-style model classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information. (Felder Richard M. & Silverman Linda K., 1988). Learners have their preferred ways of perceiving, organizing and retaining information that are distinct and consistent (Chou & Wang, 2000). Then, individuals have their preferred methods of interacting with, taking in, and processing stimuli and information when they learn (Li, Yu, Liu, Shieh, & Yang, 2014).

Li et al claim (2014) the best way to assist students is to create a harmonious learning environment, and to use teaching methods that are suitable to the students' learning styles. Learning style is an important consideration when planning for effective and efficient instruction and learning (Childress & Overbaugh, 2001). Zhang and Lambert (2008) state that a better understanding of learning styles can be beneficial to both teachers and students.

During last decades, engineering education has been transformed to match new students' characteristics. A common point among the modernization movements is the recommendation to place the student at the center of the learning process, which drives the increasing use of active learning techniques (Hartikainen, Rintala, Pylväs, & Nokelainen, 2019). Student-centered strategies increase student engagement, which is linked to teaching effectiveness. The positive results have already been widely explored (Burke & Fedorek, 2017; Cho, Mazze, Dika, & Gehrig, 2015; Prince, 2004).

Finally, academic performance is usually associated to an index, as Grade Point Average (GPA). This paper will use this index as the score that summarize effectiveness of students' learning.

3 Methodology

The main goal of this paper is to analyse whether there is correlation between entrepreneurial capacity and academic performance. Entrepreneurial capacity will be measured by alumni-founded companies (AFC). These companies have alumni between their founders and can be seen as an actual result of entrepreneurial attitude from students.

3.1 Method to assign a company as AFC

To establishing the method to sort alumni-founded companies, two databases were used in this study: (1) a de-identified open database from the Brazilian Internal Revenue Service – IRS, and (2) university internal system of student registration. Since student data is identified, special permission was obtained for this study. Individuals cannot be identified because all results are provided as aggregates.

The first step is to list all companies that have alumni as partners. This first list may contain multinational companies that have attributed legal responsibility to directors (alumni included), since these records are filed together with the companies' corporate data. In addition, a large company can create a second company, which has alumni among its partners. In this case, the company could not be considered an AFC. By the other hand, if a company has a legal entity between its partners, but the entry of this legal entity occurs after first moment, it is probable that an acquisition – total or partial – happened.

Then, to be classified as AFC, two main criteria must be followed: (1) When the company does not have a legal entity as a partner, an alumni must have joined the company as a partner up to 30 days after company's starting date; and (2) If the company does have a legal entity as a partner, it must have joined the company after day 30 of company's starting date.

3.2 Pilot sample

The approach used in this paper quantifies entrepreneurial activity at Universidade Federal do Rio de Janeiro (UFRJ) and uses its Industrial Engineering program alumni as a first attempt to a demographic study of UFRJ's alumni-founded companies.

Initial population of this study consisted of 2363 alumni who graduated between 1990 and 2020. From 1990 to 2000, around 60% of this population had either missing or invalid ID document number registered in the database, since only by 2001 the university started an integrated institutional data system, gathering data from different and independent internal sources. Then, only 1800 individuals from the original list were used in the companies search. Table 1 shows how is the distribution of graduates over decades.

Table 1. Graduate distribution over decades

Decade	Number of graduates
1990	348
2000	737
2010	684
2020	31

4 Results and discussion

In this section, the results achieved in the research will be shown, in addition to the analyzes on them. Initially, Table 2 shows the GPA distribution of graduates over the decades.

Table 2. GPA distribution of graduates over the decades

Decade	GPA >= 9.0	9.0 > GPA >= 8.0	8.0 > GPA >= 7.0	7.0 > GPA >= 6.0	6.0 > GPA
1990	1.1%	18.7%	52.6%	20.7%	6.9%
2000	2.2%	35.4%	43.6%	14.4%	4.5%
2010	1.5%	35.2%	45.3%	13.2%	4.8%
2020	0.0%	22.6%	58.1%	19.4%	0.0%
Total	1.7%	31.9%	46.2%	15.2%	5.0%

It is observed that the percentage of graduates with a GPA equal to or greater than 9.0 is much lower than the other ranges, which may indicate difficulty in completing the program. When comparing the last three decades, it is possible to notice that the decades of 2000 and 2010 present similarities in the GPA ranges, except for GPA above 9.0. However, the last decade shows a reduction in the GPA range from 8.0 to 9.0 and a higher concentration between 7.0 and 8.0, compared to those two previous decades.

In the population of 1800 graduates analyzed, there is a moderate variation of GPA over the years. Figure 1 shows how this variation occurs, and it is possible to identify four cohorts:

- Cohort 1: GPA >= average + standard deviation
- Cohort 2: Average + standard deviation > GPA >= Average
- Cohort 3: Average > GPA >= Average - standard deviation
- Cohort 4: Average – standard deviation > GPA

In other words, cohort 1 is above the green line, cohort 2 is between green and blue lines, cohort 3 is between orange and blue lines, and cohort 4 is below the orange line.

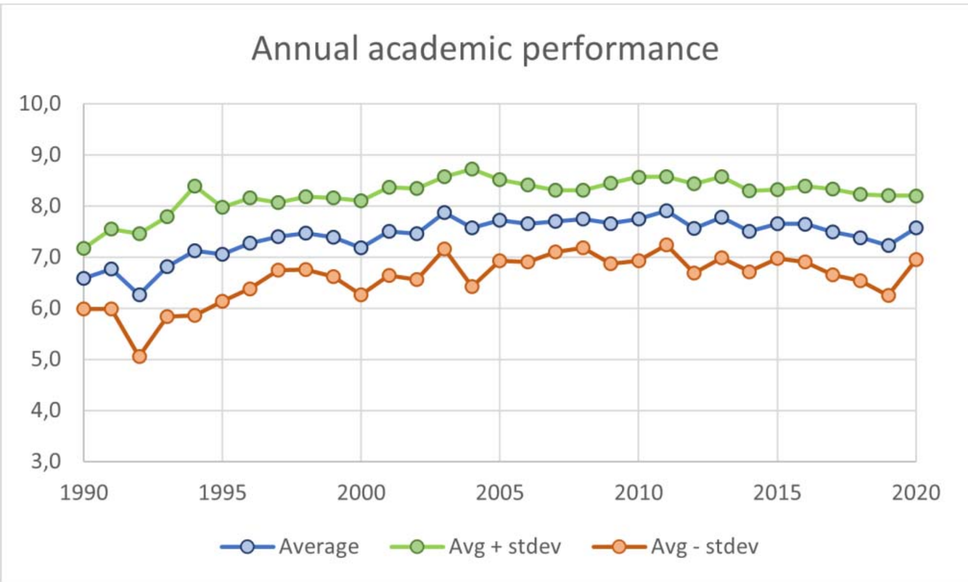

Figure 1. Annual academic performance, with 4 cohorts

Considering this population, there was the creation of 155 companies classified as AFC, which were created by 125 graduates. Table 3 shows the distribution of these 125 entrepreneurs, according to their decade of graduation.

Table 3. Entrepreneurs' distribution over decades of graduation

Decade	Number of entrepreneurs	Ratio between entrepreneurs and graduates
1990	15	4.3%
2000	40	5.4%
2010	70	10.2%
2020	0	0.0%

The last line of Table 3 shows that no graduate (from the group considered) from 2020 onwards founded an AFC. This can be explained by the short observation time so far, combined with a period of global economic slowdown, due to the COVID-19 pandemic and the conflict between Russia and Ukraine.

It is also observed that the number of entrepreneurs (second column) over the decades is strictly increasing. This fact can be explained by several factors, such as: (i) increase in the number of graduates with complete data in the academic system, which increases the effectiveness in the search for founded companies; (ii) period of economic growth in Brazil, linked to the stabilization of the currency and fight against hyperinflation; and (iii) ongoing technological revolution, which allows companies to be created with less investment than in the predominantly industrial phase.

To calculate the correlation between GPA and entrepreneurial activity, each entrepreneur had the activity indicator value 1, while the others had the value 0. Thus, the correlation found was -0.01. Another attempt was to replace the absolute value of the GPA with its range, as shown in the tables 2 and 5. Thus, the correlation was -0.003. Aggregating graduates in cohorts by annual academic performance, the correlation with entrepreneurial activity is 0.01. These values suggest that does not exist relevant correlation between GPA and entrepreneurial capacity.

To analyze how entrepreneurs are distributed in cohorts by annual academic performance, Table 4 is exhibited below.

Table 4. Entrepreneurs versus annual academic performance cohorts

Cohort	Number of graduates	Number of entrepreneurs	Ratio between entrepreneurs and graduates
1	241	9	3.73%
2	754	61	8.09%
3	544	37	6.80%
4	267	18	6.92%

It is possible to see that the rate of entrepreneurs is not directly linked to the annual cohort. In addition, the lowest rate of entrepreneurs is exactly in the cohort with the best academic performance. One possible explanation, which could be further investigated in future studies, is the fact that students in this group may have a higher tendency to pursue an academic career. This fact is yet another indication of the lack of connection between the indicators.

The distribution of entrepreneurs in the GPA ranges, both in absolute numbers and relative to the total number of graduates in each range, is presented in table 5.

Table 5. Entrepreneurs versus GPA

GPA	Number of entrepreneurs	Ratio between entrepreneurs and graduates
GPA >= 9.0	2	6.67%
9.0 > GPA >= 8.0	43	7.44%
8.0 > GPA >= 7.0	56	6.64%
7.0 > GPA >= 6.0	15	5.21%
6.0 > GPA	9	9.28%
Total	**125**	**6.80%**

The first observation in Table 5 highlights the percentage of approximately 6.8% of entrepreneurs in the considered program. This rate is almost the same in all GPA ranges, except in the last row of the table, where the number shows a jump of almost 3 percentage points, or 50% relative.

This is one more indication that entrepreneurial capacity is not directly linked to academic performance, due to two factors: in addition to not showing large fluctuations between GPA ranges, the range with the lowest GPA values has the highest percentage of entrepreneurs. Table 5 shows how entrepreneurs are distributed over the decades and in the GPA ranges.

Table 6. Ratio between entrepreneurs and number of graduates over decades of graduation

Decade	GPA >= 9.0	9.0 > GPA >= 8.0	8.0 > GPA >= 7.0	7.0 > GPA >= 6.0	6.0 > GPA
1990	0.0%	0.6%	1.4%	1.4%	0.9%
2000	0.0%	1.9%	2.2%	0.8%	0.5%
2010	0.3%	3.9%	5.1%	0.6%	0.3%
2020	0.0%	0.0%	0.0%	0.0%	0.0%

It is possible to verify that the ranges with the highest concentration of entrepreneurs change from one decade to another. When looking at the last two complete decades, which have the highest volume of graduates, entrepreneurs are most concentrated in the GPA column between 7.0 and 8.0.

The evidence presented is limited, both by the size and scope of the sample, and by the gap in older data. However, they suggest that the relationship between academic performance and entrepreneurial ability may not be as strong as it is with employability, for example.

Despite the limitations, it is indisputable that the ranges with the highest GPA values do not have a high concentration of entrepreneurs, neither decade after decade, nor in the accumulated total. This fact reinforces the suspicions of the lack of correlation between the two analyzed indicators.

5 Conclusion

This work aimed to investigate whether there is a correlation between academic performance and entrepreneurial capacity. For this, a sample of around 2350 graduates in Industrial Engineering at the Universidade Federal do Rio de Janeiro, distributed over about 30 years, was analyzed.

Entrepreneurial activity is an important factor for economic growth, both regionally and nationally, as can be seen in developing countries. In this way, the university needs to update itself in the preparation of individuals who are able to identify opportunities and apply their knowledge.

The first analyzes presented in this study indicate that there is no direct correlation between entrepreneurial capacity and academic activity. Although studies need to be deepened and extended, these indications serve as a warning for deeper investigation and possible adjustments in higher education courses, with the aim of promoting the update mentioned above.

As future work, it is suggested that the studies be deepened with other courses, in addition to considering the size of the companies classified as AFC, to prevent the analyzes from being contaminated by companies without employees, for example. This type of company may indicate that the legal entity was created to camouflage the hiring of an individual.

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5.3 Epilogue

Nowadays, it is stablished that universities third mission is to impact the market (Audy, 2017; Compagnucci & Spigarelli, 2020; Etzkowitz, 1983; Vefago et al., 2020). Then, more than only scientific publications, university needs to impact the society in different ways, new business included (Etzkowitz, 2013). Besides this, there is a concern about the role played by the university to provide professionals able to not only seek good jobs, but to create good jobs (Schulte, 2004).

An increasing body of entrepreneurship research is focused on examining the factors that drive individuals' intentions to participate in entrepreneurial endeavors. According to Adekiya and Ibrahim (2016), students are more likely to have a strong intention to pursue entrepreneurship if they believe that engaging in this activity can help them achieve their primary objectives and aspirations. Nwankwo *et al.* (2012) stated that entrepreneurial education is a successful method for encouraging and strengthening university students' interest in entrepreneurship. Moreover, early exposure to entrepreneurial training may be particularly effective in increasing interest in entrepreneurial career (Dyer, Gregersen, & Christensen, 2008).

The paper presented in this thesis chapter investigated whether there was relationship between academic performance and entrepreneurial activity. Despite the sample size, and the limitations related to it, first results shown lack of evidence of that relationship. From these results, it is possible to extend reflections and propose a new question: certainly, is there truly no correlation between the two indicators, or does the issue lie within the assessment mechanisms, which may not effectively capture the entrepreneurial potential of the students?

Additionally, more inquiries can be posed. In a world marked by intense debates on the modernization of engineering education and explicit recommendations for the use of project-based learning, how should assessment methods be adapted? Is retaining traditional exams with conventional questions the optimal choice, even when assessing leadership skills, teamwork, and critical thinking is essential? Then, this investigation opens the door to a broad debate on the adequacy of assessments throughout the course and the alignment between course planning and the results achieved by graduates.

Finally, this chapter is the last piece (2 of 2) to achieve the second objective of Part I. To delve further into discussions regarding the educational process of emerging engineers, this thesis concludes Part I and initiates Part II.

PART II – AXIS "The process: engineering education and active learning"

Although active learning has already been validated as an effective way to influence student learning and is increasingly incorporated into the classroom, especially due to its important role in transforming engineering education, there is no way to qualify and evaluate the use of these techniques by teachers (Van Amburgh et al., 2007).

Maturity models can bridge this gap. They allow professionals to evaluate organizational performance, support management and enable improvements (Maier et al., 2012). Furthermore, maturity models are instruments for evaluating organizational elements and selecting appropriate actions, which lead to higher levels of maturity and better performance (Kohlegger et al., 2009).

There are four maturity models in the field of education, but none that specifically allow you to evaluate the implementation of active learning in a course (Marshall, 2006; Mughrabi & Jaeger, 2016; Nelson, Clarke, Stoodley, & Creagh, 2015; Thong, Yusmadi, Rusli, & Nor Hayati, 2012). In addition to the difficulty of measuring the use of active learning in the classroom, there is no way to assess the level of maturity of active learning implementations in a course or program at a Higher Education Institution (HEI), including engineering schools. This gap makes it difficult to diagnose the status of a given implementation and, consequently, leads to less assertiveness in decision making, reducing the effectiveness of changes and active learning as a whole. In this axis, the main objective is to propose a way to evaluate maturity level in the use of active methods. To achieve this objective, there are two components, detailed in the following chapters: a conceptual maturity model to assess active learning implementations, and an index to measure level of lecturer self-awareness.

6. Engineering education active learning maturity model (E^2ALM^2)

6.1 Prologue

The development of a maturity model to assess active learning implementations started in the first months of this doctoral trajectory. Initially, there was an intention to investigate whether it could be stablished a relationship between the exposure of students to active learning techniques and birth/strengthening of behaviors or attributes of an innovator engineer.

After the literature review to search ways to measure how students were exposed to active learning techniques, results were frustrating. In the realm of education, there are four different maturity models, yet none of them is designed to assess the incorporation of active learning within a course. These four models were cited in the previous section and will be detailed below. The positive way to analyze this situation was: "there is a gap that can be covered".

First discussions about feasibility and plausibility of this type of assessment occurred in the Forum on Philosophy, Engineering and Technology – fPET 2020 (Arruda & Silva, 2020). After that, the first conceptual model was presented at International Conference on Active Learning in Engineering Education – PAEE/ALE 2021 (Arruda & Silva, 2021b). The draft was extended and deepened to propose the Engineering Education Active Learning Maturity Model – E^2 ALM^2 (Arruda & Silva, 2021a). In the design phase, the maturity model could be applied to an institution, a program or a course. The approach chosen was bottom-up, that is, the proposed model will have the scope of a course and could, in future work, be extended to higher levels.

This model is in direct dialogue with some previous works, from three different fields: engineering education, active learning, and maturity models. Figure 10 shows how E^2ALM^2 is placed in the space defined by those three fields. The works indicated in the figure are:

- C – reference in the proposal of initiative CDIO (Crawley et al., 2014);
- GS – book of global relevance that deals with the need for new engineering training in the 21st century (Goldberg & Somerville, 2014);
- UN – UNESCO report about engineering for sustainable development, with several issues about engineering education;

- F(1) – reference paper that deals with different teaching and learning styles in the field of engineering education (Richard M. Felder & Silverman, 1988);
- F(2) – paper that deals with the use of active learning techniques in the field of engineering education (Richard M. Felder et al., 2000);
- P – paper that addresses the effectiveness of active learning methods (Prince, 2004);
- Ba – book that discusses different ways to increase student engagement and is one of the main references on the subject of active learning (Barkley, 2010);
- Mu, Ma e N – maturity models focused on education (Marshall, 2006; Mughrabi & Jaeger, 2016; Nelson et al., 2015);
- M – paper that deals with the importance of using maturity models to support management towards improvements (Maier et al., 2012);
- Ko – paper that highlights the use of maturity models as tools for competitive differentiation (Kohlegger et al., 2009);
- Kl – paper that defines maturity model as a generic approach that describes the development of an organization over time (Klimko, 2001);
- dB – paper that debates the three forms of a maturity model: descriptive, prescriptive and comparative (de Bruin et al., 2005).

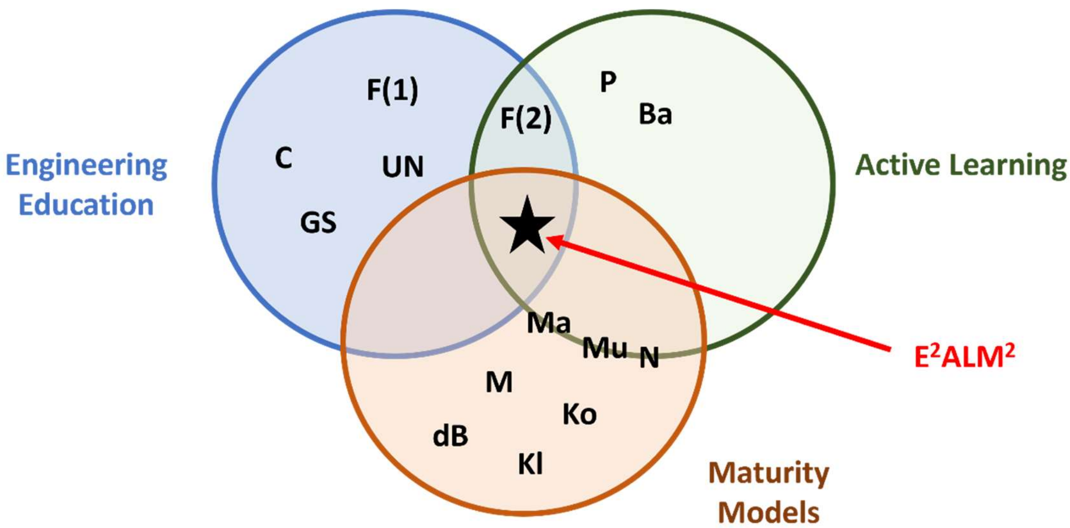

Figure 12 - Positioning of E^2ALM^2

Source: the author

6.2 Full text

Paper published in journal Education Sciences (Arruda & Silva, 2021a)

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education sciences

Article

Assessment and Evaluation in Active Learning Implementations: Introducing the Engineering Education Active Learning Maturity Model

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Abstract: With the technological changes experienced in the world in recent decades, society has changed as a whole, due to the speed and availability of information that exists today. As student attention decreases, critical thinking and Active Learning, which places the student at the center of the learning process, have gained prominence. Considering the growing popularity of these techniques, this article proposes the Engineering Education Active Learning Maturity Model (E^2ALM^2), a framework that allows practitioners to assess the current maturity of Active Learning implementation in a program or a course. E^2ALM^2 was built from a literature review of key success factors (KSF) for Active Learning implementations, which were divided into dimensions. Each KSF is composed of constructs, which are detailed with variables. Each variable has a proposed measurement method and an estimated uncertainty level. The framework can support diagnosis and practical improvements in real settings.

Keywords: Active Learning; maturity model; engineering education

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1. Introduction

Since the beginning of the second half of the 20th century, the world has gone through technological evolutions that have transformed several areas of knowledge. Since the appearance of the first computers, data processing capacity and speed have increased exponentially, and this has led people and society to new behaviors. Education in general has changed, and so has engineering education [1,2].

With the transformations experienced in recent decades, current students were born surrounded by many technological resources. With almost all the information available on mobile phones, knowing how to make sense of it becomes increasingly important.

Engineering schools are experiencing a global trend of adaptation of their programs to the reality of the 21st century. Several movements are attempting to modernize programs and teaching practices, such as the CDIO initiative [3]. This initiative "provides students with an education stressing engineering fundamentals set in the context of Conceiving—Designing—Implementing—Operating (CDIO) real-world systems and products" [4]. Additionally, accreditation criteria of engineering programs in USA, established by the Accreditation Board for Engineering and Technology—ABET (called EC2000) [5], have changed. Such novel criteria require US engineering departments to demonstrate that, in addition to having a solid knowledge of science, math, and engineering fundamentals, their graduates have communication skills, multidisciplinary teamwork capabilities, lifelong learning skills, and awareness of the social and ethical considerations associated with the engineering profession [6]. Finally, completely novel engineering colleges are being created, with totally different proposals from the traditional 20th century model, such as the Olin College [7] and Aalborg University [8].

A common topic among the engineering modernization movements is the importance of placing the student at the center of the learning process, as highlighted in the learning outcomes of the EC2000 (Criterion 3. i—"a recognition of the need for, and an ability to engage in life-long learning") [9] and Standard 8 of the CDIO ("Active Learning") (p. 153, [3]). Putting the student at the center of the learning process, along with increasing student engagement, is arguably achieved by the use of Active Learning [10–22].

Active Learning still lacks a definitive unique definition, but three stand as the most popular. Prince defines it as "any instructional method [used in the classroom] that engages students in the learning process" [23], Roehl as "an umbrella term for pedagogies focusing on student activity and student engagement in the learning process" [24], and Barkley as "an umbrella term that now refers to several models of instruction, including cooperative and collaborative learning, discovery learning, experiential learning, problem-based learning, and inquiry-based learning" [14]. Hartikainen [10] shows 66 definitions of Active Learning, grouped by three main categories: (1) defined and viewed as an instructional approach; (2) not defined but viewed as an instructional approach; and (3) not defined but viewed as a learning approach.

Among the main Active Learning techniques, the following stand out: Problem-Based Learning (PBL) [8,23,25–29], Cooperative and Collaborative Learning [13,23,30–35], and the Flipped Classroom [20,36–39].

Furthermore, the pedagogical results and effectiveness of Active Learning are also widely documented [19,23,40–45]. Hartikainen [10] related positive effects on the development of subject-related knowledge, professional skills, social skills, communication skills, and meta-competences.

However, there are problems both in research and in the implementation of Active Learning. Prince [23] points out that comprehensive assessment of Active Learning is difficult due to the limited range of learning outcomes and different possible interpretations of these outcomes. Streveler [46] notes that "active learning is not a panacea that is a blanket remedy for all instructional inadequacies. Instead, it is a collective term for a group of instructional strategies that produce different results and require differing degrees of time to design, implement, and assess". Fernandes [47] related that "students identify the heavy workload which the project entails as one of the main constraints of PBL approach". There are also the least researched, but much-mentioned, barriers of resistance to novelty on the part of lecturers and students [43,48–52].

Although Active Learning has already been validated as an effective way to influence student learning and is increasingly being incorporated into the classroom, there is no way to qualify and evaluate the use of Active Learning techniques by faculty members [40]. There are four maturity models in the field of education, but none that specifically allow the assessment of the implementation of Active Learning in a course [53–56]. In addition to the difficulty of measuring Active Learning usage in the classroom, there is no way to assess the maturity level of Active Learning implementations in a course or a program of a Higher Education Institution (HEI), engineering schools included. This gap blurs the diagnostics of the status of a given implementation and consequently leads to less assertiveness in decision making, reducing the effectiveness of changes and Active Learning as a whole.

Maturity models can be a bridge to this gap. They enable practitioners to assess organizational performance, support management, and allow improvements [57]. Maturity modeling is a generic approach that describes the development of an organization over time through ideal levels to a final state [58]. In addition, maturity models are instruments to assess organizational elements and select appropriate actions, which lead to higher levels of maturity and better performance [59].

Therefore, this work will propose a conceptual maturity model that allows evaluating Active Learning implementations at the level of a specific course. This model targets the incremental enhancement of courses and seems logically to be the first step towards a more general and comprehensive framework that can extend its reach to evaluate institutions as a whole.

2. Methodology

Based on the research objectives, the broad keyword "active learning" was used in Scopus and Web of Science databases to search for abstracts of peer-reviewed journal articles. Additional keywords related to "success factors" and "engineering education" were used to refine the search. Ultimately, 31 studies were selected for review. Figure 1 uses the PRISMA model [60,61] to describe the literature review process.

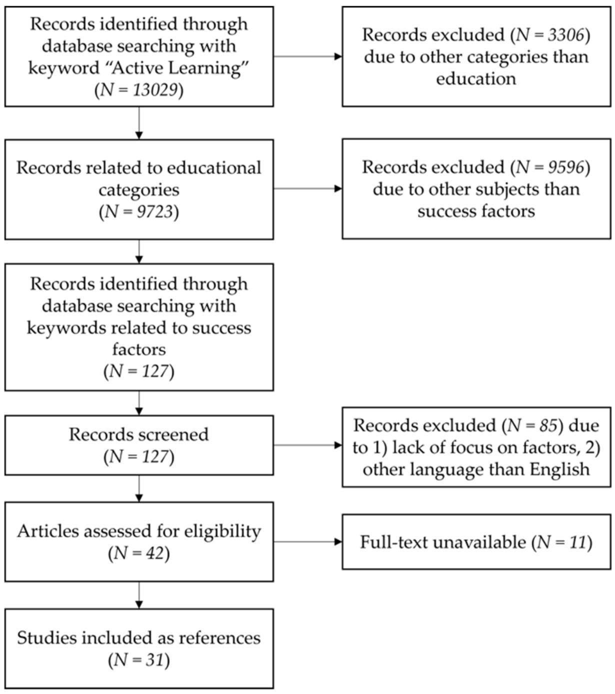

Figure 1. Source selection process (N = 31).

The initial search returned a total number of 13,029 articles. Approximately 25% (3306) of the records were excluded because they belonged to categories other than education. The objective of this criterion was to exclude articles that used "active learning" in different purposes.

With the sample reduced to 75% of the original size (9723), filters were applied in the databases to match keywords related to success factors: "critic* factor*", "key factor*", and "success factor*". This step led to the reduction of the sample to 127 articles.

The abstracts of these 127 articles were judged against the following inclusion criteria: (1) reported research on key factors and (2) written in English. These criteria were intended to eliminate articles that had some keywords related to success factors but that did not actually address them. This step resulted in the reduction of the sample to 42 articles, whose full texts were searched. Of these, 11 full texts were not available for download, which resulted in the selection of 31 references that were included in the literature review. After the literature selection stage, references were read to identify the Key Success Factors (KSF) for the implementation of Active Learning.

The software MaxQDA® was used to extract and accumulate text snippets that represented key success factors. Then, similar snippets were combined into single KSFs to avoid duplication. Next, a definition based on the literature was attributed to each factor. The following step was to define the relevant constructs for each factor and for each construct, the variables that would be used for measurement.

Finally, each variable had a measurement method proposed and an uncertainty degree estimated.

The research method is presented in Figure 2.

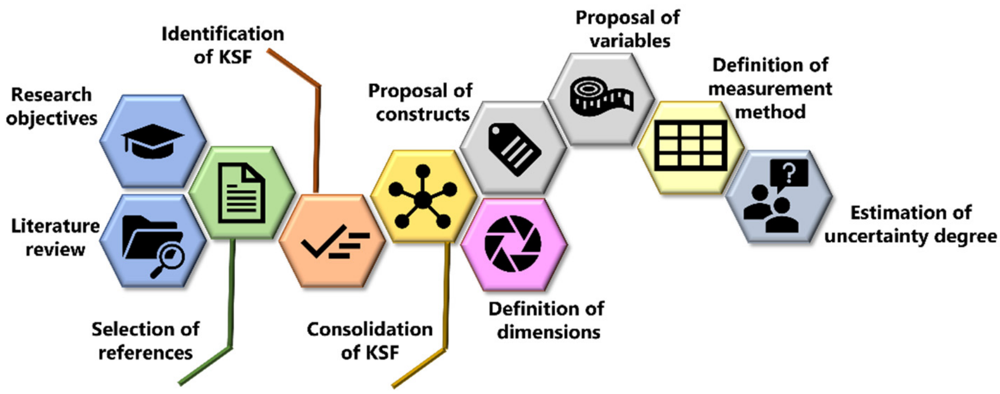

Figure 2. Research procedures.

3. Results

The 31 sources included for the literature review provided 14 key success factors, grouped into five dimensions according to their similarity and relatedness to a specific aspect of the educational environment. Table 1 shows the dimensions and their related KSF.

Table 1. Dimensions, KSF, and references.

Dimension	KSF	References
Content quality	Course artifacts	[16–18,42,49,53,62–66]
	Student assessment	[18,34,42,62,67–70]
	Learning facilitation	[17,18,42,53,67,70,71]
Organizational environment	Culture	[72]
	Policy	[19,72]
	Student feedback	[25,49,73]
	Instructional design	[74,75]
Organizational infrastructure	Classrooms	[76–81]
	Technology	[16,19,42,70,82]
Lecturer	Knowledge	[49,72]
	Skills	[72]
	Attitude	[42,72]
Interactions	Between students	[42,62]
	With lecturers	[42,75]

Following up on the creation of dimensions, each of the 14 KSF was detailed into 41 constructs. The constructs were detailed into 90 variables that could operationalize objective measurements to assess the maturity of a given implementation. Then, a measurement method was proposed for each variable, as well as an uncertainty degree estimated based on each measurement method. Three measurement methods were proposed:

- A questionnaire faculty in charge of a course should answer (Lecturer Questionnaire, LQ),
- Another questionnaire directed to students (Student Questionnaire, SQ), and
- An external evaluation from a third party not directly involved in the course (External Evaluation, EE).

As a result, Figure 3 shows the Engineering Education Active Learning Maturity Model (E^{2}ALM^2) with four levels.:

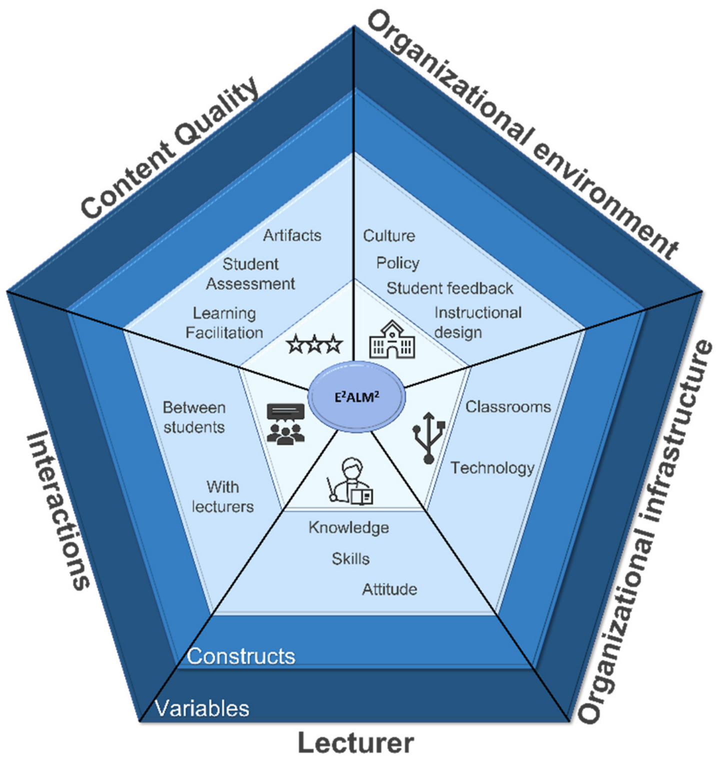

Figure 3. E^2ALM^2.

All dimensions and their KSF are defined in the following sections. Each KSF is detailed with its constructs and variables. Each variable has a measurement method (MM) and uncertainty degree (UD) suggested.

3.1. Content Quality

This dimension concentrates the factors related to the core of the learning process, such as the quality of the problems, projects, or cases studied (artifacts); the level of difficulty required from the students; whether the activities facilitate learning; and whether the evaluation criteria are clear and consistent. The three KSF are detailed below.

3.1.1. Course Artifacts

Course artifacts (problems, projects, or cases studied) should:

- Engage students with real-life problems and active experiences [62];
- Provide students with a variety of additional instructional resources, such as simulations, case studies, videos, and demonstrations [62];
- Be suitable to achieve different targets including the support of the students' learning process and establishing learning outcomes requirements [53];
- Be clearly written, in the right length, useful, flexible, and provide an appropriate degree of breath [63];
- Have suitable intellectual challenge [16–18,42,64]; and
- Begin with an explanation of its purpose [49,65,66].

Table 2 describes the KSF "Course Artifacts" with more detail. Its constructs were derived from the list of requisites presented above. Variables were proposed to measure each construct, as well as the most suitable measurement method (MM) and the uncertainty degree in each measurement.

Table 2. KSF "Course Artifacts".

Construct	Variable	MM	UD
Use of real-life problems	% of course content based on real-life problems	SQ and LQ	Medium
Application of active experiments	% of classes using active methods	SQ and LQ	Medium
	Students' perception of hands-on activities	SQ	Low
Variety of instructional resources	Quantity of instructional resources used	SQ and LQ	Low
	% of classes using resources other than the board or projector	SQ and LQ	Low
	Students' perception of the use of various resources	SQ	Low
Adequacy to learning outcomes (LO)	% of classes linked directly to an LO	SQ and LQ	Medium
	Students'perception of reaching an LO	SQ	Medium
Suitability of intellectual challenge	Students' perception of the level of difficulty presented	SQ	Low
Clarity in writing of course activities	Students' perception of the clarity used	SQ	Low
Size of course activities	Students' perception of size	SQ	Low
Explanation of purpose of course activities	Students' perception of clarity in the purpose of the activities	SQ	Low
	% of activities in which the purpose is explained to students	SQ	Low

3.1.2. Student Assessment

Student assessment needs to be clear, concise, and consistent. This involves instructions, assignments, assessments, due dates, course pages, and office hours [62]. Furthermore, criteria for success must be communicated clearly and monitored [18,34,42,67–70]. Table 3 details the KSF "Student Assessment".

Table 3. KSF "Student Assessment".

Construct	Variable	MM	UD
Clearness of assessment methods	Perception of students on the clarity of assessment methods	SQ	Low
	Are the assessment methods defined in advance?	SQ and LQ	Low
	% of activities that have defined what is expected of the student	SQ and LQ	Low
Clearness of criteria for success	Perception of students on the clarity of success criteria	SQ	Low
	Are the success criteria defined in advance?	SQ and LQ	Low
Communications with students	Is information about assessment methods and success criteria made available before (or at the beginning of) the course?	SQ and LQ	Low
	Students' perception of communication of assessment methods and success criteria	SQ	Low

3.1.3. Learning Facilitation

Learning facilitation includes the preparation of students to conduct activities and tasks required in addition to activities related to the facilitator guiding the learning process of the students [53]. It also involves providing students with regular opportunities for formative feedback from the lecturer [17,18,42,67,70,71]. Table 4 details the following levels of this KSF.

Table 4. KSF "Learning Facilitation".

Construct	Variable	MM	UD
Preparation of students to conduct activities required	% of activities flagged as supporting another activity	SQ and LQ	Medium
	Students' perception of the existing preparation for conducting activities	SQ	Medium
	Students' perception of the teacher's performance as a facilitator	SQ	High
	Intensity of the participation of monitors or auxiliary teachers during the course	SQ and LQ	Medium
Formative feedback from teacher	% of activities where there is formative feedback from the teacher	SQ	Medium
	Students' perception of the intensity of support received via formative feedback	SQ	Medium

3.2. Organizational Environment

The factors of this dimension represent abstract aspects of the institution, such as culture, policy, and the practice of collecting feedback from students.

3.2.1. Culture

Organizational culture is a set of values systems followed by members of an organization as guidelines for behavior and solving the problems that occur in the organization [72]. This way, an organization and its members should have behavior alignment, and an organization should have guidelines to solve problems. Table 5 details the following levels of this KSF.

Table 5. KSF "Culture".

Construct	Variable	MM	UD
Acceptance of changes by the organization	Ease of approval of pedagogical changes	LQ	Medium
	Ease of approval of administrative changes	LQ	Medium
Behavior alignment	Clarity of expected behaviors	LQ	Medium
	Existence (or maturity) of behavioral guidelines	LQ	Low
Ability to solve problems	Perception of the speed with which problems are solved	LQ	Low
	Perception of transparency in problem solving	LQ	Low
Defining rules	Existence (or maturity) of a code of ethics	LQ	Low
Adequacy to the rules	Perception of the existence of punishments for those who violate certain rules	LQ	Medium

3.2.2. Policy

Organization policy is a set of program plans, activities, and actions that allows the prediction of how the organization works and how a problem would be solved [72]. Once time is needed to prepare the activities, teachers must have it for implementing something new in their classes [19]. Table 6 describes more details of this KSF.

Table 6. KSF "Policy".

Construct	Variable	MM	UD
Organizational support for the preparation of activities	Perception of the existence of time available for planning new activities	LQ	Low
	% average of teachers' time in classroom activities	LQ	Low
	% average of teachers' time in administrative activities	LQ	Low
	Average amount of administrative functions performed by teachers	LQ	Low
	Perception of the availability of auxiliary resources for the preparation of activities	LQ	Low
Adequacy of pedagogical plans	Perception of the adequacy of existing teaching plans to the use of AL	LQ	Medium

3.2.3. Student Feedback

Organizations are expected to collect feedback from students [25,49,73] and provide the support needed to successfully complete the activity [49].

Thus, it is possible to identify three different requirements for organizations carry on successfully this process: having a suitable process of feedback collection, using suitable feedback, and having an adequate student feedback process.

The following levels of the KSF "Student Feedback" are shown in Table 7.

Table 7. KSF "Student Feedback".

Construct	Variable	MM	UD
Collecting student feedback	Existence (or maturity) of the process of receiving feedback from students	SQ	Low
Using student feedback	Perception of students on the fulfilment of their placements in feedbacks	SQ	Medium
	Number of objective actions resulting from student feedback in the last years	EE	Low
Quality of the student feedback	Is feedback anonymous?	SQ	Low
	Is the collection in person or remote?	SQ	Low
	Perception of students about the ease of the process of giving feedback	SQ	Low

3.2.4. Instructional Design

Brophy [74] and Paechter et al. [75] highlight the importance of the structure and coherence of the curriculum and the learning materials. Thus, it is possible to identify two requirements to this KSF:

- Curriculum should be suitable to the course needs; and
- Curriculum and learning material should have coherence with each other.

Table 8 shows the following levels of this KSF.

Table 8. KSF "Instructional Design".

Construct	Variable	MM	UD
Structure of the curriculum	Perception about the adequacy of the curriculum to the needs of the course	SQ	High
Coherence of the curriculum and the learning material	Student perception of the alignment of the curriculum with the course material	SQ	Medium

3.3. *Organizational Infrastructure*

This dimension contains factors that represent the infrastructure available for course activities.

3.3.1. Classrooms

Classrooms designed for improved Active Learning experience [76] and equipped with technologies can enhance student learning and support teaching innovation [77–81]. Thus, two different requirements emerge for this KSF:

- Organizations should have appropriate classrooms for Active Learning; and
- Organizations should provide classrooms with technological support.

Table 9 describes more details of this KSF.

Table 9. KSF "Classrooms".

Construct	Variable	MM	UD
Classrooms designed for improve Active Learning experience	Existence of classrooms for Active Learning	SQ and LQ	Low
	Classroom availability for Active Learning	SQ and LQ	Low
	% of activities performed in an environment suitable for Active Learning	SQ and LQ	Medium
Classrooms equipped with technologies to enhance student learning and support teaching innovation	Existence of classrooms equipped with multimedia devices and/or laboratories	SQ and LQ	Low
	Availability of classrooms equipped with multimedia devices and/or laboratories	SQ and LQ	Low
	% of activities performed in a technologically appropriate environment	SQ and LQ	Low

3.3.2. Technology

The school should provide equipment and technological structure [19,42]. This involves availability, reliability, accessibility, usability of devices, internet (Wi-Fi), learning support, and inclusive learning environment [16,42,70,82].

Table 10 shows the details of KSF "Technology".

Table 10. KSF "Technology".

Construct	Variable	MM	UD
Availability of technology	Availability of multimedia devices	SQ and LQ	Low
	Internet availability on campus	SQ and LQ	Low
	Availability of e-learning system	SQ and LQ	Low
Reliability of technology	Reliability of multimedia devices	SQ and LQ	Medium
	On-campus internet reliability	SQ and LQ	Low
	Reliability of e-learning system	SQ and LQ	Medium
Accessibility of technology	Accessibility of multimedia devices	SQ and LQ	Medium
	On-campus internet accessibility	SQ and LQ	Low
	Accessibility of e-learning system	SQ and LQ	Low
Usability of technology	Usability of multimedia devices	SQ and LQ	Medium
	Campus internet usability	SQ and LQ	Low
	Usability of e-learning system	SQ and LQ	Medium

3.4. Lecturer

The lecturer is single most important actor in a successfully implementation of Active Learning. This dimension groups factors that represents their knowledge, skills, and attitude to carry out education innovation.

3.4.1. Knowledge

Knowledge is a combination of framed experience, values, and contextual information that provides an environment for evaluating and incorporating new experiences [72]. DeMonbrun et al. highlighted the relevance of experience to lecturer [49]. Therefore, lecturer should have suitable experience as faculty member and information about Active Learning.

Table 11 details the KSF "Knowledge".

Table 11. KSF "Knowledge".

Construct	Variable	MM	UD
Experience	Activity time as a lecturer	LQ	Low
	Highest academic title	LQ	Low
	Time since the highest titration	LQ	Low
Contextual information	Level of knowledge about Active Learning	LQ	High

3.4.2. Skills

Skills are the ability to use reason, thoughts, ideas, and creativity in doing, changing, or making things more meaningful so as to produce a value from the results of the work [72]. The lecturer should have skills about educational innovations in general and about Active Learning specifically. Table 12 shows this KSF in detail.

Table 12. KSF "Skills".

Construct	Variable	MM	UD
Skills about Active Learning	Amount of participation in Active Learning events	LQ	Low
	Number of books read on Active Learning	LQ	Low
	Amount of Active Learning techniques over which you have mastery	LQ	Low
Skills about educational innovations	Amount of participation in events on educational innovations	LQ	Low
	Number of books read on educational innovations	LQ	Low

3.4.3. Attitude

Attitude encompasses a very broad range of activities, including how people walk, talk, act, think, perceive, and feel [72]. Hegarty and Thompson [42] highlight the relevance of lecturer attributes and teaching methods, such as approachable, supportive, enthusiastic, and interesting delivery. Table 13 shows the following levels of this KSF.

Table 13. KSF "Attitude".

Construct	Variable	MM	UD
Willingness to adopt Active Learning techniques	Qualitative perception of disposition	EE	High
	Number of periods in which adoption was attempted	LQ	Low
	Number of subjects in which adoption was attempted	LQ	Low
	Time since last adoption attempt	LQ	Low
Demographics	Age	LQ	Low
	Current position	LQ	Low
	Study area	LQ	Low

3.5. Interactions

Placing students at the center of the learning process requires them to step out of the role of recipients of information and become active agents. The interaction between students and between them and teachers allows this transition to happen.

3.5.1. Between Students

Opportunities for students to work together and obtain peer feedback included in the learning design [42]. Chen, Bastedo, and Howard [62] emphasize that the course should provide online and face-to-face opportunities for students to collaborate with others.

Table 14 shows this KSF in detail.

Table 14. KSF "Interactions between Students".

Construct	Variable	MM	UD
Interactions in general	Quantity of work/projects carried out in group in the course	SQ	Medium
	% of the grade of the discipline from group work	SQ	Medium
Online collaboration	Number of remote meetings with other students throughout the course	SQ	Low
	Number of online presentations made by the student with assistance from other students	SQ	Low
Face-to-face collaboration	Number of face-to-face meetings with other students throughout the course	SQ	Low
	Number of face-to-face presentations made by the student with the assistance of other students	SQ	Low

3.5.2. With Lecturers

Interaction between students and lecturer supports knowledge construction, motivation, and the establishment of a social relationship [75]. Furthermore, constructive and enriching feedbacks from the lecturer lead to increasing academic success and feelings of support [42]. Table 15 details this KSF.

Table 15. KSF "Interactions with Lecturers".

Construct	Variable	MM	UD
Interactions students/professors	Number of orientation meetings throughout the course	SQ and LQ	Low
	Number of meetings to monitor projects throughout the course	SQ and LQ	Low

3.6. Measurement Scales

Most of E^{2}ALM^2 variables are related to the perception of students and teachers. They can be measured on a five-point Likert scale [83], coded as 5: strongly agree; 4: agree; 3: neither agree nor disagree; 2: disagree; and 1: strongly disagree.

The model also involves numerical variables, such as the percentage of activities that define clearly what is expected of the student or the percentage of activities in which the purpose is explained to students. For these variables, it is also possible to use a five-point scale, however with coding based on frequency or ranges, such as 5: always, 4: often, 3: occasionally, 2: rarely, and 1: never.

Finally, there are binary variables, e.g., whether assessment methods are defined in advance.

3.7. KSF Weights

In the proposed model, each dimension has a score independent of the others. Thus, there is no need to define weights for the dimensions. However, it is necessary to define the weight that each KSF has in the composition of the score within its dimension. Two approaches are possible: (i) a uniform distribution inside the dimension and (ii) a distribution according to the relative relevance, based on number of references that support each KSF. Table 16 presents KSF weights under two criteria.

Table 16. KSF Weights.

Dimension	KSF	(i) Uniform Distribution	Number of References	(ii) Relative Relevance
Content quality (references = 26)	Artifacts	0.33	11	0.42
	Student Assessment	0.33	8	0.31
	Learning Facilitation	0.33	7	0.27
Organizational environment (references = 8)	Culture	0.25	1	0.13
	Policy	0.25	2	0.25
	Student Feedback	0.25	3	0.38
	Instructional Design	0.25	2	0.25
Organizational infrastructure (references = 11)	Classrooms	0.50	6	0.55
	Technology	0.50	5	0.45
Lecturer (references =5)	Knowledge	0.33	2	0.40
	Skills	0.33	1	0.20
	Attitude	0.33	2	0.40
Interactions (references = 4)	Between students	0.50	2	0.50
	With lecturers	0.50	2	0.50

4. Discussion

As explained in the introduction, there is a lack of instruments that can help engineering schools and lecturers assess Active Learning implementations. The use of maturity models can support them in this task.

According to Bruin et al. [84], the maturity assessment can be descriptive, prescriptive, or comparative in nature. A purely descriptive model can be applied for an as-is diagnosis, with no provision for improving maturity or providing relationships with performance. A prescriptive model emphasizes the relationships between variables for final performance and indicates how to approach maturity improvement to positively affect the outcome. Therefore, it allows the development of a roadmap for improvement. A comparative model allows benchmarking across sectors or regions. Thus, it would be possible to compare similar practices between organizations to assess maturity in different sectors.

The E^{2}ALM^2 is a descriptive maturity model (according to Bruin et al.'s classification), which can be understood as the first step in a life cycle that will allow the evolution to a prescriptive model. This evolution requires more knowledge about the impact of actions and the identification of replicable actions that support the advance in the maturity level. This difficulty is especially important due to the difference in results obtained in education when different contexts and conditions are compared [43].

Although there are four other maturity models in the field of education, they have a different focus from E^2ALM^2. These models are focused on: Project-Based Learning (PBLCMM) [53], Student Engagement (SESR-MM) [54], Curriculum Design (CDMM) [55], and e-Learning [56]. In addition to the difference in focus, none of these models provide an assessment of the same requirements and with the scope of E^2ALM^2. In addition to these four models, there is an extremely simple scale, which is neither a theoretical model with scientific references nor peer-reviewed, but which has a similar objective to assess the use of Active Learning [85].

The E^2ALM^2 model allows the diagnosis of the current stage of Active Learning implementation with a focus on a course, from the objective measurement of 90 variables. For most variables, the suggested measurement method is a questionnaire for the lecturer, for the student, or for both. This choice aims to facilitate the application of the model in real cases, reducing the need for an external evaluator to observe the activities throughout the entire period to issue its report.

Obviously, collecting impressions through questionnaires introduces the possibility of bias, both for the teacher and the student. Therefore, it will be necessary to use response validation techniques when creating the questionnaires. Because of this possibility of bias, all variables had an estimated uncertainty degree. In cases where the uncertainty degree is high, the statistical validation of answers will need to be stricter. As a way to avoid possible contamination in the results due to bias, some variables are measured by questions asked to both the lecturer and the students.

The use of Active Learning has several positive effects, as explained in the introduction, but there are also some difficulties and limitations. Streveler states that Active Learning is not a solution for all instructional inadequacies [46]. The increasing workload for lecturers [52,86] and students [47], the resistance to changes [43,48–51], and the need to align curriculum and course activities [86,87] are challenges that need to be overcome in Active Learning implementations.

Furthermore, it is important to emphasize that the E^2ALM^2 model does not aim to assess the overall quality of an engineering program, but the maturity level of Active Learning implementation, which is a recommendation of the main modernization movements in the Engineering Education field around the world. Courses and schools can still be of a high quality even though they follow a more traditional approach to engineering education. The point here is that whoever wants to modernize their engineering education approach will struggle with the implementation of Active Learning as a pedagogical and cultural element, and the E^2ALM^2 can shed light for managers and lecturers during the messy times of changes, infrastructural adaptations, and resistance from students and faculty members.

As future work, we recommend: (i) defining further studies to test the scale of each variable; (ii) determining empirical testing of the weights of each KSF in their respective dimensions; (iii) testing the questionnaires to measure all variables; (iv) validation of the framework in different cultural settings, for instance with an international panel of experts; and (v) application of the framework to evaluate the maturity of real cases, which will allow qualitative and quantitative analyses.

5. Conclusions

This study proposed a framework to evaluate the maturity of adoption of Active Learning by a specific course. The variables described here can serve as a checklist to lecturers adopting Active Learning and as a metric to evaluate the comprehensiveness and quality of existing initiatives.

The proposed model is descriptive, because it allows evaluating the current situation, but it can be understood as a first step towards the construction of a prescriptive model, which can indicate good practices and replicable actions to increase the level of maturity.

E^2ALM^2 was designed so that its application is easy, centered on questionnaires for lecturers and students, without the need for long periods of external observation, which would lead to greater expenses and prevent scalability.

E^2ALM^2 allows faculty members to assess the current state of Active Learning implementations and therefore compare states before and after planned interventions with specific objectives.

Despite having the focus on a course, the diagnosis of a program or an engineering school can be made as a composition of the evaluations of the courses that comprise it, which also favors managerial actions.

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6.3 Epilogue

Engineering Education Active Learning Maturity Model – E^2ALM^2 is the first piece (1 of 2) to achieve the objective of Part II of this research. Starting with the abstract discussions about plausibility to propose a way to assess a teaching method, finishing with a maturity model divided into five dimensions, fourteen success factors and around ninety variables, originating from previous literature about engineering education and active learning.

After publication of conceptual model, E^2ALM^2 was applied in a controlled environment, but already involved five courses, from four different institutions in Brazil and Portugal. This pilot application will be the subject of a future publication, after finishing this doctoral trajectory. It generated 132 answers and was fundamental to:

- statistical validation of questionnaires, according to Cronbach Alpha (Cronbach, 1951);
- identification of difficulties for application in real cases; and
- deepening the analysis of what is important to study and inform the faculty and the institution that wants to evaluate their courses.

Main lessons learned during the E^2ALM^2 building were about research methodology and networking. As cited above, the trajectory from free debates culminated with a publication that generated a lot of pride. Most relevant aspects are detailed below.

- Literature review – manipulation of databases Scopus and Web of Science to search works about key success factors, use of important tools to process papers (MaxQDA and Mendeley) and factors consolidation in groups.
- Learning about bibliometric techniques and the use of appropriate tools for it – Bibliometrics aims primarily to analyze scientific or technical activity through quantitative study of publications. Its application allows for essential questions to be addressed in the initial survey of a scientific field, such as "what are the primary sources," "who are the leading authors," or "which authors tend to collaborate on publications". Main tools are Bibliometrix and VOSViewer, and they are detailed in the chapter 8.
- Presentation on important conference (PAEE/ALE 2021) – previous analysis of other authors, selection of most relevant authors to stimulate an approach, finished with following private presentation to selected and very important researchers; and
- Submission to an important journal – more knowledge about revision process, development of capacity of elaborate a cover letter addressing main

revisors' comments, concluding with the first submission accepted in international journal.

Despite pride and very relevant lessons learned, there are negative points too. The model firstly has limitations intrinsic to the proposal of a maturity model, in any environment. In designing the conceptual model, critical success factors were raised from existing literature. However, it is possible that some other factor is relevant to the outcome of implementing active learning but has not been previously mapped. Furthermore, it is not possible to guarantee that the survey was completely unbiased.

In addition to the limitations already mentioned, there are others related to sample size. The model was tested with five courses, but still lacks quantitative studies to guarantee the quality of the tools applied.

Finally, as the next step in a maturity model, it is desirable for the E^2ALM^2 to move from descriptive to prescriptive. New studies can support this upgrade, when generate body of knowledge about the active learning implementations and good practices in educational institutions, after applying the model. This can be designed as a practical guide for the educational institution to improve its indicators in the model.

7. Lecturer self-awareness index (LSAI)

7.1 Prologue

After applying E^2ALM^2 to the pilot sample, the research leaned towards some aspects presented a divergence between students' and lecturers' perceptions about the same course. Then, the concept of Lecturer Self-Awareness Index (LSAI) was born to try measuring that distance of perceptions. The LSAI design was presented at the PAEE/ALE 2022 international conference (Arruda & Silva, 2022).

Since the E^2ALM^2 application uses questionnaires applied to course professor and their students, LSAI appears as a complement to measure the discrepancy between the lecturer's and the student's perception. This index allows a lecturer to identify items where their perception differs from that of the students and if there is a bias in their analysis. This tool can help improve decisions in course preparation and lead to better service.

In the last quarter of 2022, the paper about LSAI proposal was submitted to European Journal of Engineering Education – EJEE. After few weeks, this submission was rejected, but brought several suggestions that may improve quality of this work. EJEE's refusal mentioned new needs for in-depth quantitative analyses, which requires new data collection. Although submission has been rejected, editors recognized merit in the work and opened the chance to re-submit addressing principal concerns identified. To achieve this, there is a need to develop new partners and carry out new applications of the model, with the aim of increasing the database collected and allowing more robust quantitative studies.

7.2 Full text

This is the manuscript exactly how it has been submitted to European Journal of Engineering Education (EJEE).

Lecturer Self-Awareness Index: measuring the alignment between lecturer and student perception

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Abstract

The widespread use of Active Learning techniques transformed Engineering Education in the last decades. To assess how these techniques have been used, the "Engineering Education Active Learning Maturity Model (E^2ALM^2)" (Arruda & Silva, 2021) emerged. This framework collects data from questionnaires answered by students and lecturers. However, divergencies between the two may compromise the improvement plan if lecturers' self-awareness is problematic. To diagnose these divergences, this work presents the Lecturer Self-Awareness Index (LSAI) as a complement to the E^2ALM^2. The index identifies whether the lecturer's assessment is biased (more severe or lighter than the students'). This work presents the mathematical formulation, interpretation, and classification of the LSAI and the application of a pilot study to validate the index statistically. The results confirmed the validity of the index and enabled a critical analysis of the cases. Improving lecturer self-awareness is important for effective change and LSAI can contribute to the continuous improvement of a course.

Keywords: Active Learning; self-awareness; student perception; assessment

1 Introduction

One of the great challenges of higher education in the 21st century is to adapt traditional teaching techniques to the reality of today's students, who have different characteristics from previous generations (Hartikainen, Rintala, Pylväs, & Nokelainen, 2019). Student-centered techniques increase student engagement, which is linked to teaching effectiveness. The positive results have already been widely explored (Burke & Fedorek, 2017; Cho, Mazze, Dika, & Gehrig, 2015; Prince, 2004).

Self-awareness is positively associated with transformational leadership (Titrek & Çelik, 2011), leadership performance and success (Axelrod, 2012; Caldwell & Hayes, 2016; Showry & Manasa, 2014; Whetten & Cameron, 2016). It leads to better decision making, once it connects the past and present experience (Kamenov, 2013), and supports effective learning, because the more students know their 'self', the better they can serve their clients and increase their own personal developments (Murphy, 2007). Furthermore, self-awareness increases sympathy (Boyer, 2010; Gair, 2011; Smith, 2011), reduces egocentrism (Gendolla & Wicklund, 2009; Scaffidi Abbate, Boca, & Gendolla, 2016), and is perceived as central to improving management skills (Whetten & Cameron, 2016).

Engineering Schools eager to modernize educational practices need to understand their current maturity of Active Learning, which can be the first step of a renovation program. The framework Engineering Education Active Learning Maturity Model - E^2ALM^2 (Arruda & Silva, 2021) may be used to this measurement. This framework processes data collected from students and lecturers of a course to depict the current maturity level of the Active Learning implementation in terms of five dimensions, composed of 14 key success factors (KSF) that summarize 41 constructs.

Regardless of the specific maturity level in active learning implementation, the perceptions of students and lecturers can be quite misaligned, due to the natural difference in points of view. The aim of the Lecturer Self-Awareness Index (LSAI) is to depict these possible discrepancies and provide the decision-making process with feedback between how lecturers and students perceive the benefits and characteristics of a given active learning implementation.

In this article, the concept of self-awareness is emphasized, bringing some definitions, motivations, and limitations. Additionally, the concept of Active Learning is presented, followed by E^2ALM^2

details. Then, LSAI is defined and detailed. Finally, the conclusion shows some discussions about the advantages and limitations of the index.

2 Background

Traditional expositive lectures cannot be the only way to teach students anymore. Students need to learn not be taught and traditional lectures is a passive form of teaching. More active learning methodologies are needed. Nevertheless, despite the vast literature available on Active Learning, there is still no consensus definition on the topic. Hartikainen (Hartikainen et al., 2019) shows 66 definitions grouped by three main categories: (1) defined and viewed as an instructional approach; (2) not defined but viewed as an instructional approach; and (3) not defined but viewed as a learning approach. Here, three popular definitions are highlighted: “any instructional method [used in the classroom] that engages students in the learning process” (Prince, 2004), “an umbrella term for pedagogies focusing on student activity and student engagement in the learning process” (Roehl, Reddy, & Shannon, 2013) and “an umbrella term that now refers to several models of instruction, including cooperative and collaborative learning, discovery learning, experiential learning, problem-based learning, and inquiry-based learning” (Barkley, 2010).

In spite of the definitions, they all agree in one point: an active learning methodology is student-centered and must engage and responsible students for their own learning. However, this shift demands a change and some movements that promote this change. In the Engineering Education field, it is possible to identify several movements with the objective of modernizing programs and teaching process, such as the CDIO initiative (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014), the change in ABET's accreditation criteria (called EC2000) (Lattuca, Terenzini, & Volkwein, 2006), and the greenfield creation of engineering colleges with proposals totally different from the traditional 20th Century model, such as Olin College (Goldberg & Somerville, 2014) and Aalborg University (Mohd-yusof, Arsat, Borhan, Graaff, & Kolmos, 2013). The common point among these modernization movements is indeed the recommendation to place the student at the center of the learning process, which drives the increasing use of active learning techniques (Hartikainen et al., 2019). However, are active learning methodologies the best for all students? The trend is to answer positively but students have different learning styles.

Learning styles characterizes the way students learn. Each one learns in a different and unique way. Finding an instructional strategy that works for each student's learning style is a challenging assignment for lecturers. According to Felder and Silverman (Felder & Silverman, 1988) there are 32 learning styles, attending to the basic dimensions: sensory/intuitive, visual/auditory, inductive/deductive, active/reflective and sequential/global. Knowing that, lecturers could, at least, provide conditions for all students to effectively learn, for example, by diversifying their instructional methods (A. C. Alves, Fernandes, & Uebe-Mansur, 2021) or adopting teaching techniques that address the best way the learning styles (Felder & Silverman, 1988).

According to some authors (Dunn & Carbo, 1981; Felder & Silverman, 1988) engineering field is a field where students are more likely to be active then reflective learners. This could be one of the reasons for all interest in having active instructional methods in engineering that drives many lecturers to include it. Some examples could be founded in many publications (Guerra, 2014; Guerra, Ulseth, & Kolmos, 2017; Lantada et al., 2013; Pereira & Barreto, 2016; Sousa, Moreira, & Alves, 2013). Matching learning styles with instructional methods will increase student performance (Felder & Silverman, 1988), or at least, increase their motivation, as is the case in Alves et al. (A.C. Alves et al., 2018).

Motivation is also related with self-awareness. According to Flavian (Flavian, 2016) psychologists and educators usually use the concept of self-awareness to describe the student ability to think about, talk about, and define feelings, thoughts and/or actions.

Nevertheless, the term self-awareness is widely used in practitioner and scientific publications, the exact meaning of the term is still unclear (Carden, Jones, & Passmore, 2022). The literature brings several definitions of self-awareness (Nutt Williams, 2008; Sutton, 2016; Sutton, Williams, & Allinson, 2015), but confusion between the concepts of self-awareness, self-knowledge and self-consciousness is common (Morin, 2017; Sutton, 2016). Also, definitions seem to depend on focus and context (Sutton, 2016).

Goleman (1995) defines self-awareness as "knowing one's internal states, preferences, resources, and intuitions". There are statements that self-awareness refers to the constant consciousness of feelings, thoughts and behaviors (Harrington & Loffredo, 2010; Nutt Williams & Fauth, 2005) and how someone's behaviors impact other individuals (Mayer, Salovey, & Caruso, 2004).

In their systematic literature review, Carden et al. (2022) offer the following definition:

> "Self-awareness consists of a range of components, which can be developed through focus, evaluation and feedback, and provides an individual with an awareness of their internal state (emotions, cognitions, physiological responses), that drives their behaviors (beliefs, values and motivations) and an awareness of how this impacts and influences others."

However, self-awareness is a difficult journey. Practicing it may feel risky and frightening for some students, and its development requires a safe learning environment (Feize & Faver, 2019). In the process of developing self-awareness, a person might find discrepancies between the real self and the ideal self (Gallwey, 2001; Silvia & Duval, 2001). At the same time, when a student is motivated and self-confident, he/she will be able to reflect in the learning process and growth in this process. Thus, attending to this benefit for students is important to provide the conditions for this self-awareness and to measure it.

Finally, Govern and Marsch (2001) discuss the manipulation and measurement of levels of situational self-focus. Titrek and Celik (2011) analyses the Self-Awareness Competence Scale and Demerouti et al. (2011) state that a high level of self-awareness could be considered as a high consistency between self-evaluation and other evaluations.

From the consensus on the importance of using Active Learning techniques, there are different levels of maturity in this subject. At one extreme, it is possible to observe isolated actions of lecturers who experience a change in a course. At the other extreme, there are programs designed as project-based, with materials and assessment methods aligned, in addition to adequate infrastructure for classes in formats different from the traditional model, in which students attend the class in rows watching a lecturer in front of the classroom.

3 Engineering Education Active Learning Maturity Model (E^2ALM^2) framework

The Engineering Education Active Learning Maturity Model - E^2ALM^2 (Arruda & Silva, 2021) has the purpose of diagnosing the maturity level of the implementation of active learning in a course. This diagnosis is divided into five dimensions, which are divided into fourteen key success factors (KSF). Once each KSF is composed of one or more constructs, there are 41 constructs in total. For each construct, some variables will be used for its measurement, which totals 89. Table 1 below shows the composition of E^2ALM^2 in its four levels, with a breakdown of the first two levels.

Table 1 - E^2ALM^2 components

Dimension	KSF	Constructs (Qty)	Variables (Qty)
Content quality	Course Activities	8	13
	Student Assessment	3	7
	Learning Facilitation	2	6
Organizational environment	Culture	5	8
	Policy	2	6
	Student feedback	3	6

	Instructional design	2	2
Organizational infrastructure	Classrooms	2	6
	Technology	4	12
Lecturer	Knowledge	2	4
	Skills	2	5
	Attitude	2	7
Interactions	Between students	3	6
	With lecturers	1	1

3.1 E^2ALM^2 application

From questionnaires applied to the students and the faculty responsible for the course, the variables receive numerical values, and the evaluation is carried out in the five dimensions of the model. Each dimension is represented on an axis, as shown in Figure 1. The score for each dimension can range from 1 (lowest maturity level) to 5 (highest maturity level).

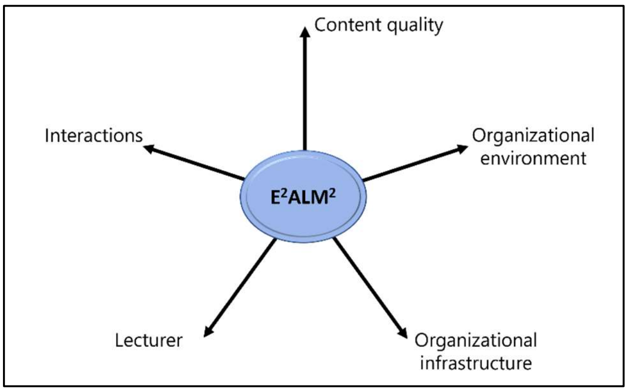

Figure 1 - E^2ALM^2 representation

When applying the E^2ALM^2 framework to a course, the result can be displayed as a radar graph. Next, Figure 2 shows the result of an example course, and the average and maximum obtained in other similar courses that were evaluated together.

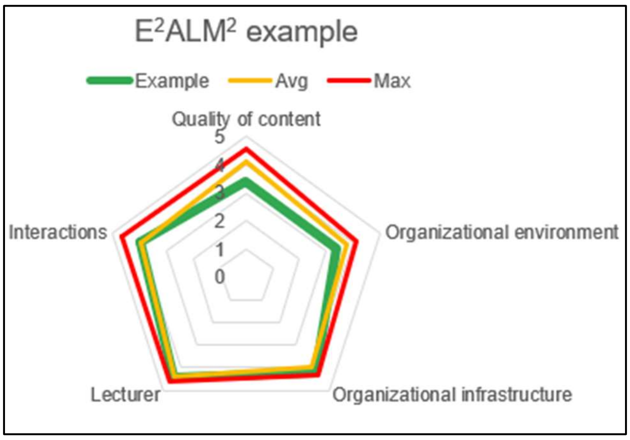

Figure 2 - E^{2}ALM^2 example

From the identification of the strengths and weaknesses of each course in the critical factors for a good implementation of active learning, the institution can promote actions that aim to improve the indicators, focusing efforts on bottlenecks.

3.2 Questionnaires and evaluation

To apply the model to real cases, two questionnaires are used: Student Questionnaire (SQ) and Lecturer Questionnaire (LQ). Figure 3 shows the E^{2}ALM^2 structure and those questionnaires. At the lowest level of E^{2}ALM^2 framework, each variable has a grade.

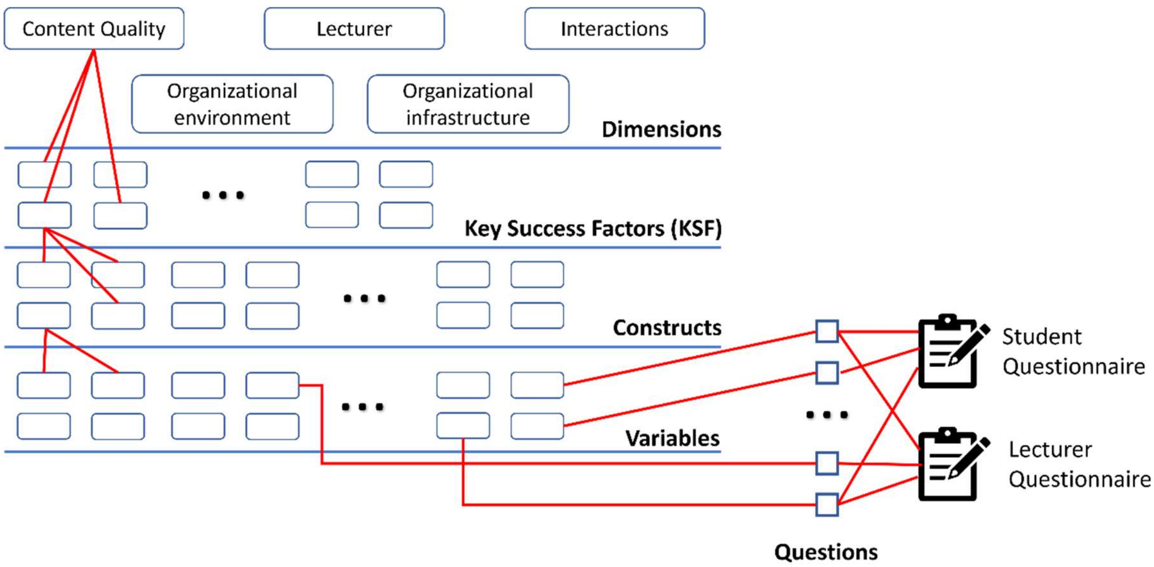

Figure 3 - E^{2}ALM^2 structure and questionnaires

The questions posed in the two questionnaires follow the Likert scale of 5 points (Likert, 1932). From the students' and lecturers' responses, there is a conversion from the textual response to numerical values. Just as an example, two questions are shown: “In this course, ________________________ real-life problems were used” and “In this course, __________ students developed practical activities”. In these questions, Table 2 shows the available answer options and their associated numeric values.

Table 2 - Likert scale values

Textual response	**Numeric value**
Always	5
Often	4
Sometimes	3
Rarely	2
Never	1

In SQ, the score for each question is calculated as the average of all students' responses. In LQ, the question score is just the lecturer's answer, as it is unique.

Each question in the questionnaires is linked to a variable, and based on the result obtained in this question, a value is assigned (Question value). Figure 4 shows the condition to calculate this value. From the Question Value of all questions, the score for the linked variable is calculated. The construct score is the average of the variables that compose it. The KSF score is the average of the constructs that compose it.

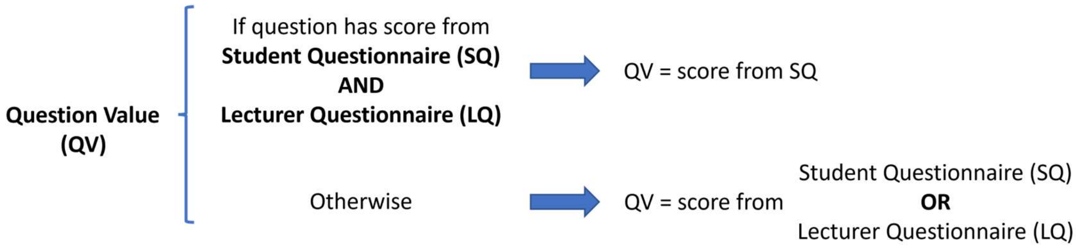

Figure 4 - Question value condition

Then, to calculate the dimension score, the grades of the KSF that compose it and the weights are used, calculated from the application of the Analytical Hierarchy Process – AHP method (Saaty, 2008), with answers from paired comparisons of importance between the KSFs that make up the evaluated dimension. These answers were provided by Active Learning experts consulted specifically for this purpose. Figure 5 shows the process to calculate the dimension score.

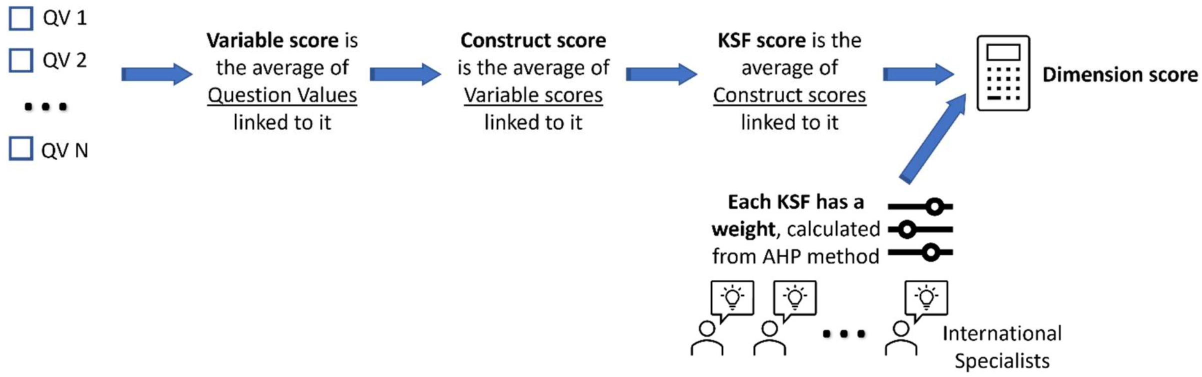

Figure 5 - Dimension score process

4 Lecturer Self-Awareness Index (LSAI)

By using a maturity model to evaluate the implementation of Active Learning in a course, there is the possibility of diagnosing opportunities for improvement. However, there is a risk of divergence between the perceptions of the lecturer and the students in relation to the service provided. If this divergence is very large, the lecturer's actions in an attempt to improve the conditions of the course can be concentrated outside the focus where students most perceive the need. Therefore, it is important to assess whether these perceptions are aligned. Hence, the concept of self-awareness gains importance.

Due to this fact, the Lecturer Self-Awareness Index (LSAI) was created as a way of identifying the discrepancy between the two points of view. Figure 6 shows the E^2ALM^2 framework and its KSFs that make up the LSAI.

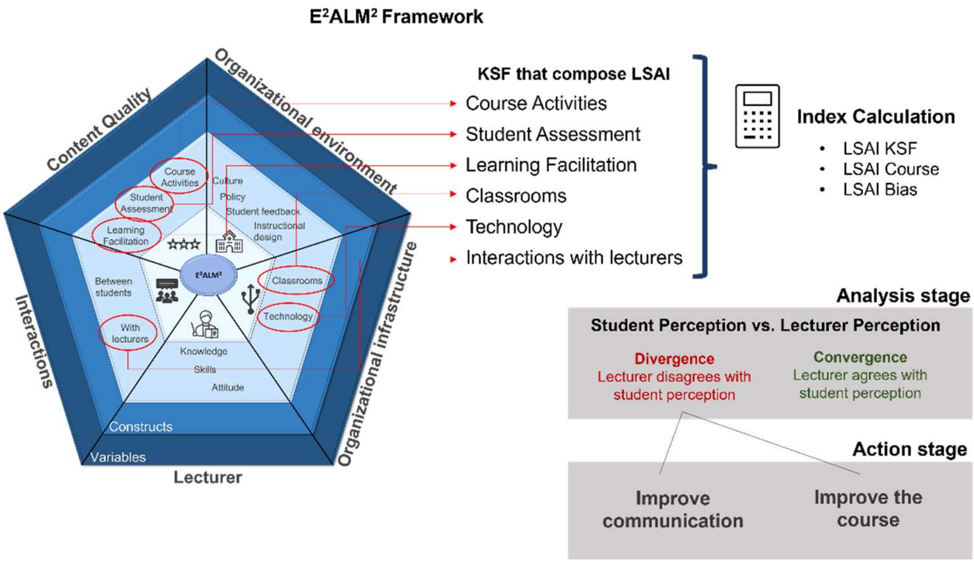

Figure 6 - E^2ALM^2 framework and LSAI process

Due to its nature, LSAI can only be calculated from KSF that have both student and lecturer measurements. It is calculated from the difference of each question in the Student Questionnaire and in the Lecturer Questionnaire. The maximum value indicates that the lecturer's perception is fully aligned with the students' perception, while the minimum value indicates the total misalignment between the two perceptions.

The process to evaluate and use properly LSAI values is presented as follows:

1. E^2ALM^2 stage – from the model application, each KSF that compose LSAI has values of LQ and SQ.
2. LSAI Analysis stage
    a. LSAI KSF – From values of LQ and SQ of each KSF, the index is calculated;

b. LSAI Course – every LSAI KSF are associated into a single indicator;
c. LSAI Bias – this indicator allows to perceive whether lecturer perception has bias to be more or less critical than the students.

3. Action stage – Based on the interpretation of the results of the three indicators, actions can be proposed, with the aim of improving communication with students or the quality of the course itself.

The following subsections will detail: the composition of the LSAI, the calculation of the index and the bias indicator, as well as how the result can be interpreted.

4.1 LSAI composition

The constructs that compose the LSAI calculation (those that have scores in both the SQ and the LQ) are shown in the Table 3.

Table 3 - LSAI constructs and Key Success Factors

Construct	Key Success Factor	Dimension
Use of real-life problems	Course Activities	Content Quality
Application of active experiments	Course Activities	Content Quality
Variety of instructional resources	Course Activities	Content Quality
Adequacy to Learning Outcomes (LO)	Course Activities	Content Quality
Clearness of assessment methods	Student Assessment	Content Quality
Clearness of criteria for success	Student Assessment	Content Quality
Communications with students	Student Assessment	Content Quality
Preparation of students to conduct activities required	Learning Facilitation	Content Quality
Classrooms designed for improve active learning experience	Classrooms	Organizational infrastructure

Classrooms equipped with technologies to enhance student learning and support teaching innovation	Classrooms	Organizational infrastructure
Availability of technology	Technology	Organizational infrastructure
Accessibility of technology	Technology	Organizational infrastructure
Usability of technology	Technology	Organizational infrastructure
Interactions students/lecturers	Interactions with lecturers	Interactions

As shown in the Table 3, LSAI is calculated from just six KSF: Course Activities, Student Assessment, Learning Facilitation, Classrooms, Technology e Interactions with lecturers.

According to the authors, those six factors have following specifications:

- Course Activities (problems, projects or cases studied) should: engage students with real-life problems and active experiences; provide students with a variety of additional instructional resources, such as simulations, case studies, videos, and demonstrations; be suitable to achieve different targets including the support of the students' learning process and establishing learning outcomes requirements; be clearly written, in the right length, useful, flexible, and provide appropriate degree of breath; have suitable intellectual challenge; and begin with an explanation of its purpose.
- Student Assessment needs to be clear, concise, and consistent. This involves instructions, assignments, assessments, due dates, course pages, and office hours. Furthermore, criteria for success must be communicated clearly and monitored.

- Learning facilitation includes the preparation of students to conduct activities and tasks required in addition to activities related to the facilitator guiding the learning process of the students. It also involves providing students with regular opportunities for formative feedback from the lecturer.
- Classrooms should be designed to improve Active Learning experience and be equipped with technologies that can enhance student learning and support teaching innovation.
- Technology involves availability, reliability, accessibility, usability of devices, internet (Wi-Fi), learning support, and inclusive learning environment.
- Interaction between students and lecturer supports knowledge construction, motivation, and the establishment of a social relationship. Furthermore, constructive and enriching feedbacks from the lecturer lead to increasing academic success and feelings of support.

As can be seen in the specifications above, in addition to the nature of the LSAI, all the KSFs that make up this indicator have the potential for different perceptions by the lecturer and the students. However, the capacity to trigger actions to improve the course (and the conditions that surround it) is much more concentrated on the lecturer than on the students, because although the lecturer acts as a facilitator and co-constructor of learning, he has a role in the organization structure. This way, it is possible to identify students as clients of the service provided by the organization and it is essential that there is a way to assess how much the lecturer's perception is in fact aligned with the perception of clients (students) in relation to this service.

4.2 LSAI interpretation

The application of E^2ALM^2 allows the diagnosis of a course in the five dimensions that make up the index, as already discussed. LSAI is composed of a subset of E^2ALM^2 key success factors. For each KSF, lecturer and student perceptions may converge or diverge. Possible combinations are shown in the Figure 7.

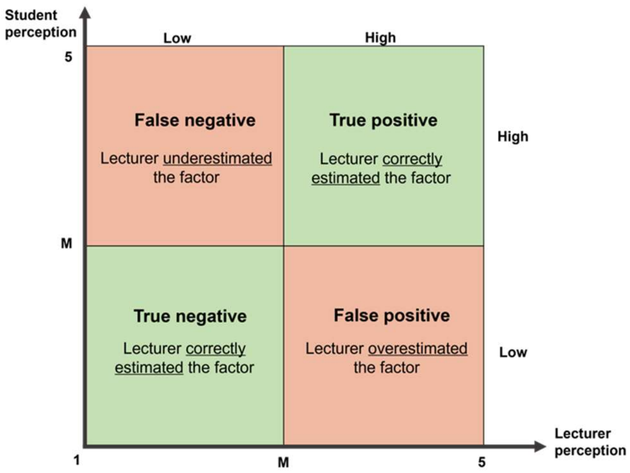

Figure 7 - Student and lecturer perceptions

The dividing line on each axis is positioned at the median (M) of all responses. From the answers to the questionnaires, the LSAI in its six KSF is also calculated. The line $LSAI_{max}$ is the bisector of the quadrant shown in the **Erro! Fonte de referência não encontrada.**.

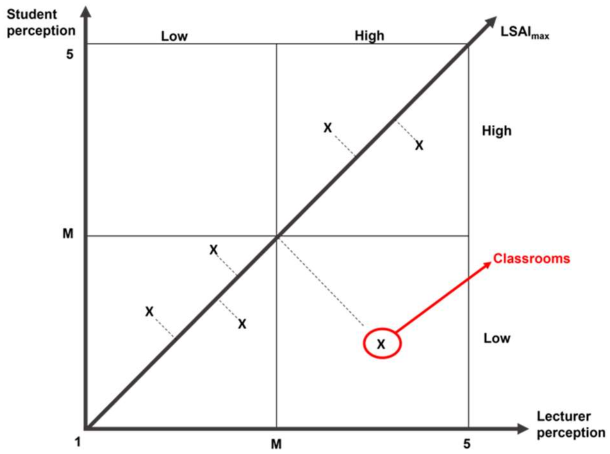

Figure 8 - LSAI example

Analyzing the example shown in **Erro! Fonte de referência não encontrada.**, it is possible to identify that the KSF in which perceptions are most discrepant is "Classrooms". This KSF is a component of the dimension "Organizational infrastructure", which had the lowest grade between five dimensions of E^2ALM^2 (according to results shown in Figure 9).

Figure 9 - Example of E^2ALM^2 real application

Then, while this dimension is possibly a course weakness, the lecturer's and students' perception are misaligned. This way, any effective improvement action could be hampered.

Looking at this example, two variables of KSF "Classrooms" are showed: (i) % of activities performed in an environment suitable for Active Learning and (ii) % of activities performed in a technologically appropriate environment. So, if the lecturer is not concerned with finding more suitable physical spaces for the activities of the course, this indicator will hardly improve. Thus, students' perception of quality will remain compromised. Here, it is important to remember that self-awareness as considered as central to improving management skills (Whetten & Cameron, 2016).

4.3 LSAI definition and classification

In the LQ *versus* SQ chart, the $LSAI_{max}$ line indicates the greatest possible convergence between the assessments. For each factor, the further away from the $LSAI_{max}$ line, the greater the divergence between the lecturer's and the students' perception. The maximum length of each axis is 4, since the coordinate on each axis can vary from 1 to 5. Therefore, the maximum distance from any point on the graph to the line $LSAI_{max}$ is $2\sqrt{2}$. This way, the normalized LSAI of each KSF_i is calculated by:

$$\mathrm{LSAI}_{\mathrm{KSF}_i} = \frac{2\sqrt{2} - D_i}{2\sqrt{2}}$$

where D_i is the distance from KSF_i to the line $LSAI_{max}$.

Thus, in a normalized way, the LSAI can vary from 0 to 1, where higher values indicate that the lecturer's perception is more convergent with the students' perception.

Looking at the course broadly, the course LSAI is calculated by:

$$\mathrm{LSAI}_{\mathrm{course}} = \frac{\sum_{i=1}^{6} \mathrm{LSAI}_{\mathrm{KSFi}}}{6}$$

Table 4 shows the proposed classification based on normalized LSAI value.

Table 4 - LSAI classification

Normalized LSAI value	LSAI Classification
$0.9 < \mathrm{LSAI} \leq 1.0$	Excellent
$0.8 < \mathrm{LSAI} \leq 0.9$	Very good
$0.6 < \mathrm{LSAI} \leq 0.8$	Good
$0.4 < \mathrm{LSAI} \leq 0.6$	Fair
$0 \leq \mathrm{LSAI} \leq 0.4$	Poor

4.4 Bias

The LSAI indicates the alignment between the lecturer's and the students' perceptions, from the distance of points in the LQ *versus* SQ chart to the LSAI_{max} line, as described in the previous section. In addition to this analysis, it is important to identify whether there is any bias in the lecturer's perception. That is, if the lecturer has any tendency to be more or less critical than the students in relation to some factor.

The first step in identifying the possible bias is the determination of the "center of mass" (MC) of the points in the LQ *versus* SQ chart, according to the equations:

$$\mathrm{LQ}_{MC} = \frac{\sum_{i=1}^{6} \mathrm{LQ}_{\mathrm{KSFi}}}{6} \text{ and } \mathrm{SQ}_{MC} = \frac{\sum_{i=1}^{6} \mathrm{SQ}_{\mathrm{KSFi}}}{6}$$

If the lecturer tends to be more critical than the students, $\mathrm{LQ}_{MC} < \mathrm{SQ}_{MC}$. So, the MC will be positioned above the $\mathrm{LSAI}_{\max}$ line. Likewise, if the lecturer tends to be less critical than the students, $\mathrm{LQ}_{MC} > \mathrm{SQ}_{MC}$. So, the MC will be positioned below the $\mathrm{LSAI}_{\max}$ line.

The greatest possible difference between the lecturer's and the students' perception is 4, obtained when one side evaluates the factor with the maximum score (5), and the other side evaluates it with the minimum score (1). From the MC positioning, the normalized LSAI_Bias indicator is calculated by:

$$\mathrm{LSAI\_Bias} = \frac{\mathrm{LQ}_{MC} - \mathrm{SQ}_{MC}}{4}$$

As the indicator is normalized, the interpretation is according to the Table 5:

Table 5 - Bias Interpretation

Normalized LSAI_Bias	**Interpretation**
$1 \geq \mathrm{LSAI\_Bias} > 0$	Lecturer has a better evaluation of the course than the students (less critical lecturer)
$\mathrm{LSAI\_Bias} = 0$	No bias
$0 > \mathrm{LSAI\_Bias} \geq -1$	Lecturer has a worse evaluation of the course than the students (more critical lecturer)

5 Case study

To validate the questionnaires and allow qualitative analysis, the E^2ALM^2 was applied to 5 courses, listed below:

- Introduction to Engineering Project 2 (Brazil) – 83 respondents out of a total of 99 students
- Planning, Management and Evaluation of Social Projects (Portugal) – 9 respondents out of a total of 15 students

- Product Design (Brazil) – 14 respondents out of a total of 29 students
- Production Systems Organization I (Portugal) – 9 respondents out of a total of 67 students
- Time and Motion Study (Brazil) – 17 respondents out of a total of 22 students

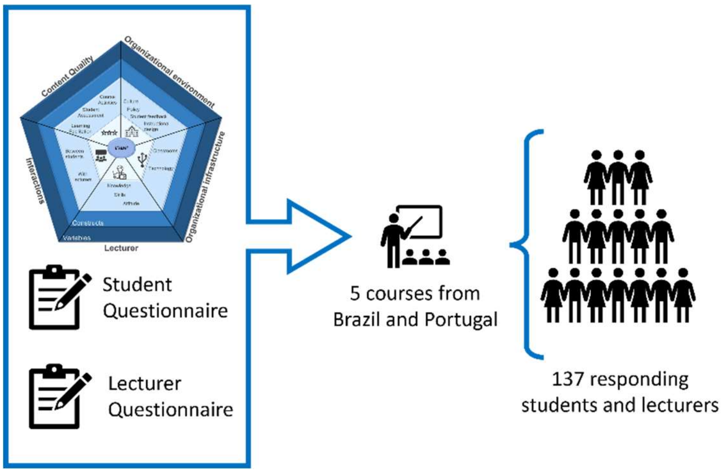

Figure 10 - E^2ALM^2 application in Brazil and Portugal

5.1 Description of courses studied

5.1.1 Introduction to Engineering Project 2 (IEP 2)

The Introduction to Engineering Project 2 (IEP 2) course is offered in the 4th semester of the undergraduate engineering course of a university of excellence in Brazil, considered one of the top 3 engineering schools in the country, and is carried out by students who will graduate in different specialties later (such as Mechanical or Civil Engineering, for example). The main purpose of the course is to offer a technological challenge of project development, viable for 4th semester students to exercise different knowledge simultaneously. Among the knowledge worked with students are agile project management and business modeling methods. In addition, attitudes and skills related to teamwork and oral expression are worked on and the challenges offered come from military organizations or the defense industry.

5.1.2 Planning, Management and Evaluation of Social Projects (PMESP)

Planning, Management and Evaluation of Social Projects (PMESP) is a curricular unit from the 2^{nd} year of the Social Education degree programme, at one of the most important universities in Portugal. This curricular unit aims to develop student competences in the field of project management applied to social projects. At the end of this curricular unit, students are expected to be able to: understand the basic concepts of the methodology of project design; develop competences of analysis of the information for designing and implementation social projects; identify and describe the phases of the project planning and implementation; define criteria and apply techniques for the evaluation of a social project; apply knowledge through the development of a group project; develop transversal skills such as teamwork, collaboration, problem solving, creativity, time management, decision-making, critical thinking, amongst others. The teaching and learning approaches used in this curricular unit are Project-based learning (PBL) and Service Learning (SL), where students develop an interdisciplinary project, in interaction with a social partner, to solve a specific need or problem identified in the local community (Abelha & Fernandes, 2021; Abelha, Fernandes, Miguel, & Sousa, 2020; Fernandes, Abelha, Albuquerque, & Sousa, 2020; Fernandes, Abelha, Fernandes, & Albuquerque, 2018). Student assessment has a strong component of formative assessment, provided by regular feedback and several milestones and deliverables throughout the project (oral presentations, project report, team Padlet, individual portfolio, etc.).

5.1.3 Product Design (PD)

The Product Design course, carried out by one of top three Brazilian universities, is offered in the 5th semester of the graduation in production engineering. The objective of this course is to allow the student to learn how to develop a hands-on startup, developing and testing a business idea throughout the course through a practical project with weekly deliveries. In the analyzed period, all projects were required to address the NFT market. Weekly, students present their work and receive feedback from lecturers. The lectures are recorded and must be watched prior to the synchronous meetings.

5.1.4 Production Systems Organization I (PSOI)

Production Systems Organization I (PSOI) is a course of the third year, first semester in one of the two main engineering schools in Portugal. Mainly, it explores Lean Production Systems and Lean Thinking principles. The purpose is to provide a methodology for the students to design production systems, particularly, production lines and/or cells with focus in reducing wastes. Then, the detailed contents include production families formation following Group Technology and clustering methods, balancing methods and operation modes, standard work, layout methods among others (Alves, 2018; Alves et al., 2015; Alves, 2007). In this course is promoted the active learning methodology of hands-on activities with a role-playing of the students´ team assembling a product chosen by them in a production line or cell, also designed by the team. Detailed activities developed by the team could be found here (Anabela C. Alves, 2020; Anabela C. Alves & Soares, 2020; Soares & Alves, 2021b, 2021a).

5.1.5 Time and Motion Study (TMS)

The Time and Motion Study course, carried out by the same university of PD, is offered in the 3rd semester of the graduation in production engineering. The objective of this course is to teach the basic techniques of time and motion study together with concepts from the Theory of Constraints. In the course, students need to choose an organization and act as consultants, studying the productive capabilities and work processes (production or marketing/sales), identifying restrictions, and suggesting improvements. Each group presents the progress made weekly and discusses with the lecturer. In addition, the exhibition contents are presented live.

It should be noted that the PMESP course is part of the Social Education Program at a Portuguese university, and not of an Engineering program. However, the course deals with topics related to the field of Engineering and allows analyzing the application of the E^2ALM^2 framework in other fields.

5.2 E^2ALM^2 Statistical Validation

For statistical validation of the questionnaires, Cronbach's Alpha was used (Cronbach, 1951). According to Sekaran & Bougie (2016), this is "the most popular test of interitem consistency reliability". Taber (2018) highlighted the wide use of this coefficient in "most widely considered to be high-status research journals and which routinely included reports of empirical work across science education".

There are several tables for classifying the values found in Cronbach's Alpha. Taber (2018) qualitatively describes the ranges used in papers in leading science education journals. In a simplified way, values above 0.70 are considered high and sufficient. Values above 0.90 are considered excellent.

The results found were 0.94 for the SQ and 0.79 for the LQ. Analyzing only the subset of the questionnaires with the questions that are used to calculate the LSAI, the Cronbach's Alpha obtained was 0.79. These results allow us to positively evaluate the quality of the questionnaires applied in E^2ALM^2. Figure 11 shows how the values obtained from Cronbach's Alpha are positioned in the acceptance regions. This way, it is possible to conclude that questionnaires are suitable to use.

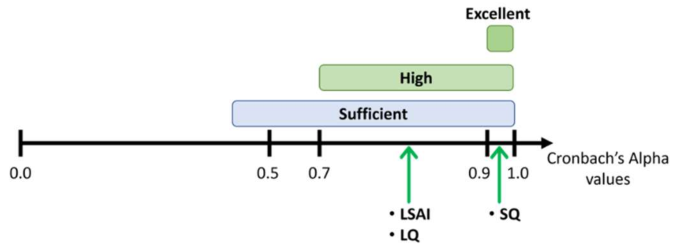

Figure 11 - Cronbach's Alpha classification

5.3 Results and discussions

5.3.1 1st stage – E^2ALM^2 results

This E^2ALM^2 application had a total of 137 respondents (132 students and 5 lecturers). The median of all responses obtained in this application was 4. Thus, this will be the value used to divide the axes into low and high areas.

Table 6 shows the results obtained in the application of E^2ALM^2 in the 5 courses studied, for all the key success factors that make up the LSAI. Figure 12 shows the location of these results on LQ *versus* SQ chart.

Table 6 – Values of LQ and SQ of KSF that compose LSAI

	IEP 2		PD		PMESP		PSOI		TMS	
	LQ	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**
Course Activities	4,400	3,293	4,400	3,780	4,800	4,349	4,600	3,865	4,400	4,072
Student Assessment	5,000	3,735	4,250	4,418	4,750	4,762	3,750	4,651	4,250	4,580
Learning Facilitation	4,000	3,263	3,000	3,900	4,000	4,489	4,500	4,000	4,000	4,259
Int. with lecturers	5,000	4,217	5,000	4,143	5,000	5,000	5,000	3,333	5,000	4,294
Classrooms	4,333	3,271	4,500	3,679	2,333	4,167	2,833	3,667	4,500	3,765
Technology	4,500	4,369	4,417	4,262	3,167	4,593	4,083	4,667	4,250	4,392

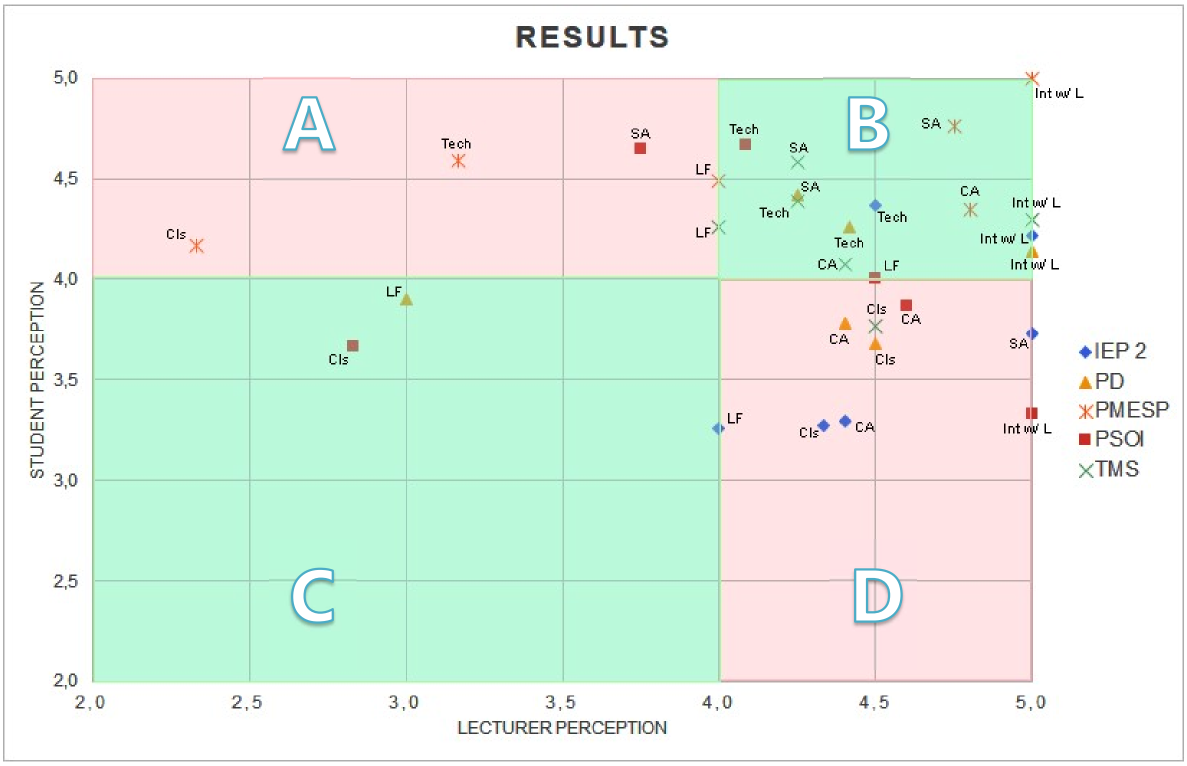

Figure 12 - Results of E^2ALM^2 real application chart

There is a total of 30 points marked on the chart as there are 5 courses, each course with 6 KSF plotted. There are 16 points in the True Positive (B) region (53.3%), 2 points in the True Negative (C) region (6.7%), 9 points in the False Positive (D) region (30%) and 3 points in the False Negative

(A) region (10 %). In other words, 40% of the results show a high discrepancy between the perceptions of students and lecturer.

In regions of high divergence, there is a much higher concentration of cases in which the lecturer's evaluation is higher than that of the students (False Positive – 9 occurrences) than the reverse (False Negative – 3 occurrences).

There are 18 points (60%) in which the lecturer's evaluation is greater than or equal to that of the students and 22 points (73.3%) in which the lecturers' evaluation is above the median (value 4.0), which are indications that there is (in this sample) an inclination of the professors to have a good perception about the courses, which is not always confirmed by the students.

On the other hand, analyzing only the grades given by the lecturers (LQ), the results are $\mu_{LQ} = 4,267$ and $\sigma_{LQ} = 0,677$, and analyzing only the grades of the students (SQ), they are $\mu_{SQ} = 4,108$ and $\sigma_{SQ} = 0,469$. Within the range $[\mu-\sigma, \mu+\sigma]$ of each group of grades, there are 20 items in the LQ group and 17 items in the SQ group. With close mean values and similar behavior in the distribution, there are apparently no indications that either of the two groups was much more critical or much less critical than the other.

5.3.2 2nd stage – LSAI calculation and analysis

Table 7 shows distance values from each point on LQ *versus* SQ chart to the line $LSAI_{max}$.

Table 7 - Distance results

Distance to $LSAI_{max}$	**IEP2**	**PD**	**PMESP**	**PSOI**	**TMS**
Course Activities	0,783	0,439	0,319	0,519	0,232
Student Assessment	0,895	0,119	0,008	0,637	0,233
Learning Facilitation	0,521	0,636	0,346	0,354	0,183
Int. with lecturers	0,554	0,606	0,000	1,179	0,499
Classrooms	0,751	0,581	1,296	0,589	0,520
Technology	0,092	0,109	1,008	0,412	0,101

Table 8 shows normalized LSAI values for each factor (LSAI KSF) and for all analyzed courses (LSAI course), in addition to the mean and standard deviation. Table 9 shows how these values are distributed across the rating ranges.

Table 8 – Normalized LSAI results

Normalized LSAI	IEP2	PD	PMESP	PSOI	TMS	μ	σ
Course Activities	0,723	0,845	0,887	0,816	0,918	0,838	0,075
Student Assessment	0,684	0,958	0,997	0,775	0,918	0,866	0,132
Learning Facilitation	0,816	0,775	0,878	0,875	0,935	0,856	0,062
Int. with lecturers	0,804	0,786	1,000	0,583	0,824	0,799	0,148
Classrooms	0,734	0,795	0,542	0,792	0,816	0,736	0,113
Technology	0,967	0,961	0,644	0,854	0,964	0,878	0,140
LSAI course	0,788	0,853	0,825	0,783	0,896	0,829	0,112

Table 9 - LSAI course and LSAI KSF classification results

	LSAI course		LSAI KSF	
	Qty	%	Qty	%
Excellent	0	0%	9	30%
Very good	3	60%	10	33%
Good	2	40%	9	30%
Fair	0	0%	2	7%
Poor	0	0%	0	0%

Figure 13 shows areas of LSAI classification and how the results are located on chart LQ versus SQ.

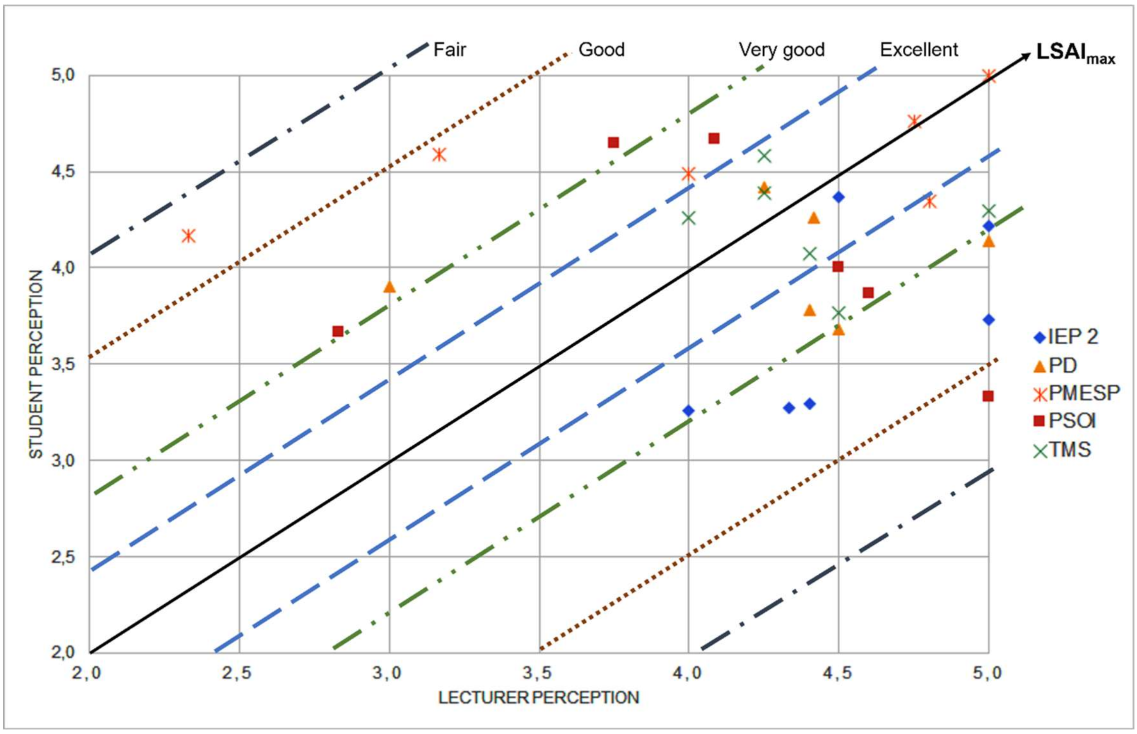

Figure 13 - LSAI results chart

The best normalized LSAI course was achieved by TMS, with the points distributed evenly around the $LSAI_{max}$ line (three below and three above). Also noteworthy is the occurrence of two points almost exactly on the $LSAI_{max}$ line, both from the PMESP course.

At the other extreme, two courses had very close LSAI courses: IEP 2 (0.788) and PSOI (0.783). Although they are very close values, there are different interpretations of these results. One of the main purposes of the LSAI, which is to identify whether there is a bias in the lecturer's perception, appears in the case of the IEP 2 course. In this case, the lecturer's perception tends to be better than that of the students, with a concentration of points in the region below the $LSAI_{max}$ line. In the case of the PSOI course, it is not possible to identify this tendency, since the points are distributed on both sides of the bisector line. This effect appears at the center of mass of the points of each course, as shown in Table 10. While the normalized LSAI_Bias for the PSOI course is very close to zero (0.024), for the IEP2 course this value is 0.212, almost 10x higher. This indicates the lecturer's bias. On the other hand, the PMESP course had a bias that indicates that the lecturer was more critical than the students. It is worth noting that, in this course, the *Classrooms* factor was a point where there was a great divergence between perceptions, with the lecturer evaluating much more severely than the students.

Table 10 - Mass Center and Bias results

	IEP 2		**PD**		**PMESP**		**PSOI**		**TMS**	
	LQ	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**	**LQ**	**SQ**
Mass Center	4,539	3,691	4,261	4,030	4,008	4,560	4,128	4,030	4,400	4,227
Normalized LSAI_Bias	0,212		0,058		-0,138		0,024		0,043	

5.3.3 3rd stage – Suggested Actions

Introduction to Engineering Project 2 (IEP2) had LSAI course equal to 0.788 and LSAI_Bias equal to 0.212. These results suggest that the lecturer tends to evaluate the course more leniently than the students, in addition to the possibility of improvement in their self-awareness, since the LSAI course was rated only as good. It is possible to suggest that actions to improve the course be concentrated on the *Student Assessment*, *Course Activities* and *Classrooms* factors, which are those that combine lower student evaluations and high lecturer evaluation.

Product Design (PD) had LSAI course equal to 0.853 and LSAI_Bias equal to 0.058. The results indicate that the lecturer has his perception aligned with the students, without clear bias. That is, he does not tend to be more or less critical than the students. Actions to improve the course can be concentrated on the *Course Activities* and *Classrooms* factors, which were in the False Positive region.

Planning, Management and Evaluation of Social Projects (PMESP) obtained LSAI course equal to 0.825 and LSAI_Bias equal to -0.138. These values indicate that the lecturer's perception is highly aligned with the students' perception, but the lecturer tends to be more critical than the students in her assessment. The lecturer has the most severe assessment on the infrastructure (*Classrooms* and *Technology*), which is not followed by the students. The effort that could be spent on improvements in this dimension is not a priority, which may facilitate improvement in other areas.

Production Systems Organization I (PSOI) presented LSAI course of 0.783 and LSAI_Bias of 0.024. This indicates that there is a possibility to increase the alignment between lecturer and student perceptions, but that there is no lecturer bias. Actions to improve the course can be concentrated on the factors *Interaction with Lecturer* and *Course Activities*, which were positioned in the False Positive region.

Time and Motion Study (TMS) had the highest LSAI course in the sample (0.896) and LSAI_Bias of 0.043. The results indicate that the perceptions of lecturer and students are highly aligned, and there is no bias on the part of the lecturer. Course improvements can be concentrated on the *Classrooms* factor, which had the lowest student rating.

In a transversal way, it is possible to perceive that, in these cases studied, there was a greater tendency of the professors to evaluate the course in a milder way than the students. However, this can be a trap, as the lecturer may feel that the course does not need improvement.

Additionally, PMESP course has a distribution similar to that of the other courses, both in the LQ *versus* SQ chart, as well as in the values of LSAI course and LSAI KSF. This result leads to believe that E^2ALM^2 and LSAI can be applied in other environments, and not only in the field of Engineering Education.

6 Conclusion

Active Learning is a wide concept that has been boosted during last years, especially in Engineering Education field. As a first step to an improvement plan, it is necessary to diagnose the status of a course. Then, to assess the maturity level of an AL implementation, E^2ALM^2 is used.

Additionally, self-awareness is understood as an important capacity to high levels of leadership, better decision making and management skills. Thus, this concept is intrinsically linked to the way to improvement actions, with the goal of upgrade course conditions and evaluation.

After E^2ALM^2 application, some factors can show misalignment between lecturer's and students' perceptions. To identify this discrepancy, this paper presented Lecturer Self-Awareness Index (LSAI). This index supports the identification process of critical factors that need special attention to get better results to students.

As a limitation, it is important to highlight that E^2ALM^2 does not assess the quality of a course but identifies the maturity level related to active learning. In addition, data collection made only with questionnaires can lead to some kind of bias or have answers that reflect some student dissatisfaction with other factors. Other issues may also influence the results, namely, external factors, that can also have an impact on the lecturers and students' perceptions of the active learning experience. For example, the fact that a lecturer is already familiar to students, due to being a lecturer in previous years or lecturer of more than one course throughout the study plan, will have impact on the student key factors, specially the one related to interaction with lecturers. Besides this, the class size, the number of years that the lecturer is responsible for the course and his/her previous pedagogic training, are important features that need to be considered in the analysis.

These limitations can be overcome by a deeper study, including also qualitative data, either with interviews or focus groups to lecturers and students, concerning their experiences, motivations, difficulties, and challenges with active leaning environments.

The results of this study indicate that although E^2ALM^2 has the term 'Engineering Education' in its name, this model can be used in other areas.

As future work, we also suggest a quantitative study, comparing different applications of E^2ALM^2 and searching cause-effects relations between practices and results. This could be a start of a predictive model, that can provide hints and suggest approaches to enrich courses.

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7 References

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7.3 Epilogue

Lecturer Self-Awareness Index (LSAI) is the second piece (2 of 2) to achieve the objective of Part II of this research. The research method followed in this case was similar to described about E^2ALM^2: a draft presented in international conference, collection of impressions and feedback, improvement of the manuscript and submission to an international journal.

Main lessons learned in this process were about collaboration with other researchers and the mindset to achieve high level results. During the meetings to organize teamwork and tasks distribution between the authors, what journal would be the target was an important issue. Then, the choice was to submit to the journals with higher impact factors and relevance to the field engineering education, even this would bring a hard work to be done. From the initial meetings (based on draft presented in PAEE/ALE 2022) to the first journal submission, to Journal of Engineering Education, it took around three months of intense dedication. This submission was rejected, and here is another lesson: no weakness, keep the confidence about the work quality and new submission to another journal. This way, work was submitted to European Journal of Engineering Education.

The reject and resubmit decision from EJEE brought a possibility to design roadmap needed to improve the paper. Essentially, it is necessary to deep quantitative foundations. There are weaknesses about validity and factor structure of the index, beyond sample size. These improvements will permit adjusts and optimizations in the questionnaires used to collect responses from students and lecturers.

Because of that, next steps are (i) expand the network of partner researchers, (ii) new data collection, (iii) better quantitative analysis and (iv) new submission. Due to doctoral deadlines, these steps will be done after the conclusion of this trajectory.

8. Bibliometrix and VOSViewer: tools for bibliometrics

8.1 Prologue

Systematic Reviews (SR) have gained increasing significance within several contexts. With the growing volume of publications on a given subject, researchers encounter greater challenges in comprehensively grasping the entire landscape of a knowledge domain. Research encompasses both a technoscientific dimension and a profoundly human and social one. Achieving success as a researcher extends beyond simply assembling noteworthy research findings; it also hinges on the underlying network of professional - and even personal - relationships. The connections among researchers represent a potential source of bias and thus warrant careful control during the research process. Nevertheless, an inherent portion of such bias emanates from the affiliations that researchers typically maintain when co-authoring articles, the sources they favor, and the authors they hold in high regard. Moreover, authors' prior reputations can potentially lead to greater citation and success for their work, compared to a similar article authored by an unknown individual from an unfamiliar institution or a non-traditional country.

Furthermore, from an individual perspective, researchers must formulate a career strategy that acknowledges the intensifying competition in the job market, which is a consequence of the diminishing psychological barriers that once existed across the world (Beerepoot & Lambregts, 2015; Waaijer, Teelken, Wouters, & van der Weijden, 2018). The Covid-19 crisis has significantly accelerated the adoption of remote work, bringing researchers from diverse geographic locations together. Authoring a paper with colleagues exclusively from one country or a specific region is likely to encounter decreased acceptance, given the increasing standards for defining rigorous research. This dynamic contributes to a scenario where individuals, research groups, and institutions, collectively, will increasingly rely on more than just "conducting high-quality research" (by any standard). It necessitates actively nurturing a network of co-authors and crafting a well-defined career strategy.

8.1.1 Scientometrics and bibliometrics

Citation data has been accessible for various purposes since the 1950s. Nevertheless, during this period, indexing procedures were inconsistent and lacked coordination. Seven decades ago, Eugene Garfield (1955) authored the seminal work that laid the foundation for the citation analysis framework as it is recognized today. Citation analyses form the bedrock of what is now referred to as bibliometrics and scientometrics.

The term "scientometrics" is widely employed in the literature and encompasses multiple definitions (Abramo, 2018). In general, scientometric research "encompasses methodologies for measuring the quality and impact of research" (Mingers & Leydesdorff, 2015). One of the initial pioneering endeavors in visualizing research domains based on citation data was the creation of a historical map of DNA research, undertaken by Garfield in the 1960s (Garfield, Sher, & Torpie, 1964). Concurrently, Derek Price (1961; 1963) conducted Scientific Network Mapping studies using the same data.

Scientometrics and bibliometrics are techniques available for a few decades, but its use has been somewhat limited to a few researchers who specialize in this field. Bibliometrics software will tend to be progressively more important as institutions and individuals will be required to have a broader portrayal of the evolution of a specific field.

8.1.2 Tools

Main tools in bibliometrics and scientometrics are VOSViewer and Bibliometrix. These tools are the subject of the paper commented in this chapter.

VOSviewer was introduced in 2010 (Van Eck & Waltman, 2010) and is a software application designed for the generation and exploration of network-based maps. While its primary purpose is the analysis of academic records, it can also be employed to construct, visualize, and explore maps derived from various types of network data, including social networks.

Bibliometrix is a package designed to be used within the R software environment. R serves as both a programming language and a free platform for statistical computing, and it is supported by the R Core Team and the R Foundation for Statistical Computing. Bibliometrix is a comprehensive tool for analyzing science mapping and was introduced in 2017 (Aria & Cuccurullo, 2017).

Bibliometrix facilitates three key phases of the bibliometric analysis process, including data import and conversion to R format, bibliometric analysis of a publication dataset, and the creation of matrices that enable the identification of keyword co-occurrences in publications, collaboration patterns among authors and institutions, and how they are collectively cited, among other things. These matrices serve as input data for conducting network analysis, multiple correspondence analysis, and various other data reduction techniques.

8.1.3 Main purpose

The main bibliometric analysis performed using VOSviewer or Bibliometrix are the following:

- **Authors:** most relevant and emerging authors in a particular field or topic (measured by total number of publications, total citations, H index, network centrality measure, connectivity measures to different coauthors, diversity of coauthor profiles (e.g. different countries, backgrounds, institutions).
- **Institutions or nations:** Institutional/ national productivity and impact (measured by their affiliated authors' production).
- **Publications:** number of citations, network centrality measures, immediacy index.
- **Sources** (journals, conference proceedings, etc.): sources that publish the most, total citations, most cited publications.
- **Relationships:** co-authorship (authors, institutions and countries), co-citation (documents, sources, authors, organizations and countries), diversity of relationships, dominant subgroups. Co-authorship is characterized when two nodes in the network (authors, institutions and countries) publish the same work together. Co-citation occurs when a third node in the network cites, in the same job, two other nodes. The greater the number of co-citations, the stronger the relationship between the two co-cited nodes. Bibliographic coupling is the opposite of co-citation. Two network nodes are bibliographically coupled if there is a third network node that is cited by both publications.
- **Keywords:** Keyword co-occurrence. Keyword co-occurrence exists when two or more keywords are present in the same document.

8.1.4 The published paper

The selection of the journal for submission was based on the identification of papers with a similar profile through a comparison of tools. Upon reviewing publications in Journal of the Medical Library Association, it became evident that it would be possible to publish in a reputable journal with a lower entry barrier, given that conducting the comparative analysis of tools was significantly more accessible than producing an article with primarily scientific content.

8.2 Full text

Paper published in Journal of the Medical Library Association (Arruda, Silva, Lessa, Jr., & Bartholo, 2022)

dx.doi.org/10.5195/jmla.2022.1434

DOI: dx.doi.org/10.5195/jmla.2022.1434

VOSviewer (version 1.6.17, July 22, 2021). Centre for Science and Technology Studies, Leiden University, The Netherlands. https://www.vosviewer.com; free, donations accepted.

Bibliometrix (version 3.1, Sep 24, 2021). Department of Economics and Statistics, University of Naples Federico II, Italy. info@bibliometrix.org; https://www.bibliometrix.org/; free, donations accepted.

INTRODUCTION

As the materials on a given topic increases, researchers and librarians find it more difficult to grasp the big picture of a field. Outlining the state of the art, the relationships, opportunities and main players of a given community of practitioners and scholars calls for a map that connects research information, venues, themes, as well as relationships among authors and institutions. The understanding that may emerge from such a big picture is necessary to formulate research, publication, institutional or career strategies. Authors such as Beerepoot et al [1] and Waaijer et al [2] argue that this need has increased with the reduction of the psychological distance of the world, a phenomenon that accelerated during the Covid-19 pandemic. By furthering remote work, many more connections became possible on a worldwide scale. This has led to a change in expectations, that increasingly takes international collaboration and multi-country data for granted, enlarging the requirements of what is to be considered "doing good research".

DOMAIN VISUALIZATION

Domain visualization based on citation analysis represents the relationships between sources in a two-dimensional space. This diagram offers a map of the dynamics of the literature and the paths that connect it. This network comprises nodes and edges and admit to customization in order to support a given analysis. Nodes may represent individual pieces of publication, journals, researchers, institutions or keywords. Edges represent the existence or type of relationship between pairs of nodes [3]. This allows the expression of any of a number of possible big pictures of the state of field. It may serve to enlarge the understanding of an individual researcher about the shape and directions of a given subject, it can support the definition of the breadth and reach of the plan for a Systematic Review and avoid biases during the process of source selection [4]. This article will review two of the most popular and promising domain visualization software packages available: VOSviewer and Bibliometrix.

VOSviewer

VOSviewer was released in 2010 by Nees Jan van Eck and Ludo Waltman (Leiden University) [5]. VOSviewer is a software tool for creating and exploring maps based on network data. While intended primarily for analyzing academic records, it can be used on any type of network data (social networks, e.g.). VOSviewer explores co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation links in one of three possible representations: network, overlay, or density visualization.

Bibliometrix

Bibliometrix was launched in 2017 by Dr. Massimo Aria (University of Naples Federico II) and Dr. Corrado Cuccurullo (University of Campania Luigi Vanvitelli) [3]. It is a package that must be used within the R software environment. R is both a programming language and a free environment for statistical computing, supported by the R Core Team and the R Foundation for Statistical Computing. Bibliometrix is a comprehensive mapping analysis tool that supports three phases of the bibliometric analysis process: (i) data import and conversion to R format; (ii) bibliometric analysis of a dataset and (iii) the construction of matrices. Matrices are customizable and allow mapping in great resolution, being input data for performing network analysis, multiple correspondence analysis, and many other data reduction techniques including domain visualization.

MAIN PURPOSE

For the purposes of this article, the main concerns of domain visualization correspond to the representation of the attributes and connections of:

- Authors
- Institutions or nations
- Publications
- Sources
- Relationships
- Keywords

SOFTWARE COMPARISON

VOSviewer and Bibliometrix can be compared succinctly in terms of their installation and usage requirements and of their functionalities (Table 1).

Table 1 Comparison of VOSviewer and Bibliometrix.

Item	VOSviewer	Bibliometrix
Software requirements	Linux, Windows or MacOS	Linux, Windows or MacOS
Install requirements	Download the appropriate version for your operating system	Requires installation of R language IDE and then of the Bibliometrix package
Requires programming knowledge	No	Yes

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Ease of use	High	Low
Customizability	Low	High
Import data from (file formats accepted)	SCOPUS (CSV), Clarivate Analytics Web of Science (Plaintext or tab-delimited), PubMed/MedLine (MEDLINE) and Dimensions (CSV)	SCOPUS (BibTeX or CSV), Clarivate Analytics Web of Science (Plaintext, BibTeX or EndNote), PubMed/MedLine (MEDLINE), Cochrane Database of Systematic Reviews (Plaintext) and RISmed (RIS).
Load multiple files	Yes	Yes
Data analysis from multiple sources	No	Yes
API support	Microsoft Academic, Crossref, Europe PMC, Semantic Scholar, the OpenCitations Corpus (OCC), OpenCitations Index of Crossref open DOI-to-DOI citations (COCI), and Wikidata	Dimensions, NCBI PubMed and Scopus
Exports spreadsheets	Yes	No
Dictionary creation (thesaurus)	Yes	No
Exclusive analysis that only one of the tools delivers	Temporal evolution of authors and institutions	-Impact indexes (H-index, G-index, M-index) Totalization of authors, sources, base documents
Flexibility and responsiveness to the user	High	Low

VOSviewer is a button-and-window-interface software, confined to its preprogrammed functions and possibilities.

Bibliometrix is a coding terminal that requires knowledge of the R programming language and allows complete customization.

It is important to note that Bibliometrix's developers also created Biblioshiny, a user interface that requires no coding knowledge to simplify usage. However, Biblioshiny does not allow file import of multiple files for the same analysis, imposing the task of merging different files that must be from the same database. This excludes it from consideration in this article.

FEATURES

Software requirements

Both Bibliometrix and VOSviewer can be used in the main operating systems (Windows, Linux, and MacOS). VOSviewer was developed in Java, which leads to platform portability. Bibliometrix is a package in the R programming language, which leads to operating system flexibility, but requires an IDE for R, like R Studio.

Need for programming knowledge

VOSviewer does not require any programming knowledge.

Only Bibliometrix requires the user to have knowledge of programming in R language.

Ease of use

VOSviewer is immediately accessible with a standard graphical interface.

Bibliometrix requires a customized interface to be programmed, if desired.

Loading multiple files

The main reference databases limit the export of metadata in a single file. Web of Science allows users to export the metadata of 500 references; Scopus allows 2000. Users have to create more than one file and import them one at a time whenever the number of desired references exceeds the limit.

Both VOSviewer and Bibliometrix allow loading metadata from multiple files.

Data Analysis from multiple sources

VOSviewer accepts files from different databases, but only one source can be used at a time. Depending on user's requirement, this may be a significant issue, because any one database does not hold the whole literature of any given field: users must combine metadata from different sources.

Only Bibliometrix allows users to analyze data from multiple sources concurrently.

Flexibility and responsiveness to the user

Flexibility is linked to this diversity of possible manipulation of parameters (colors, lines, labels). Responsiveness to the user is the possibility of seeing changes as they are made without the need to run the program again.

VOSviewer is both more flexible and more responsive than Bibliometrix.

API support

Both VOSviewer and Bibliometrix allow using an API to automate the communication with the indexing databases (Web of Science, PubMed etc.), keeping the database updated automatically.

ANALYSIS THAT ONLY ONE OF THE SOLUTIONS DELIVERS

VOSviewer

Spreadsheet export

This functionality allows the data used to create bibliometric maps to be exported to spreadsheets, easing the usual clutter of domain visualization to identify relationships and nodes that might otherwise be missed.

Creation of thesaurus

Due to the diversity of keywords in the documents, it is common to have to deal with the occurrence of different words that have the same meaning, as

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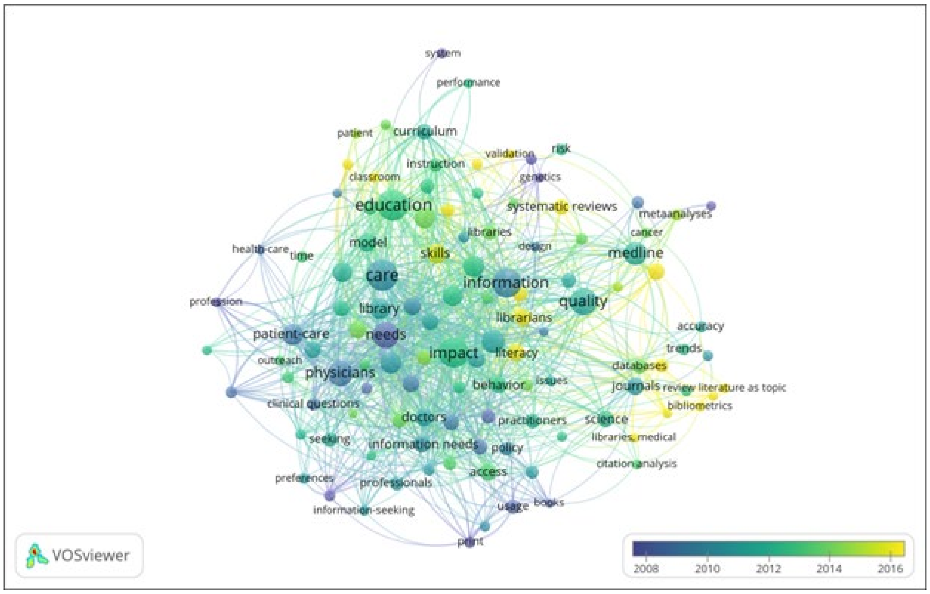
Figure 1 Overlay map of keyword co-occurrence over time for papers published at the Journal of the Medical Library Association (JMLA).



Note: Metadata includes all 1826 articles in the Journal of the Medical Library Association (JMA) (references), retrieved from Web of Science [September 7th, 2021].

simply as the use of singular and plural in keywords. A thesaurus makes it possible to deal with this problem, allowing references with keywords that are synonymous to be addressed jointly.

Temporal Data Visualization

The visualization of temporal data can color code network nodes to the year of publication allowing the identification of trajectories and trends in a given field (Figure 1, for keywords, for example).

Bibliometrix

H-index, G-index, M-index

The impact indexes of sources and authors (H-index, G-index, M-index)

Production over Time

A map of authors' production over the time.

Total Numbers

The total of authors, sources and publications from the database used.

CONCLUSION

VOSviewer and Bibliometrix are fit for purpose in providing domain visualization, yet each offers a distinctive set of capabilities and requirements.

VOSviewer is the more user-friendly offering simplicity, flexibility and responsiveness to user demands as well as greater graphic quality at the price of bounding alternatives to its preprogrammed functions and requiring repeating analysis due to its inability to combine data from different sources.

Bibliometrix is the more robust and versatile, being capable of greater customization by users and of (a) performing analyses using files from multiple databases, (b) accepting files from the Cochrane Database of Systematic Reviews (CDSR) and from RISmed, (c) offering exclusive analyzes at the price of a steeper learning curve that includes programming.

It can be argued that each fills a particular niche. VOSviewer may be all that a given user or set of users need. However, as a particular capability is required, it may turn out to be a first step before deciding on the extra effort that Bibliometrix will demand.

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8.3 Epilogue

The best title to this epilogue is “Unassuming Article, Astonishing Outcome”.

At the outset of the research (in 2020), an extensive bibliometric study was conducted with the aim of comprehending the field of engineering education around the world, thereby facilitating the delineation of the research space. As a consequence of the investigations into the utilization of the two tools, a documentation was produced, comparing their functionalities, features, and limitations, and this documentation was published in an article in 2022 (Arruda et al., 2022). It is evident that the paper publications occurred only after two years, and the main content of this article appears to be a seemingly straightforward documentation of comparisons between two tools. Here lie the first significant lessons learned: the effective utilization of available resources (time) and the recommendation to "think in writing", which greatly contributed to the final published version.

From a rather unassuming article, created from study notes, the outcome as a scientific publication was surprisingly impactful. Researchers, more than just seeking publication, aim to be cited as it signifies the relevance of their research. This article has received 42 citations until the completion of this thesis, for comparison, the E^2ALM^2 proposal was published a year earlier and has one-third of those citations.

Here, a connection can be made to the incidental theme of this thesis: *impact* measurement. Despite requiring fewer hours of work, the impact of this article in terms of citations was significantly greater. This underscores another lesson learned: the careful selection of the journal is an essential aspect of a researcher's work.

Apart from the choice of journal, defining the article's profile was also important, as review articles tend to receive more citations.

In conclusion, it is worth noting a somewhat somber and nebulous analysis: as a scientific contribution, this article holds much less significance than an analysis of results from an engineering course. However, it will likely receive more citations than articles with a narrow focus on a specific field. Hence, the question for reflection arises: is this academically fair? Is this system of measurement and impact assessment genuinely contributing to the advancement of science and encouraging professionals to devote their time to scientific research?

9. Conclusions

9.1 The new era of engineering education: from *learn* to *think*; from *act* to *impact*

For the sake of clarity, let us recap some of the key points addressed throughout this thesis, making the necessary comments to properly connect the arguments.

Over the past few decades, it has been observed that society has undergone profound transformations, accumulating in the last century more cumulative technological breakthroughs than in thousands of preceding years (Kanga, 2021). All of these transformations led the United Nations to establish the 17 Sustainable Development Goals (SDGs) in 2015, with the aim of creating a more equitable, sustainable, and prosperous world for all (UNITED NATIONS, 2015).

Naturally, the speed at which information emerges and becomes outdated has become the most crucial variable distinguishing the current generation from previous generations (DeLong, 2004; Weichert et al., 2004). In addition, thanks to the increasing use of mobile technologies and social media, the newer generations of students tend to be less patient and more eager to have what they desire immediately, without the need to wait for it (Lombardi & Oblinger, 2007).

Considering the facts outlined above, we face a significant educational challenge today: how to promote student engagement in an audience that tends to be more impulsive, teaching content with a short shelf life, and which will soon require the same student to revisit that subject to stay updated or even learn completely new things in the same theme.

In parallel with this challenge, society's expectations regarding engineers have also evolved. While decades ago, engineers were expected to design bridges, buildings, or cars, today there is a desire for engineers to be "more entrepreneurial", "more innovative", or "more sustainable".

In summary, the focus has shifted from *learn* to *think*, and from *act* to *impact*. Modern engineers must possess the capacity to *learn*, but they need to go further and cultivate the ability to *think* about their solutions. They should be capable of *act*, but, most importantly, should remain attentive and tailor their solutions to achieve the desired *impact*.

9.2 The engineer profile in the world of *think* and *impact*

The various terms used by several authors to refer to contemporary engineers (such as 21st-century engineer, modern engineer, innovative engineer, entrepreneurial engineer, or global engineer, among others) implicitly or explicitly convey the same expectation in terms of the desired profile: skills considered essential for employability, entrepreneurship, and the ability to propose solutions capable of addressing the Sustainable Development Goals (SDGs) and the challenges of the current world.

Many fundamental principles in engineering remain unchanged, but engineers, as well as the engineering field in its entirety, must adapt to and tackle additional skills and emerging trends. This adaptation is crucial to determine the competencies required for a sustainable future (Vieira & Haugerud, 2021). Decades ago, abilities like communication, teamwork, and sustainability were not deemed crucial for an engineer.

Kanga (2021) argues that engineers are required not only to have technical expertise but also to integrate imperatives and values linked to the demands of the twenty-first century. This desired profile is not exactly the same as what was observed in the 20th century, as highlighted in the previous section. The shift from the realm of *learn* and *act* to the world of *think* and *impact* has introduced significant differences in the engineer's profile, especially concerning the so-called soft skills.

For instance, in the field of computer engineering, YouTube produces approximately 100 petabytes of fresh data annually (David Stephenson, 2017), along with around 72 hours of video content each minute (C. L. P. Chen & Zhang, 2014), and Facebook generates more than 10 petabytes of log data per month. Then, modern computer engineer must focus their attention on two domains that are both distinct and challenging:

- the necessity to devise tactics and construct procedures and algorithms for the efficient examination of extensive datasets becomes apparent in light of the fact that Big Data systems comprise a multitude of evolving technologies and proficiencies. These encompass domain-specific knowledge, data analytics, statistical acumen, and advanced data visualization skills. (Mohanty, Jagadeesh, & Srivatsa, 2013).
- the apprehension of avoiding involvement in discriminatory practices. Several cases have arisen in which predominantly concealed algorithmic decision-making has significantly worsened bias against particular demographic groups. (Angwin, Larson, Mattu, & Kirchner, 2016; Perez, 2019).

Finally, contemporary engineering students must acquire the skills to analyze and address the challenges confronting society and to create technologies that enhance sustainable living (Kolmos, 2021).

To address this paradigm shift, this thesis dedicates its Part I to analyzing the profile of the modern and more innovative engineer that society desires. Initially, we presented the book chapter " What Sort of Engineering Do We Want? How Far Are We From It? A Manifesto for Socially Situated Professional Ethics" published in the book titled "Rethinking Technology and Engineering", of the notable series “Philosophy of Engineering and Technology” by Springer. In this manuscript, the authors emphasize the necessity for engineering to align its objectives with the constraints imposed by society, all while keeping the essence of their work in focus: to provide the best possible solution, given a particular scenario, utilizing available resources optimally, and adhering to ethical, moral, and social principles. Additionally, the Latin American perspective offers an alternative viewpoint compared to the more commonly propagated perspective centered in the Northern Hemisphere.

Building upon this discussion, the thesis presents its contributions to address one of the significant gaps resulting from the shift from *act* to *impact*: the challenge of measurement and assessment.

In Chapter 4, the BR-AFC method for identifying companies founded by alumni of a Brazilian institution was presented. This proposal has been accepted for publication in the Brazilian Journal of Operations and Production Management and is expected to be published in 2024, according to the journal's schedule. This method serves as the initial step in quantifying the entrepreneurial activity of a specific group, such as engineers graduating from a particular university. By applying the BR-AFC method, it becomes possible to assess whether the *impact* generated by the engineers aligns with the program's pedagogical objectives. Additionally, it allows for the identification of the economic sectors in which these companies operate, facilitating an evaluation of the outcomes resulting from training in a specific field. For instance, it enables the identification of whether a program's emphasis has yielded outcomes in terms of business establishment in that field of knowledge. The concern over these relations has been extensively discussed in publications regarding the third mission of the university and the necessity for collaboration between academia and industry (Cadorin, 2021; Etzkowitz, 2003, 2013; Etzkowitz & Klofsten, 2005).

In Chapter 5, the application of the BR-AFC method on a pilot sample from the Industrial Engineering program at UFRJ allowed for an investigation into the potential correlation between entrepreneurial activity and students' academic performance. This represents just the initial analysis in a vast spectrum of possibilities. Although the result indicated that there is no direct relationship between entrepreneurial activity and academic performance, this inquiry necessitates further examination with a more comprehensive database. Such research can potentially support revisions to the pedagogical projects of programs with learning objectives associated with the establishment of new businesses.

These three chapters, collectively, demonstrate how the thesis accomplishes the objectives outlined for Part I:

- Promote debate about the characteristics of currently trained engineers; and
- Begin debate and measurement about the potential professional paths of engineers after graduation, as a mechanism for evaluating training paths and improving the design and focus of undergraduate courses.

9.3 The process: engineering education to address 21st century demands

The field of engineering education must act swiftly to advance in these domains, particularly considering that it typically takes some years to train an engineer. Around the world, some countries graduate their engineers in five years, and especially in Europe this process takes three years. Students commencing their engineering education today will be applying their knowledge beyond the scope of the current Sustainable Development Goals – SDG (Kolmos, 2021). As technology continues to evolve and grow in complexity, the learning outcomes for engineering education must also evolve accordingly, necessitating modifications in both the educational content and the learning methods.

In fact, engineering education has adopted diverse approaches in response to the transformation necessity. Jamison *et al.* (2014) identified three knowledge modes within a curriculum, each accompanied by corresponding learning strategies: the academic mode, which places a strong emphasis on theoretical knowledge; the market-driven mode, which prioritizes employability; and the community-driven mode, which centers on civic society and sustainability.

One of the significant ongoing changes in the field of engineering education is the increasing adoption of active learning. This term encompasses various classroom techniques that ultimately shift the focus away from the instructor and place the student at the core of the learning process. Several publications have already demonstrated noteworthy outcomes regarding the connection between active learning and sustainability skills, soft skills, and lifelong learning, all without compromising technical skills (El-Adaway, Pierrakos, & Truax, 2015; Lattuca et al., 2006; Servant-Miklos et al., 2020; Soeiro et al., 2021).

Despite the notable rise in the significance and utilization of active learning in engineering education, we once again encounter the challenge of assessment. Once more, as we transition from *act* to *impact*, we require new assessment tools. In this regard, Part II of this thesis concentrates its contributions toward the proposition of a maturity model applicable to a specific course and the proposal of an instructor's self-awareness indicator.

Chapter 6 introduces the article "Assessment and Evaluation in Active Learning Implementations: Introducing the Engineering Education Active Learning Maturity Model", which has been published in the Education Sciences journal. E^2ALM^2 enables the assessment of active learning implementation in a course, based on previously examined success factors from the literature. It can serve as the basis for future analyses of program direction, investigating the impact of its actions with the goal of aligning the course with the current world's demand for soft skills. Additionally, it facilitates the evaluation of an entire program, adopting a bottom-up approach, with courses forming the foundation and the program at the apex.

Chapter 7 introduces an indicator derived from the E^2ALM^2, known as the Lecturer Self-Awareness Index (LSAI). Active learning places the student at the core of the learning process, naturally shifting the focus away from the instructor. In this context, it falls upon the instructor to assume new roles, no longer as the sole possessor of knowledge but as a facilitator of the process. However, how can they effectively lead the course if their perceptions diverge from those of the students? Furthermore, how can they take action to enhance the course in such a scenario? By measuring these potential disparities in perceptions, the LSAI can be used in conjunction with the E^2ALM^2 to better guide efforts toward course and university program improvement.

Lastly, Chapter 8 introduces the article titled "Resource Review - VOSViewer and Bibliometrix," published in the Journal of the Medical Library Association. Interestingly, the most pertinent discussions in this chapter are found in the prologue and epilogue rather than the published article itself.

The discussions are particularly interesting due to the outcome achieved by the article from a scientific work perspective. The number of citations, as well as the citations-per-page indicator, underscores how an inadequate evaluation system can misguide the development of a field. In terms of scientific contribution, this article is much less significant than the others presented in this thesis. However, it undeniably received the highest number of citations. This result can be interpreted as a judicious choice of journal or article type, but it can also lead to the interpretation that the current evaluation system is inadequate.

Given the discussed changes and the necessity for the evolution of engineering education and the role of the professor, it is imperative to contemplate the methods of performance measurement by which professionals will be assessed.

First, it is essential to highlight engineering knowledge cannot be reduced to scientific knowledge. According to Rolston and Cox (2015), the performance of graduate engineering departments cannot be assessed by the number and trend of publication in indexed scientific journals every 3 years.

Additionally, one of the most significant factors influencing the work of faculty members in colleges and universities is the institutional reward system, which has the potential to either promote or hinder a focus on teaching (Lattuca et al., 2006).

Hence, it is essential to consider the reasonableness and feasibility of evaluating the performance of researchers and educators solely based on their scientific publications, particularly in a context where professionals are expected to engage in additional responsibilities beyond their core expertise and comfort zone. For changes in the pedagogical framework of a course or the introduction of novel activities centered around more contemporary techniques, it is imperative for lecturers to allocate time towards the preparation of activities for their courses, due to the challenges both to students and to the lecturers (Anabela C. Alves, Van Hattum-Janssen, & Fernandes, 2021), in addition to the need to invest in their own professional development. According to Fernandes *et al.* (2023), certain critical factors significantly influence the success of pedagogical training for educators. Examples of these factors include the implementation of active learning strategies, fostering collaborative environments for lecturers, and affording ample time for feedback and self-reflection. However, how can this need be reconciled with the existing demands for scientific publications? This reflection sheds light on the inherent inconsistencies within a solely indicator-focused approach.

Table 4 summarizes main reflections and challenges from each thesis chapter. Not all reflections are aligned with a specific trend. The purpose of listing them is precisely to facilitate visualization and encourage the reader to adopt a critical perspective on the topics.

Table 4 - Reflections and challenges about chapters

Chapter	Main reflections and challenges
6. Engineering Education Active Learning Maturity Model (E^2ALM^2)	This model does not evaluate the course quality, but it does evaluate the maturity level of active learning use. Main reflection of this chapter is about the trend to prioritize soft-skills development and the consequence of this movement on the technical skills. Main challenge derived from this chapter is how to use the evaluation tool to really improve courses and programs.
7. Lecturer Self-Awareness Index (LSAI)	This index measures how aligned is the students' and lecturers' perceptions about the course. Main reflections here are: • Why is this index necessary? • Why is there mismatch between those two perceptions? • Are lecturers supposed to be able to detect correct diagnose from the course?

	• How can lecturers effectively lead the course if their perceptions diverge from those of the students?
8. Bibliometrix and VOSViewer: tools for bibliometrics	The primary reflection centers on an evaluation system for lecturers that proves to be unjust, leading professionals to channel their energies into activities that contribute minimally to the progress of science and practically nothing to address societal needs.

Finally, three chapters of Part II, taken together, lead to achieving the previously defined objectives to this axis. The main objective was to propose a way to evaluate maturity level in the use of active learning techniques. It would be unfolded in two pieces: (i) development of a maturity model to assess active learning implementations with the scope of a course; and (ii) development of an index to measure level of lecturer self-awareness.

9.4 Agenda for future research

From the author's perspective, this thesis represents merely the initial step toward a vast expanse that unfolds ahead. However, the suggestions presented in this section do not exceed this boundary; they remain as suggestions. When conceiving a hammer, the ancient inventor knew it would be used for driving nails. Yet, they could never have envisioned the significance of the structures these nails would support, or the importance of the connections established through the use of these nails on a surface. Consequently, the artisan proposing a tool may envisage its intended use but cannot estimate the outcomes arising from that utilization.

Given that the primary theme of the thesis is the transition of engineering from act to impact, and that the thesis presents three proposed assessment tools, the next logical step is the consolidation of the utilization of these tools. In addition to this step, the discussions can also be extended and enriched in subsequent stages. Table 5 shows main future developments of each thesis chapter.

Table 5 - Major future developments

Chapter	Major Future Developments
Part I - AXIS "The profile: new engineer and the impact on society"	
3. The engineer profile we want to deliver to society	Analysis may incorporate perspectives from beyond South America. Social and ethical aspects in engineering can be further explored. Analysis of the extent to which these aspects are integrated into engineering programs.
4. Identification of Alumni-Founded Companies (AFC)	Analysis about AFC may include: • field of operation • level of technological intensity • lifespan • number of jobs created • estimative of payroll involved, and • estimative of tax revenue collected.
5. Entrepreneurial activity and academic performance	Investigation about the existence of correlation between academic performance and AFC relevance (measured by revenue or size) Debates about the adequacy of tools for student assessment and the learning outcomes

Part II - AXIS “The process: engineering education and active learning”	
6. Engineering Education Active Learning Maturity Model (E^2ALM^2)	Further applications in real courses to advance quantitative studies, parameter adjustments, and questionnaires optimization. Analysis about the relationship between the maturity level of courses and the development of specific competencies in students. From this, measurement of how much active learning contributes to the development of soft skills
7. Lecturer Self-Awareness Index (LSAI)	
8. Bibliometrix and VOSViewer: tools for bibliometrics	Studies on potential advancements in lecturer evaluation systems that consider not only indicators of scientific production but also their contribution to real-world problem-solving in contemporary society.

In Part I of the thesis, the discussion regarding the profile of the contemporary engineer can be broadened by incorporating perspectives from beyond South America. Furthermore, the social and ethical aspects in engineering can be further explored, leading to an analysis of the extent to which they are integrated into engineering programs.

The BR-AFC method can serve as the foundation for numerous future analyses regarding the entrepreneurial activities of graduates from a specific institution or program. The investigation presented on the potential relationship between academic performance and entrepreneurial activity represents an initial, more in-depth examination of the entrepreneurial impact of the Industrial Engineering program at UFRJ. From there, various other factors can be analyzed, including the field of operation of alumni-founded companies (AFC), the level of technological intensity of AFC, the lifespan of AFC, the number of jobs created, estimates of payroll involved, and estimates of tax revenue collected, to name a few.

Depending on further information regarding employment, it is possible to assess the validity of a widely circulated statement: "education is an investment". Given that a significant portion of top-tier universities in Brazil are funded with public funds, it is feasible to investigate the relationship between the amount of resources allocated to a specific university and the tax revenue collected over a certain period in the future.

In Part II of the thesis, the proposed tools (E^2ALM^2 and LSAI) rely on further applications in real courses to advance quantitative studies, parameter adjustments, and questionnaire optimization. For large-scale implementation, it is essential to establish new partnerships. This development, in turn, depends on a careful plan for disseminating the models and attracting professors interested in applying them to their courses. This process involves specific relationship-building actions that should not be underestimated.

Based on the results obtained from E^2ALM^2, it will be possible to analyze the relationship between the maturity level of courses and the development of specific competencies in students. This analysis can lead to the measurement of how much active learning contributes to the development of soft skills, for example.

Finally, the challenge posed regarding the evaluation system of educators based on indicators related to their scientific output can be expanded to encompass broader analyses, enabling a better alignment of the observed variables with the reality of 21st-century professors and their role in the academic world, which is increasingly shifting from *act* to *impact*.

9.5 Final remarks

The doctoral journey is arduous and painful. At times, it instills doubt in the researcher about the feasibility of their research, while at other times, the doubt concerns the relevance of their study. As one advances into the unknown, an inevitable step for a student aspiring to become a doctor, uncertainties loom on the horizon, potentially shrouding all visions in obscurity. However, with each step forward, this hazy vision gradually transforms into clearer images. And thus, with a strong dose of faith, the future doctor contributes their small brick to the vast edifice of knowledge.

The debates and impact assessment methods presented in this thesis still appear unclear to the author. No matter how strong their faith and enthusiasm for the progress of research stemming from these contributions, uncertainties remain highly relevant. The significant challenge that lies ahead lies in the expansion of the methods' usage, as well as the increase in the quantity and complexity of the generated analyses.

Finally, may all the discussions and reflections presented in this thesis contribute to enabling the reader to individually assess the issues, and may large-scale policy decisions (such as public policies for education, for example) become more rooted in technical aspects. They should cease to be decisions based on convenience but rather be decisions that adequately measure and guide the desired *impact*.

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APPENDIX A – E^2ALM^2 Questions

The questions below constitute the Lecturer Questionnaire (LQ) and Student Questionnaire (SQ) of the E^2ALM^2. Next to each posed question, there is tracking of which construct and variable it assesses, along with an indication of the linkage questionnaire (in the column Measurement Method – MM).

Both questionnaires are online available:

- Lecturer questionnaire (LQ): https://forms.gle/MrfyyxvqK2aU38rv9
- Student questionnaire (SQ): https://forms.gle/7H5pCtXaucsdqpgy7

ID	Variable	Construct	Question	Opt 1	Opt 2	Opt 3	Opt 4	Opt 5	MM
1	% of course content based on real-life problems	Use of real-life problems	During this course, real-life problems were ___________ used.	Never	Rarely	Sometimes	Often	Always	SQ and LQ
2	% of classes using active methods	Application of active experiments	In this course, how often methods other than lectures (such as case studies, problems discussed in class, student research outside the classroom, or other methods other than active learning) were used?	Never	Rarely	Sometimes	Often	Always	SQ and LQ
3	Students' perception of hands-on activities	Application of active experiments	During this course, how often did students develop hands-on activities?	Never	Rarely	Sometimes	Often	Always	SQ
4	Quantity of instructional resources used	Variety of instructional resources	How many of these resources were used in this course? (Board, Projector, Videos, Simulations, Problems, Case studies or Group works)	1 or 2	3	4	5	6+	SQ and LQ
5	% of classes using resources other than the board or projector	Variety of instructional resources	How often were instructional resources other than whiteboard and/or projector used in the course?	Never	Rarely	Sometimes	Often	Always	SQ and LQ

6	Students' perception of the use of various resources	Variety of instructional resources	In this course, you got the feeling that the use of varied instructional resources was ________ suitable.	Never	Rarely	Sometimes	Often	Always	SQ
7	Students' perception of the level of difficulty presented	Suitability of intellectual challenge	When developing the activities, you had the feeling that the **level of difficulty** was suitable.	Never	Rarely	Sometimes	Often	Always	SQ
8	Students' perception of the clarity used	Clarity in writing of course activities	The problems/case studies used were **written clearly enough** to carry out the activities.	Never	Rarely	Sometimes	Often	Always	SQ
9	Students' perception of size	Size of course activities	The problems/case studies used were of **adequate size** to carry out the activities.	Never	Rarely	Sometimes	Often	Always	SQ
11	Students' perception of the existing preparation for conducting activities	Preparation of students to conduct activities required	Students received adequate preparation to carry out the activities of the course.	Never	Rarely	Sometimes	Often	Always	SQ
12	Students' perception of clarity in the purpose of the activities	Explanation of purpose of course activities	The problems/case studies used had a clear purpose.	Never	Rarely	Sometimes	Often	Always	SQ
13	% of activities in which the purpose is explained to students	Explanation of purpose of course activities	Students were ________ explicitly informed of the purposes of each activity performed.	Never	Rarely	Sometimes	Often	Always	SQ
14	% of classes linked directly to an LO	Adequacy to Learning Outcomes (LO)	In this course, activities and classes are ________ directly related to learning outcomes.	Never	Rarely	Sometimes	Often	Always	SQ and LQ
15	Students' perception of reaching an LO	Adequacy to Learning Outcomes (LO)	You consider that you have fully achieved the learning outcomes for this course.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
16	Perception of students on the clarity of assessment methods	Clearness of assessment methods	In this course, the assessment methods were completely clear.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
17	Are the assessment methods defined in advance?	Clearness of assessment methods	When starting the course, the assessment methods were defined in advance.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
18	% of activities that have defined what is expected of the student	Clearness of assessment methods	In the activities of this course, it is ______ defined what students are expected to deliver in order to obtain the maximum grade for the activity.	Never	Rarely	Sometimes	Often	Always	SQ and LQ

19	Perception of students on the clarity of success criteria	Clearness of criteria for success	In this course, the criteria for success were completely clear.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
20	Are the success criteria defined in advance?	Clearness of criteria for success	When starting the discipline, the criteria for success were defined in advance.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
21	Is information about assessment methods and success criteria made available before (or at the beginning of) the course?	Communications with students	At the beginning of the course, information about assessment methods and success criteria was known.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
22	Students' perception of communication of assessment methods and success criteria	Communications with students	You have been adequately communicated about the assessment methods and criteria for success.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
23	Students' perception of the teacher's performance as a facilitator	Preparation of students to conduct activities required	The lecturer acted as a learning facilitator.	Never	Rarely	Sometimes	Often	Always	SQ
24	Intensity of the participation of monitors or auxiliary teachers during the course	Preparation of students to conduct activities required	In the course, there was ________ the participation of teaching assistants and auxiliary instructors.	Never	Rarely	Sometimes	Often	Always	SQ and LQ
25	% of activities where there is formative feedback from the teacher	Formative feedback from teacher	In the course, students ________ received feedback from the lecturer at the end of the activities.	Never	Rarely	Sometimes	Often	Always	SQ
26	Students' perception of the intensity of support received via formative feedback	Formative feedback from teacher	Lecturer feedback comments received by students were relevant.	Never	Rarely	Sometimes	Often	Always	SQ
27	Perception about the adequacy of the curriculum to the needs of the course	Structure of the curriculum	The course curriculum meets your learning expectations.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ

28	Student perception of the alignment of the curriculum with the course material	Coherence of the curriculum and the learning material	The course curriculum and learning materials used are aligned.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
29	Quantity of work / projects carried out in group in the course	Interactions in general	Course activities were ________ group activities.	Never	Rarely	Sometimes	Often	Always	SQ
30	% of the grade of the discipline from group work	Interactions in general	What percentage of the course grade is attributed to group assignments?	Less than 20%	Between 20% and 40%	Between 41% and 60%	Between 61% and 80%	More than 80%	LQ
31	Number of remote meetings with other students throughout the course	Online collaboration	In the course, there were ___________ ONLINE MEETINGS among students to carry out group work.	Never	Rarely	Sometimes	Often	Always	SQ
32	Number of online presentations made by the student with assistance from other students	Online collaboration	In the course, there were ________ ONLINE PRESENTATIONS by students for other students.	Never	Rarely	Sometimes	Often	Always	SQ
33	Number of face-to-face meetings with other students throughout the course	Face-to-face collaboration	In the course, there were ________ IN-PERSON MEETINGS among students to carry out group work.	Never	Rarely	Sometimes	Often	Always	SQ
34	Number of face-to-face presentations made by the student with the assistance of other students	Face-to-face collaboration	In the discipline, there were _________ IN-PERSON PRESENTATIONS by students for other students.	Never	Rarely	Sometimes	Often	Always	SQ
35	Number of orientation meetings throughout the course	Interactions students/professors	How many office hour meetings for the project did the groups of students have?	0	1 or 2	3	4	5+	SQ and LQ
37	Ease of approval of pedagogical changes	Acceptance of changes by the organization	Pedagogical changes (such as modifications to syllabus or assessment methods) in courses occur with acceptable processes and timelines.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ

38	Ease of approval of administrative changes	Acceptance of changes by the organization	Administrative changes (such as changes in roles or resources) occur with acceptable processes and timelines at the institution.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
39	Clarity of expected behaviors	Behavior alignment	Members of the institution are fully aware of the expected behavior from them.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
40	Existence (or maturity) of behavioral guidelines	Behavior alignment	The institution has defined guidelines for the conduct of its members.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
41	Perception of the speed with which problems are solved	Ability to solve problems	Issues are ________ resolved within acceptable timeframes at the institution.	Never	Rarely	Sometimes	Often	Always	LQ
42	Perception of transparency in problem solving	Ability to solve problems	Issues are ________ resolved transparently at the institution.	Never	Rarely	Sometimes	Often	Always	LQ
43	Existence (or maturity) of a code of ethics	Defining rules	The institution has a code of ethics for its members.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
44	Perception of the existence of punishments for those who violate certain rules	Adequacy to the rules	In the institution, there is _________ adequate punishment for those who violate the rules.	Never	Rarely	Sometimes	Often	Always	LQ
45	Perception of the existence of time available for planning new activities	Organizational support for the preparation of activities	Lecturers ________ have adequate available time to plan new activities in the courses.	Never	Rarely	Sometimes	Often	Always	LQ
46	% average of teachers' time in classroom activities	Organizational support for the preparation of activities	Regarding lecturers' time spent on teaching activities, you have ________ than you consider adequate.	Much less	Less	Similar	More	Much more	LQ
47	% average of teachers' time in administrative activities	Organizational support for the preparation of activities	Regarding the lecturers' time spent on administrative activities, you have ________ than you consider adequate.	Much less	Less	Similar	More	Much more	LQ
48	Average amount of administrative functions performed by teachers	Organizational support for the preparation of activities	Lecturers have administrative responsibilities in a quantity compatible with the time necessary for their pedagogical activities.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ

49	Perception of the availability of auxiliary resources for the preparation of activities	Organizational support for the preparation of activities	Lecturers __________ have the availability of necessary auxiliary resources for the preparation of pedagogical activities.	Never	Rarely	Sometimes	Often	Always	LQ
50	Perception of the adequacy of existing teaching plans to the use of AL	Adequacy of pedagogical plans	Current teaching plans for the course are suitable for the use of Active Learning methods.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
51	Perception of students about the ease of the process of giving feedback	Quality of the feedback collected	Students can easily give feedback to the institution about needs or problems.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
52	Perception of students on the fulfilment of their placements in feedback	Using student feedback	The institution is concerned with solving the problems that students point out.	Never	Rarely	Sometimes	Often	Always	SQ
53	Existence (or maturity) of the process of receiving feedback from students	Collecting student feedback	The institution has a systematic process for collecting student feedback.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
54	Is feedback anonymous?	Quality of the feedback collected	Students provide feedback anonymously.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ
55	Is the collection in person or remote?	Quality of the feedback collected	Can feedback collection take place in person or remotely?		Only remotely	Both remotely and in person	Only in person		SQ
56	Existence of classrooms for Active Learning	Classrooms designed for improve active learning experience	There are classrooms with layouts suitable for conducting group activities or roundtable discussions, different from the auditorium model.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
57	Classroom availability for Active Learning	Classrooms designed for improve active learning experience	There is **availability** for the use of **classrooms with layouts different from the lecture model**.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
58	% of activities performed in an environment suitable for Active Learning	Classrooms designed for improve active learning experience	Activities such as discussions or group work _______ are held in an appropriate place (office, lab, etc.).	Never	Rarely	Sometimes	Often	Always	SQ and LQ

59	Existence of classrooms equipped with multimedia devices and / or laboratories	Classrooms equipped with technologies to enhance student learning and support teaching innovation	There are laboratories and/or classrooms equipped with multimedia devices.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
60	Availability of classrooms equipped with multimedia devices and / or laboratories	Classrooms equipped with technologies to enhance student learning and support teaching innovation	There is **availability** for the use of **laboratories and/or classrooms equipped with multimedia devices**.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
61	% of activities performed in a technologically appropriate environment	Classrooms equipped with technologies to enhance student learning and support teaching innovation	Activities ________ take place in a technologically appropriate environment, with laboratory or multimedia devices, when they are necessary.	Never	Rarely	Sometimes	Often	Always	SQ and LQ
62	Availability of multimedia devices	Availability of technology	The institution has multimedia devices available for use.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
63	Reliability of multimedia devices	Reliability of technology	How do you rate the **reliability of multimedia devices** in the institution?	Very low	Low	Regular	High	Very high	LQ
64	Accessibility of multimedia devices	Accessibility of technology	How do you rate the **accessibility of multimedia devices** in the institution?	Very low	Low	Regular	High	Very high	LQ
65	Usability of multimedia devices	Usability of technology	How do you rate the **usability of multimedia devices** in the institution?	Very low	Low	Regular	High	Very high	LQ
66	Internet availability on campus	Availability of technology	The institution has internet access available on campus.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
67	On-campus internet reliability	Reliability of technology	How do you rate the **reliability of internet access** on the campus?	Very low	Low	Regular	High	Very high	LQ
68	On-campus internet accessibility	Accessibility of technology	How do you rate the **accessibility of internet access** on the campus**?**	Very low	Low	Regular	High	Very high	LQ
69	Campus internet usability	Usability of technology	How do you rate the **usability of internet access** on the campus?	Very low	Low	Regular	High	Very high	LQ
70	Availability of e-learning system	Availability of technology	The institution has an online learning environment (Moodle, Google Classroom, or equivalent) AVAILABLE for use.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ

71	Reliability of e-learning system	Reliability of technology	The institution has a RELIABLE online learning environment (Moodle, Google Classroom, or equivalent) for use.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	LQ
72	Accessibility of e-learning system	Accessibility of technology	The institution has a virtual learning environment (Moodle, Google Classroom, or equivalent) accessible for use.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
73	Usability of e-learning system	Usability of technology	The institution's virtual learning environment (Moodle, Google Classroom, or equivalent) is user-friendly.	Strongly disagree	Disagree	I do not agree nor disagree	Agree	Strongly agree	SQ and LQ
74	Activity time as a lecturer	Experience	How long have you been engaged in university teaching activities?	Less than 1 year	Between 1 and 5 years	Between 5 and 10 years	Between 10 and 15 years	More than 15 years	LQ
75	Highest academic title	Experience	What is your highest academic degree?		Postgraduate (Lato Sensu)	Master's Degree (Stricto Sensu)	Doctorate (Stricto Sensu)		LQ
76	Time since the highest titration	Experience	How much time has passed since your last academic degree was conferred?	Less than 1 year	Between 1 and 5 years	Between 5 and 10 years	Between 10 and 15 years	More than 15 years	LQ
77	Level of knowledge about Active Learning	Contextual information	How would you rate your level of knowledge about Active Learning?	Very low	Low	Regular	High	Very high	LQ
78	Amount of participation in events on educational innovations	Skills about educational innovations	In the last 5 years, how many educational innovation events have you participated in?	0	1	2	3	3+	LQ
79	Number of books read on educational innovations	Skills about educational innovations	In the last 5 years, how many books or scientific articles on educational innovations have you read?	0	1	2	3	3+	LQ
80	Amount of participation in Active Learning events	Skills about Active Learning	In the last 5 years, how many events on Active Learning have you participated in?	0	1	2	3	3+	LQ
81	Number of books read on Active Learning	Skills about Active Learning	In the last 5 years, how many books or scientific articles on Active Learning have you read?	0	1	2	3	3+	LQ

82	Amount of Active Learning techniques over which you have mastery	Skills about Active Learning	Considering the listed Active Learning techniques, how many of them do you master? - Problem-Based Learning - Flipped Classroom - Project-Based Learning - Collaborative Learning - Inquiry-based Learning	0	1 or 2	3	4	5	LQ
83	Number of periods in which adoption was attempted	Willingness to adopt Active Learning techniques	In the last 5 years, how many times have you attempted to adopt Active Learning techniques as the PRIMARY METHOD in a course?	0	1 or 2	3	4	5	LQ
84	Number of subjects in which adoption was attempted	Willingness to adopt Active Learning techniques	In the last 5 years, you have __________ attempted to adopt Active Learning techniques in any topic within a course.	Never	Rarely	Sometimes	Often	Always	LQ
85	Time since last adoption attempt	Willingness to adopt Active Learning techniques	How much time has passed since your last attempt to adopt Active Learning techniques?	More than 3 years	Between 2 and 3 years	Between 1 and 2 years	Between 6 months and 1 year	Less than 6 months	LQ