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A Proposal Of An Instrument To Evaluate Innovation Characteristics For Engineering Students

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Abstract

The current industry demands from graduate engineers a wide range of characteristics in the area of innovation, which responds to the new and growing needs of the market, which today are migrating towards the development of an automated and virtualized industry. This research identifies the characteristics in the area of innovation that professional engineers should possess to the holder, and therefore, those characteristics they should develop during their training at universities. However, there is little evidence on how to evaluate if these are trained in the university. This research proposes instruments to evaluate the characteristics of innovation in engineering students, providing simple and supported tools to achieve this successfully.

Keywords: Innovation abilities, engineering education, instrument of evaluating

I. INTRODUCTION

Today's industry is currently undergoing a significant transformation process, associated with the fourth industrial revolution, where technology, automation, the use of robots and process virtualization are demanding a change in the role that workers and professionals have performed [1]. In this context, the skills traditionally demanded to professionals will change according to the contribution they make within these new chains of production, privileging leadership, creativity and innovation capacities over technical capacities (which are considered to be established) [2]. Innovation, which uses new or existing knowledge to produce or improve all or part of traditional systems, and to convert ideas into new products or services, will enable professionals to contribute constantly to highly automated and technological industries [3].

Thus, in the field of engineering, engineering professionals demanded by the market must have an innovative mindset and develop skills that will allow them to optimize processes and develop new sustainable solutions [4]. In response to this, universities and major accreditation agencies for engineering careers are now promoting the incorporation of innovation training in engineering careers, to deliver skills and tools that allow them to perform successfully in the working world [5]. Universities are defining and incorporating the characteristics and concepts of innovation in engineering that their students require. Variables such as adaptability, continuous learning, communication, creativity, dedication, proactivity, among others, provide an initial conceptual framework for education [6]. From this perspective, there is a great number of characteristics that define the innovative professional in engineering; however, this wide amount of concepts does not facilitate their application in university environments and makes the evaluation and follow-up of their training in engineering students more complex [7].

In view of this situation, this research clusters and simplifies the characteristics of innovation in engineering, generating a set of 10 abilities that must be trained in engineering students, grouped into 4 types. Based on these, an instrument is proposed for the evaluation of innovation characteristics in engineering students, through standardized parametric indicators, providing a simple tool for the monitoring of students.

II. RESEARCH METHOD

The research method is organized in two stages: (1) Identification, definition, and selection of innovation characteristics for engineering students and (2) Instrument of evaluation. Figure 1 shows the stages and specifies the research tools and activities, along with the results of each stage. In the first stage, a literature review was carried out for the identification and definition of characteristics of innovation in engineering. The search was carried out in Web of Science and Scopus libraries, together with the incorporation of manuals and technical documents on innovation from recognized entities in the area and university accreditation organizations. Later, based on the bibliographic support, the research team analyzed, redefined, grouped and categorized the innovation characteristics for engineering students. In the second stage, based on a new literature review (in the same collections already defined), instruments were identified for the evaluation of competencies for engineering students. With this, the research team developed a proposal of an instrument to evaluate the characteristics of innovation in engineering students.

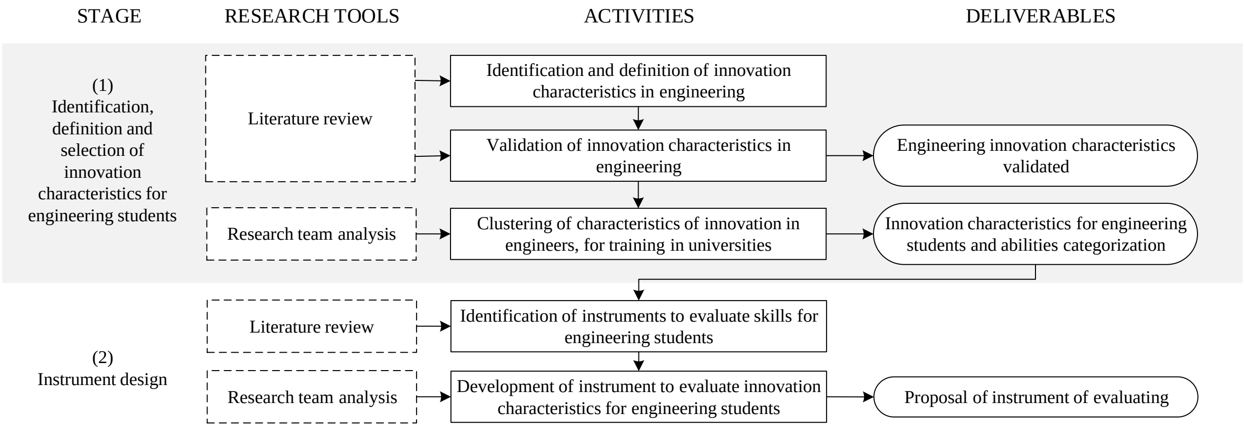

Figure 1. Research method diagram

III. CONCEPT DEVELOPMENT

The current development and the fourth industrial revolution (Industry 4.0) are establishing new standards for the industries. Automation, technology, the use of robots, digital systems, and the virtualization of systems and processes today are changing the dynamics of the industry and imposing new challenges on professionals in all productive sectors [8]. If in the 20th century advanced technical skills and specialization for the execution of processes were highly required by the market, in the 21st century the role of workers will be associated with the control and optimization of automated industrial processes, and no longer only with their execution [1]. In this context, innovation skills will be increasingly in demand and will be the hallmark of successful inclusion in the new dynamics of industry 4.0 [9]. Innovation uses existing or new knowledge to create new products, processes or services, or to improve existing products, processes or services, obtaining original results of great social or economic value, sustainable over time [10]. It is the effective realization that produces a change, to improve or to perfect part or the totality of a system, managing to turn ideas into useful elements [3].

In response to the requirements of industry and society in the 21st century, and associated with the needs for employability that demand innovation skills in new professionals, universities that are training engineers today must include the formation of innovation skills in their academic curricula [2]. This is indicated by prestigious accrediting agencies, which point out that creativity and innovation skills should be considered in the training of future engineers, and should be integrated throughout the training development [5], [11]. New engineers must be technically competent, ethically and culturally educated, able to work in teams and lead them, innovative and entrepreneurial, with the capacity of self-learning throughout their working lives [4].

Training in innovation allows engineering students to apply concepts and new ways of seeing a problem in different subjects, transforming the formation of rigid theories and processes into new options for the development, optimization or change of classic systems, promoting the use of technologies, prototyping, and creation in error-testing cycles [12].

Different authors show the application and training of innovation skills in university and engineering education contexts, indicating the key aspects that it should consider [7]. Figure 1 shows a comparative review of 20 characteristics of innovation in engineering and contrasts them with the presence of these in the 31 papers researched. 20 characteristics of innovation in engineering have been identified, corresponding to attitudes that engineering professionals must have to be considered innovative professionals. These are: (1) Communications skill: professional ability to efficiently communicate ideas and persuade others, (2) Creative: professional capable of generating new ideas or associations between ideas to produce original solutions, (3) Curiosity to do and learn: curious and reflexive professional, and in constant search of new ideas and solutions. to do so, he is constantly learning new subjects, (4) Collaborator and integrator: professional who collaborates with other people with specific knowledge and skills, to successfully achieve an innovation, (5) Leader and team Manager: professional who is a team leader and manager, facilitating and driving innovation, (6) Multiple alternatives seeker: professional who is looking for a better way to execute a process, design or make a product, (7) Business Savvy: professional who knows the role of finance, sales, supply chains, and the innovation market, (8) Knowledge Integrator: professional who integrates his own knowledge, his team's knowledge and technical to build new solutions, (9) User-Focused: professional searching for solutions focused on the user's needs, (10) Visionary: professional with a vision and objectives clear, (11) Analytical: Meticulous professional who carefully examines, (12) Challenger: Professional willing to do things differently, questioning traditional methods, (13) Deep Knowledge: Educated and knowledgeable professional on a wide range of topics, (14) Adapter: energetic professional, active to learn, do and remake, accepting positively the opinion of others, (15) Implementer: professional who organizes and manages efficiently resources to develop an innovation, (16) Passionate: professional who is passionate about his work and the goals he has achieved, transmitting his passion to his team, (17) Persistent: professional committed, determined, resilient. He has the conviction that he will achieve its goals, (18) Responsible: a professional capable of taking control of his activities and supervising a project from start to finish, responding to the results and accepting possible errors, (19) Risk Taker: professional willing to take chances and fail, and (20) Experimenter: professional capable of accepting uncertainty, using prototyping to evaluate options.

Table -1 Presence of engineering innovation characteristics in the literature review

Review articles	Communications Skill	Creative	Curiosity to do and learn	Collaborator and	Leader and team	Multiple alternatives	Business Savvy	Knowledge Integrator	User-Focused	Visionary	Analytical	Challenger	Deep Knowledge	Adapter	Implementer	Passionate	Persistent	Responsible	Risk Taker	Experimenter
Edwards et al. [13]	x	x		x	x		x	x		x	x	x				x		x		
Ferguson et al. [6]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
Holzmann [14]		x	x			x				x		x						x		
Satheesh et	x	x	x				x		x			x	x		x	x		x		

al. [15]																				
Pitso [16]		x	x			x						x	x				x	x	x	x
Galego et al. [17]							x			x							x		x	
Edwards-Schachter et al [18]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cao et al. [19]	x			x	x		x		x											
Zuo [20]	x		x	x	x						x		x			x				x
Garud et al. [21]						x	x		x	x	x	x		x				x		
Palavicini and Cepeda [22]	x	x	x	x		x			x	x					x	x				
Jarrar and Anis [23]	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x
Poveda et al. [24]		x		x	x	x	x	x	x	x		x		x	x		x			
Lounsbury et al. [25]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hebles and Llanos-Contreras [26]	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x	x	x	x
Radharamanan and Juang [27]		x				x	x	x	x		x	x	x	x	x	x	x		x	x
Schuelke-Leech [28]	x	x	x		x		x	x		x			x				x			
Shuli et al. [29]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bilén et al.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

[30]																				
Browder et al. [31]	x	x	x	x				x	x			x		x	x	x	x			x
Creed et al. [32]	x	x		x	x	x	x	x	x		x		x	x	x	x			x	x
Huang-Saad et al. [33]	x	x	x	x	x	x	x	x	x	x	x		x	x			x	x	x	
Mayhew et al. [34]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mendelson [35]	x	x	x	x	x		x	x	x		x							x		x
Oswald [36]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Selznick and Mayhew [37]	x	x	x	x	x			x		x				x	x	x		x	x	x
Taks et al. [38]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Wang and Kleppe [39]	x	x	x	x	x	x		x			x		x	x	x	x	x		x	x
Xu et al. [40]	x				x	x	x	x	x		x		x						x	
Hebles et al. [41]	x		x	x	x	x		x		x			x					x		
Sánchez et al. [42]	x	x	x	x	x	x		x	x	x		x		x	x	x	x	x	x	x
% of presence in the literature review	**81%**	**81%**	**74%**	**74%**	**74%**	**71%**	**71%**	**71%**	**71%**	**65%**	**61%**	**61%**	**61%**	**61%**	**61%**	**61%**	**61%**	**61%**	**61%**	**61%**

Table 1 shows that 20 characteristics of innovation in engineering are in more than 60% of the papers reviewed, validating they represent the profile of an innovative engineer. For training these characteristics in university engineering students, it is necessary to cluster their abilities. Figure 2 shows the clustering done, obtaining 10 innovative abilities for engineering students, which have been categorized into 4 categories (1) Technical or Practical, (2) Interpersonal or Social, (3) Reasoning, and (4) Management and Business. This clustering into 10 abilities and 4 categories of abilities allows more control for their incorporation and follow-up in university contexts.

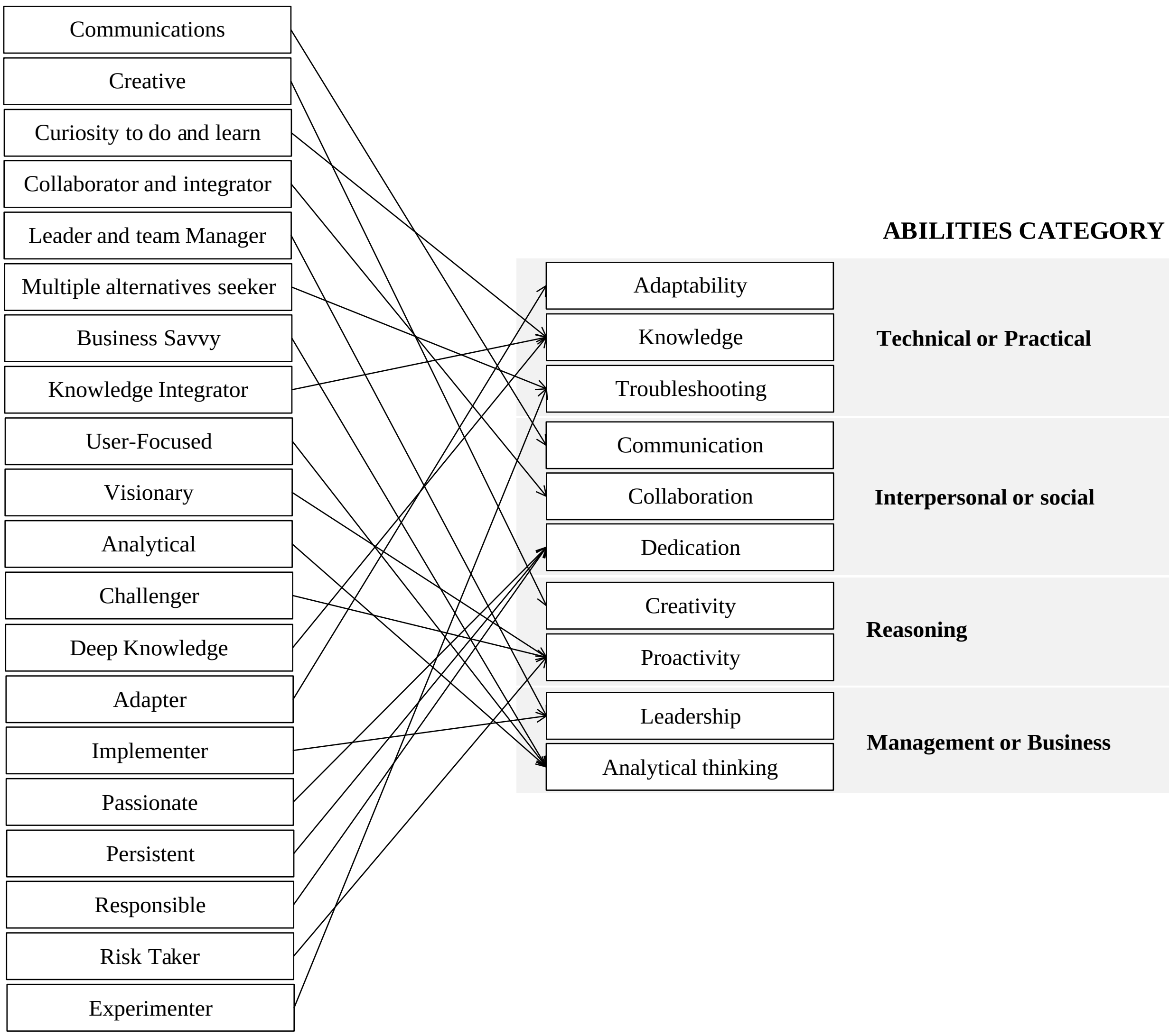

Figure 2. Abilities category

Taking the previous categorization as a reference, and clustering the characteristics associated with innovation, an investigation of instrument alternatives was carried out allowing evaluating or having a general idea of the appropriation of these attributes. The search did not turn out to be very precise to address the characteristics in a specific way, since many of the instruments made reference to case studies and analysis of situations, where instead of self-evaluating the characteristics themselves, they focused on how to act in certain scenarios, which indirectly allows inferring the skills that are behind the actions, selected in response. From the review of case studies and some simple self-evaluation tests, an instrument was designed, allowingthe integration and focus of the mentioned elements, which is detailed in the following section.

IV. INSTRUMENT DESIGN

Based on the qualification of characteristics, obtained previously, the design of an instrument that allows to enhance a measurement of the appropriation of these aspects in engineering students is presented in this section, obtaining a graphic representation of the state of the students in relation to the innovation capacity. The following aspects are considered for the design of this instrument: (I) *Situations of behavioral indicator (Statement)*: in this section, situations of behavior indicator have been specified, to obtain an approximation of the degree of appropriation of the students for a certain skill related to innovation, based on the self-evaluation and own perception of each one of them. The instrument designed considered 36 statements, grouped into four categories related to the abilities clustering identified. (II) *Weighting abilities category*: in order to emphasize the types of skills according to the different areas within engineering students, it has been considered to give weights to each of the categories, already determined previously. (III) *Evaluation Scale*: the evaluation scale used in this study is a Likert Scale, which is used to allow the individual to express how much they agree or disagree with a particular statement. In this sense, Likert Scale has the advantage of allowing the respondent to choose a degree of opinion, rahter than select a simple yes/no answer. Therefore, quantitative data is obtained, which means that the data can be analyzed with relative ease. For this case scale with five degrees of compliance is used, from 1 to 5, considering Strongly Disagree (1), Disagree (2), Neither agree nor disagree (3), Agree (4), and Strongly Agree (5). (IV) *Interpretation and visualization of the results*: To represent the results of the application of the instrument, the use of a radial chart has been considered, which is useful for seeing what aspects or variables are high or low within a data set. This visualization is ideal for displaying performance. In addition to this, it will be used representation in a Cartesian plane where each quadrant relates the characteristics of abilities with their corresponding clustering. Tables 2, 3, 4 and 5 present the behavioral indicator situations (statement) for each innovation characteristics identified.

Table 2- Technical or Practical category (AC1)

Characteristic (C)	Situation of behavioral indicator (Statement)
C1. Adaptability	S1. You accept and adapt easily to changes in a positive way and with constructivism. S2. Respond to changes with flexibility and optimism. S3. You know how to adapt your responses and attitudes to changing circumstances. S4. You rearrange priorities and strategies with agility.
C2. Knowledge	S5. You maintain an open attitude of learning throughout your professional life. S6. You know how to transmit to your collaborators the culture of continuous learning. S7. You consider knowledge as a decisive asset for competitiveness.
C3. Troubleshooting	S8. You identify the problems and look for the possible causes that have caused them S9. You know how to transform problems into opportunities or learning. S10. You look for the most practical alternatives and solutions to complex problems

Table 3- Interpersonal or Social category (AC2)

Characteristic (C)	Situation of behavioral indicator (Statement)
C4. Communication	S11. You communicate information clearly and using the appropriate language. S12. You use the appropriate channels when communicating, depending on the content and purpose of the communication. S13. You adapt your communication record to your interlocutor and situation. S14. You have active listening skills.
C5. Collaboration	S15. You put the interests of the group before the personal ones. S16. You work in coordination with the other members, sharing and delegating responsibilities. S17.You promote a harmonious and participative work environment. S18. Assume the possible consequences of your actions and those of your team or collaborators
C6.Dedication	S19. You achieve with the commitments made. S20. You carry out the tasks with dedication within the established deadlines. S21. You effectively manage time, responsibility, commitment and coordination of tasks.

Table 4- Reasoning category (AC3)

Characteristic (C)	Situation of behavioral indicator (Statement)
C7. Creativity	S22. You find new and effective ways of doing things. S23. You are looking for new alternatives to solve problems. S24. Generate new ideas to respond to future demands of the environment. S25. You view failures as opportunities to learn.
C8. Proactivity	S26. You take the initiative in solving problems instead of waiting for them to solve themselves or for someone else to solve them. S27. You are persevering and face changes positively. S28. You don't just do the tasks that are asked of you, but you know how to create new opportunities by searching for information.

Table 5- Management or Business category (AC4)

Characteristic (C)	Situation of behavioral indicator (Statement)
C9. Analytical thinking	S29. Separate the parts of a whole to analyze the meaning of each one S30. It focuses more on elements than on relationships S31. Follow sequential steps for analysis, studying linearly S32. Is decisive or convergent, focused on finding a solution
C10. Leadership	S33. You plan the tasks and resources according to the defined objectives. S34. You provide tools and techniques that allow the team to organize their work. S35. You define priorities and control the quality of work. S36. You know how to get the best from each of your collaborators.

Then, give importance weight to abilities clustering, shown in table 6.

Table 6- Abilities category weighting

Characteristic (C)	Abilities Category (AC)	Weigth (%)
C1. Adaptability	AC1.Technical or Practical	$AC1_w$
C2. Knowledge		
C3. Troubleshooting		
C4. Communication	AC2.Interpersonal or Social	$AC2_w$
C5. Collaboration		
C6. Dedication		
C7. Creativity	AC3. Reasoning	$AC3_w$
C8. Proactivity		
C9. Analytical thinking	AC4. Management or Business	$AC4_w$
C10. Leadership		

Assigned the previous weightings, it is possible to calculate the innovation factor (IF), as follows:

$$Innovation\ Factor\ (IF) = \sum_{i=1}^{4} (ACiw\ *\ Score\ Achieved\ ACi) \quad (1)$$

$$Score\ Achieved\ ACi = Average(\mathrm{Ci})\ ;\quad \mathrm{Ci} = \{\mathrm{Si}\}\ \epsilon\ \mathrm{ACi} \quad (2)$$

Where:

With the values of each abilities category, it is possible to get the results through a radial graph located on the Cartesian plane, where the quadrants represent the categorization of the abilities. As an example, to represent the above, consider the following data shown in table 7.

Table 7- Example of Abilities category weighting

Abilities Category		ACiW (%)	Caharteristics		Average (2)
AC1	Technical or Practical	20%	C1	Adaptability	3
			C2	Knowledge	5
			C3	Troubleshooting	4
			Average AC1		4
AC2	Interpersonal or Sociales	20%	C4	Communication	3
			C5	Collaboration	4
			C6	Dedication	3
			Average AC2		3,3
AC3	Reasoning	25%	C7	Creativity	2
			C8	Proactivity	5
			Average AC3		3,5

AC4	Managment or Business	35%	C9	Analytical thinking	2
			C10	Leadership	4
			Average AC4		3
Innovation Factor (IF) (1)				**3,39**	

Finally, in the next figure the calculated values are graphically represented.

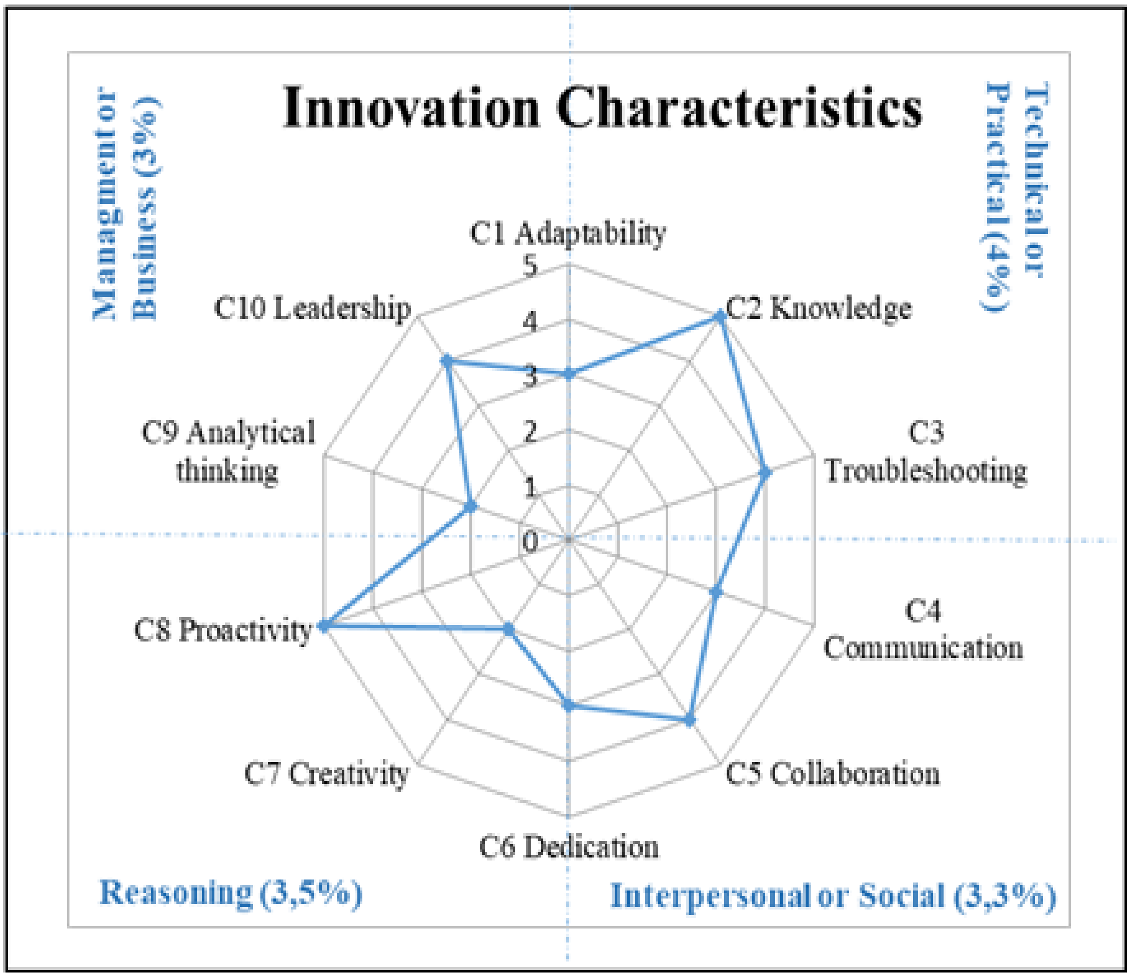

Figure 3. Chart result of innovation characteristics

V. RESULTS AND DISCUSSION

In the case of Technical or Practical Category (AC1), it can be seen that the interest in continuous learning stands out from the rest of the characteristics, which implies that it possesses an ability to search for information to solve problems. On the other hand, the ability to solve problems and the ability to adapt to changes, it is seen a little lower, which could conclude that despite having the attribute of managing learning, it does not necessarily materialize in solving problems, facing eventual changes in the environment. Related to the Interpersonal or Social category (AC2), it is possible to appreciate that good collaborative relationships are established with the members of a group. The ability to communicate ideas can improve in terms of how you transmit them clearly and effectively, along with the development of collaborative skills that Will improve the performance of your work. In this last point, attributes such as responsibility and commitment are also associated to this. Regarding the Reasoning category (AC3), a high capacity is appreciated to take the initiative in the development of actions to generate improvements in the organization or processes, acting opportunely to anticipate future situations. However, in this case the search for new solutions is not necessarily aligned with original or innovative options. For the last category, Management or Business (AC4), there is a perceived lack of ability to analyze situations from a perspective that emphasizes the identification of the parties rather than the relationships between them, which may be due to a less than decisive attitude. On the other hand, there is an adequate capacity for leadership, focused on setting objectives and planning resources effectively to achieve the objectives.

Finally, by analyzing the Innovation Factor (IF) and the radial graph that integrates the characteristics, it is possible to conclude that the value obtained from the global indicator is above the average, and in general terms the categories meet at similar levels, considering the weighting given to each one. However, when observing the graph, the resulting polygon does not have a very regular firmness, demonstrating the existing differences between the various features that have been evaluated. Also, there are some located especially close to the center, while others are found more towards the ends of the figure, indicating a better approach to the related attribute.

VI. CONCLUSION

The designed instrument allows us to obtain, in a simple and clear way, a general perspective of how the students are in terms of the development of the characteristics associated with innovation. Not only does it provide quantitative information through the Innovation Factor (FI) wich integrates all the skill categories defined for this study, but also the graphic representation allows knowing -without going into a quantitative detail- the regularity of the figure that is generated in the polar chart, understanding that the more regular the shape of the polygon is and the closer it is to the ends of the figure, the more integration exists of the characteristics required for the development of innovation, a skill that every day it becomes more important nowadays, not only in the university training process, but also in the professional performance of future engineers.

As future work, it has been suggested to apply the proposed instrument in groups that will allow comparison of results, in terms of those who have participated in skills development workshops associated with innovation (Experimental Group) and others who have not (Control Group). A concrete appreciation of the measurements made by the instrument could be obtained, as well as making some adjustments in its design, depending on the analysis of the results and the experience of the students, considering the situations of behavioral indicator evaluated.

VII. ACKNOWLEDGEMENTS

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