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ORDERING THE MOST RELEVANT SKILLS IN AN ENGINEERING DEGREE USING FUZZY LOGIC. A CASE STUDY

J M. Brotons-Martínez
Department of Economic and Financial Studies, Miguel Hernández University, Elche, Spain
jm.brotons@umh.es

H. Puerto-Molina
Engineering Department, Miguel Hernández University, Elche, Spain
hpuerto@umh.es

J. M. Cámara-Zapata
Applied Physics Department, Miguel Hernández University, Elche, Spain
jm.camara@gmail.com

Abstract

Nowadays, the increasing uncertainty of a globalized world economy poses additional challenges to the new agricultural engineering graduates. They have to face increasingly complex challenges, such as increasing demand for agricultural produce in a Climate Change situation, a growing difficulty to guarantee food safety caused by global trade, and an improvement of the resilience of productive systems based on precision agriculture. All of this along with the drawback of a reduced interest of new students in this kind of graduate study. Previous works have dealt with the importance of the general skills in an agricultural engineering degree, showing the relevance of the instrumental skills (capacity for analysis and synthesis, organization and planning capacity, ability to manage information, oral and written communication, foreign language knowledge, computer knowledge, problem resolution, and decision making). This work aims to order these instrumental *skills to face the above-mentioned challenges in a more effective way. We are aware that the result of this order presents high doses of uncertainty and ambiguity, and that is why we propose the use of fuzzy logic. The application of this methodology based on fuzzy mathematics can contribute to updating the university degrees so that graduates can successfully the new challenges they will encounter in the workplace. Results show that capacity for analysis and synthesis, organization and planning capacity, and foreign language knowledge is the best-considered skills.*

Keywords

Agricultural Engineering, Climate Change, Skills, Fuzzy

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1. Introduction

Since the end of the twentieth century, different associations, like the International Commission of Agricultural Engineering (CIGR), and AFANet-Socrates (thematic network for agriculture, forestry, aquaculture, and the environment), have attempted to develop a common curriculum of Agricultural Engineering in Europe aiming at promoting workforce mobility and contributing to the development and specialization of the sector (European Society for Engineering Education, SEFI, 2002). Following the Bologna Declaration (1999), the revision of the curricula of university degrees began to adapt its contents to the requirements of the European Higher Education Area (EHEA). In Spain, the National Agency for Quality Assessment and Accreditation (ANECA) developed the white paper for the degree in Agricultural and Forestry engineering in which they compiled the main characteristics of the degree in European countries and proposed two degrees in agricultural engineering. They analysed the opinion of graduates and companies in the sector on the importance of professional profiles and general skills in the last five years. The general skills that were most valued for the new degree proposals were encompassed within the instrumental skills (analysis and synthesis capacity, organization and planning ability, and problem-solving skills) while the least valued were personal skills (recognition of diversity and multiculturalism) and systemic (knowledge of other cultures and traditions) (ANECA, 2005). The currently taught curricula of the degrees in agricultural engineering in more than 30 Spanish universities were developed based on these assessments and according to the conditions of the EHEA. Thus, in the 2010-11 academic year, the Degree in Agrifood and Agro-Environmental Engineering (GIAA) replaced the former Titles of Agricultural Engineer and Agricultural Technical Engineer at the Higher Polytechnic School of Orihuela (EPSO) of the Miguel Hernández University (UMH). This

Higher Polytechnic School began its activities in 1972, so it is the university center with the most extended experience in Higher Education in the province of Alicante and its facilities are the largest in a Higher Education center in Spain. The degree is structured in four academic courses and ends with the public presentation and defense of the Final Degree Project.

1.1. Challenge Analysis

Currently, the progress of humanity is conditioned by paradigms of great complexity and uncertainty, such as climate change, technological development, the information and communication society, the growth of inequalities, and migration. The University contribution is key to overcome these challenges, both in the generation of new knowledge through research and innovation and in the training of people through higher education that helps the development of flexible, critical, and ethical personalities. To do this, a University update is required to review thoroughly its organization and what and how is relevant knowledge, both taking down barriers between traditional disciplines and promoting active learning that goes beyond the master class format. In Spain, just as the General Organic Law of the Educational System (LOGSE) did not achieve a paradigm shift towards relevant and globally meaningful learning in compulsory education, the Bologna Treaty has failed to change the university student from being a passive to an active learner (Vallory, 2020).

Today, the production systems provide huge amounts of food to wide-world markets, due in part to an intensive production with negative impacts on natural resources and the environment (water scarcity, loss of biodiversity, soil depletion, massive deforestation and high levels of greenhouse gas emissions). Therefore, agriculture contributes considerably to climate change, but it is also affected by it. Climate change reduces the resilience of production systems and contributes to the degradation of natural resources. To avoid this, it is necessary to meet the demand for products and services of present and future generations, while ensuring profitability, environmental protection, social and economic equity, system resilience, and efficiency in the use of resources (FAO, 2019). Global challenges include hunger and extreme poverty and some of the highest population growth rates occur in areas that depend on agriculture and that pose high risks of food insecurity. The increasing movement of people and goods, changes in environmental conditions and production practices facilitate the emergence of new threats such as the spread of diseases or invasive species, which can affect food security, human health, and the effectiveness and sustainability of production systems. New policies and technical skills are required to help eliminate threats and protect the food chains, for example, by promoting local and regional agricultural markets (FAO, 2019).

The digital transformation of society affects almost every feature of human activity (work, leisure, communication, information, etc.). Since the end of the 20th century, the most important universities in agronomy include subjects related to automatic and robotics in their curricula like Wageningen Agricultural University (NL), Silsoe College at Cranfield University (UK), University College of Dublin (IE), Ecole National du Génie Rural des Eaux et des Forêts (FR), Haifa Institute of Technology: Agricultural Engineering (IL), Gembloux University(BE), the Czech University of Agriculture in Prague (CZ), Kyoto University (JP), Okayama University, (JP) University from Putra, (MY) University of Florida (US) and Clemson University (US) (Rodríguez, 2008). However, precision agriculture has barely begun to develop, although it is expected to help meet the current challenges of production systems and food chains. The integration of communication and information technologies to production systems involves the development of decision support systems to help produce food more efficiently and sustainably, and create the basis for food security for a growing world population. Control systems, in addition to reporting, can make decisions on how autonomous, or preparing the process of decision - making so that, as a rule, the farmer only needs to monitor the processes and authorize the action proposed by the system (Panda and Bhatnagar, 2020).

The trend in the number of new students who choose to study degrees in agricultural engineering is decreasing. In recent years, the diversification of the educational opportunities favours the degrees competing with the GIAA, like the degrees in Food Science and Technology, in Environmental Sciences or Biotechnology, all offered by the UMH. There has also been an international trend to replace the name of the degree in agricultural engineering with other university degrees as biosystems engineering or agricultural and biological engineering, probably more adapted to meet more specific society demands (Aguado et al., 2011; ASABE, 2019). However, in Spain, the degrees in agricultural engineering are the only ones with regulated professional attributions and have high employment rates. Regarding the gender gap, it is still necessary to reduce the differences in employment rates and annual salaries between women and men in these degrees. It would be desirable to increase the enrollment of female students, also taking into account that their previous training may be even higher than that of their male classmates. On the other hand, international accreditations of degrees, such as through the European

Network for the Accreditation of Engineering Education (ENAEE) can help increase the enrollment of students from other European countries, thanks to programs such as ERASMUS UE, or from other continents.

1.2. Workplan

In the current situation, it is advisable to review the characteristics of the training of professionals in agricultural engineering to ensure success to face the challenges. This paper aims to determine the most suitable skills that will enable future graduates to face current and future challenges described among those defined in the current curricula of the GIAA of the EPSO (UMH) so that they can gain greater importance in future Curriculum reforms. For this purpose, opinions of experts, related to the GIAA and EPSO, were gathered and treated by fuzzy logic. The competencies taken into account are those according to the Tuning project (ANECA, 2005). With the information acquired, a blurred relationship between competencies and their characteristics is built. The use of an algorithm for the management of the different competencies will allow detecting those over which the GIAA should be prioritized.

Next, we proceed to the description of the main concepts used in the analysis. In results and discussion, the application carried out for the ordering of the most relevant skills in an engineering degree is presented and analyzed. Finally, the main conclusions of the work are exposed.

2. Methodology

To determine the skills that have the greatest capacity to adapt to the future challenges detailed in the previous section, models based on dichotomous decisions can be used, that is, models that indicate that one option is preferable to another or not, in which no graduation of these preferences are considered (Bermejo *et al*. 2017). Some authors such as Klaharn (2017) use a three-rating scale about teacher's competency using the dual-response format. In this way, we propose in this communication the use of fuzzy preference theory, since it is an adequate tool to model their intensity (Nurmi, 1981; Tanino, 1984; Baets y Fodor, 1997). Recently, Sorrosal (2012) has used self-organizing maps to analyse student evaluations of teaching. Tong et al. (2020) propose a Fuzzy Decision-Making Method for Program Evaluation and Management Policy of Vietnamese Higher Education. For this, a group of N experts was requested to assess the capacity of each of the skills

$C = \{C_j\}$, $j = 1,...,8$ to face the four challenges considered $R = \{R_k\}$, $k = 1,2,\ldots,4$. In particular, according to the Tuning Project (ANECA, 2005), we have considered:

C1: Capacity for analysis and synthesis

C2: Organization and planning capacity

C3: Ability to manage information

C4: Oral and written communication

C5: Foreign languages knowledge

C6: Computer knowledge

C7: Problem resolution

C8: Decision making

And the following challenges have been raised:

R1. Reduction of the contribution to climate change and improvement of the resilience of productive systems.

R2. Quality control and assurance of the food chain.

R3. Development of precision agriculture: communication, instrumentation, measurement, control, automation, image processing, etc.

4. Enhancement of the degree's appearance to increase students' enrollment, especially of women.

N experts were requested to assess if the proposed skill can face the corresponding challenge. A scale of six elements has been used (Sansalvador y Brotons, 2018).

Table 1: *Values Assigned to the Linguistic Labels*

Linguistic label	Value
(1) disagree	0.0
(2) Strongly disagree	0.2
(3) Disagree	0.4
(4) Neutral	0.6
(5) True	0.8
(6) Very true	1.0

(Source: Own Elaboration)

From N experts, $n_{kj}^{(1)}$ disagree with the fact that skill j is capable of facing the k challenge, $n_{kj}^{(2)}$ strongly disagree with the fact that skill j is capable of facing the k challenge, … and $n_{kj}^{(6)}$ considers that is very true the fact that skill j is capable of facing the k challenge. The ability of skill j to meet the challenge k is expressed by p_{ki} and is obtained according to:

$$p_{kj} = 0.0 \cdot n_{kj}^{(0)} + 0.2 \cdot n_{kj}^{(1)} + ... + 1.0 \cdot n_{kj}^{(5)},\ k = 1, 2, \ldots, 4,\ j=1,2,\ldots,8 \quad (1)$$

Within each challenge, we have eight values of p_{kj}, one for each skill. The membership function of each skill is obtained by dividing the corresponding p_{kj} of each skill by the maximum p_{kj} of the challenge. The membership function indicates the capacity of the subject j to face the challenges posed as a whole.

$$\mu\left(C_{kj}\right) = \mu_{kj} = \frac{p_{kj}}{\max_j\left(p_{kj}\right)},\ k = 1, 2, \ldots 4,\ j=1,2,\ldots,8 \quad (2)$$

At this point, we have one membership function for each skill in each challenge. This information can be summarized in a matrix ($\tilde{R}$). This matrix indicates the capacity of each skill to face each of the challenges posed and will be expressed by the membership function, μ_{kj}, where values close to 1 indicate that the skill is very capable of facing the challenges and values close to zero that it is not capable of facing this challenge at all (Terceño-Gomez, 2009).

$\tilde{R}$ =

	R_1	R_2	R_3	R_4
C_1	μ_{11}	μ_{12}	μ_{13}	μ_{14}
C_2	μ_{21}	μ_{22}	μ_{23}	μ_{24}
…	…	…	…	…
C_8	μ_{81}	μ_{82}	μ_{83}	μ_{84}

Next, the values of the matrix $\tilde{R}$ need to be compared between them, and a new matrix for each challenge k ($\tilde{S}_k$) is constructed according to the following expression.

$$a_{ij}\left(C_k\right) = \begin{cases} 1 & \mu_{jk} > \mu_{ik} \\ 0 & \mu_{jk} \le \mu_{ik} \end{cases} \quad (3)$$

In this way, 4 matrices of 8x8 order will be obtained, one for each skill. Values 1 indicate that the skill of the column is preferred to the skill of the row. For example, if for a given challenge $a_{23} = 1$ $a_{23} = 1$ it indicates that skill 3 faces this challenge better than skill 2. The aggregation of them, duly weighted by the weight assigned to each skill, will allow obtaining the following matrix.

$\tilde{S} =$

	C_1	C_2	…	C_8
C_1	x	β_{12}	…	β_{18}
C_2	β_{21}	x	…	β_{28}
…	…	…	…	…
C_8	β_{81}	β_{82}	…	x

From which an appropriate α-cut can be taken, that is, in cell jk, a one will be assigned if the value of the cell is greater than the α-cut and zero otherwise. Several authors use α-cut, like Saido et al. (2018) in a model for higher-order thinking in science among secondary school students. Thus, for example, if an α-cut 0.6 is taken, values greater than 0.6 will take value 1 and the lower values will take 0 value. This way there is a Boolean matrix composed of zeros and ones where the columns and rows correspond to subjects. Different methodologies have been applied to determine the importance of different subjects such as sanitized graphics theory (Terceño et al, 2009; Gil Aluja, 1999) or Interpretive Structural Modeling (Hsu, et al, 2019, Su, 2017).

For this particular, we proceeded as follows:

1. The columns integrated exclusively by zeros are selected, that is, the subjects to which they correspond are preferred over the rest. These subjects correspond to the first group that we call N_1, that is, the set of skills with the worst capacity to face the challenges posed.
2. The columns and rows corresponding to that skill are then eliminated
3. From the remaining part of the matrix, those columns integrated exclusively by zeros are re-selected, that is, they are preferred to all others. These subjects correspond to the second group and that we call N_2 and that you represent the skills that are capable of facing the challenges posed better than those of level 1.
4. The columns and rows corresponding to these matters are removed again, and so on until the matrix is depleted.

In this way, the final order from less able to more able skills to face the challenges is N_1, N_2, and so on.

3. Results and Discussion

The objective is the design of a curriculum capable of facing the challenges posed for the 21st century. Therefore, a group of experts was requested to express their opinion on the ability of each competition to meet these challenges. This respondent group was graduates of the agricultural engineering degrees of the EPSO in Orihuela (Spain): six employees, four managers, and two self-employees. According to Robbins (1994), the number of participants required for decision-making problems varies between five and seven. As a result, the number of 12 is more than enough for this research.

Table 2 shows for each challenge the capacity of the different skills to face it. This analysis was also used by Cervero *et al.* (2020). Thus, for example, for skill number 1 (capacity for analysis and synthesis) 1 expert has considered that the capacity to face the challenge of Climate change is neutral, 4 that this capacity is true, and seven consider this capacity to face the challenge is very true. Column n indicates the total number of experts who have assessed each competence, in all cases 12.

Column p indicates the capacity of each competence to meet the established challenge. Thus the ability of competition 1 (capacity for analysis and synthesis) to face the challenge of climate change is obtained as $p_{11} = (1 \cdot 0.6 + 4 \cdot 0.8 + 7 \cdot 1)/12 = 0.9$. This process is repeated for all skills and the membership function is obtained, dividing the value of p by the maximum of the column ($\mu_{11} = 0.9 / \max(0.9, 0.87, 0.68, 0.63, 0.38, 0.32, 0.63, 0.5) = 1$).

Table 2: *Capacity of Skills to Deal with the Challenges Raised*

R1. Climate change									
	1	2	3	4	5	6	n	p	μ
C1				1	4	7	12	0.90	1.00
C2				1	6	5	12	0.87	0.96
C3		1	1	5	2	3	12	0.68	0.76
C4			4	2	6		12	0.63	0.70
C5		4	5	3			12	0.38	0.43
C6	1	5	4	2			12	0.32	0.35
C7			4	3	4	1	12	0.63	0.70
C8		1	5	5	1		12	0.50	0.56

R2. Quality of the food chain									
	1	2	3	4	5	6	n	p	μ
C1				1	7	4	12	0.85	0.93
C2					5	7	12	0.92	1.00
C3		1	2	5	4		12	0.60	0.65
C4		2	5	4	1		12	0.47	0.51
C5			2	3	4	3	12	0.73	0.80
C6		1	1	8	2		12	0.58	0.64
C7			4	4	2	2	12	0.63	0.69
C8		1	1	4	4	2	12	0.68	0.75

R3. Precision agriculture									
	1	2	3	4	5	6	n	p	μ
C1				1	8	3	12	0.83	0.88
C2					1	3	4	0.95	1.00
C3		1	2	5	4		12	0.60	0.63
C4	1	2	5	4			12	0.40	0.42
C5		1	1	3	4	3	12	0.72	0.75
C6		1	5	4	2		12	0.52	0.54
C7		2	2	2	5	1	12	0.62	0.65
C8			1	2	8	1	12	0.75	0.79

R4. Degree's appearance									
	1	2	3	4	5	6	n	p	μ
C1				3	7	2	12	0.78	1.00
C2				3	8	1	12	0.77	0.98
C3			4	6	2		12	0.57	0.72
C4			3	5	4		12	0.62	0.79
C5		1	1	3	3	4	12	0.73	0.94
C6		6	4	2			12	0.33	0.43
C7	1	1	3	2	5		12	0.55	0.70
C8		1	2	2	4	3	12	0.70	0.89

(Source: Own elaboration)

Once the membership functions have been obtained, we proceed to summarize the former relationship in Table 3. Thus, the value 1.00 corresponding to competition 1 and challenge 1 indicates that the first competition (capacity for analysis and synthesis) is very capable of facing challenge 1 (climate change).

Using expression (3) to compare the results of Table 3, it is possible to build Table 4, which represents a matrix denoted by S_k. As an example, for challenge 1, the value 1 corresponding to row

C2 and column C1 indicates that skill C1 (capacity for analysis and synthesis) can face challenge 1 better than skill C2 (organization and planning capacity).

Table 3: *Challenges Assessment*

	R1	**R2**	**R3**	**R4**
C1	1.00	0.93	0.88	1.00
C2	0.96	1.00	1.00	0.98
C3	0.76	0.65	0.63	0.72
C4	0.70	0.51	0.42	0.79
C5	0.43	0.80	0.75	0.94
C6	0.35	0.64	0.54	0.43
C7	0.70	0.69	0.65	0.70
C8	0.56	0.75	0.79	0.89

(Source: Own Elaboration)

Table 4: *S_k Valuation Matrices of Each Skill as a Function of Each Challenge*

R1. Climate change								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1								
C2	1							
C3	1	1						
C4	1	1	1					
C5	1	1	1	1			1	1
C6	1	1	1	1	1		1	1
C7	1	1	1					
C8	1	1	1	1			1	

R2. Quality of the food chain								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1		1						
C2								
C3	1	1			1		1	1
C4	1	1	1		1	1	1	1
C5	1	1						
C6	1	1	1		1		1	1
C7	1	1			1			1
C8	1	1			1			

R3. Precision agriculture								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1		1						
C2								
C3	1	1			1		1	1
C4	1	1	1		1	1	1	1
C5	1	1						1
C6	1	1	1		1		1	1
C7	1	1			1			1
C8	1	1						

R4. Degree's appearance								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1								
C2	1							
C3	1	1		1	1			1
C4	1	1			1			1
C5	1	1						
C6	1	1	1	1	1		1	1
C7	1	1	1	1	1			1
C8	1	1			1			

(Source: Own Elaboration)

The average of the four S_k matrix of Table 4 has been obtained. To make it more understandable, a 0.7-cut has been obtained (Table 5). That means that if the value of a cell is lower than 0.7, the assigned value will be 0, and if the value of the cell is higher or equal to 0.7, the value assigned value will be 1.

Table 5: *α-cut 0.7*

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1								
C2								
C3	1	1			1			1
C4	1	1	1		1			1
C5	1	1						
C6	1	1	1		1		1	1
C7	1	1			1			1
C8	1	1						

(Source: Own elaboration)

To get the final order, first of all, we start with the columns which present no ones, in this case, C4 (Oral and written communication) and C6 (Computer knowledge). These are the lowest level, that is, the skills that are less preferred (Table 6). The rest of the skills are preferred to C4 and C6. As a result, we delete columns C4 and C6 and rows C4 and C4. We repeat this procedure until we get the final order.

Table 6: *Skills Ranking Procedure*

		C1	**C2**	**C3**		**C5**		**C7**	**C8**
C1	***Capacity for analysis and synthesis***	0	0	0		0		0	0
C2	***Organization and planning capacity***	0	0	0		0		0	0
C3	***Ability to manage information***	1	1	0		1		0	1
C5	***Foreign language knowledge***	1	1	0		0		0	0
C7	***Problem resolution***	1	1	0		1		0	1
C8	***Decision making***	1	1	0		0		0	0

(Source: Own Elaboration)

Within the agricultural engineering respondents, there were different professional profiles, from the entirely related to production processes to those related to information management, the environment, and land management. Figure 1 shows that regardless of the professional profile analyzed, the results indicate that there is a sustained interest in favouring instrumental skills related to management and the business and management environment, as indicated in previous studies (ANECA, 2005). Other authors such as Yu and Tang (2020) have also built hierarchical network models for English teaching. However, the assessment of knowledge of foreign languages has increased in recent years, probably due to the need for team working and the promotion of international mobility of students and professionals. Thus, the ability to collaborate and work in multidisciplinary groups is more valued than computer skills that, on the other hand, can be taken for granted for nowadays' students.

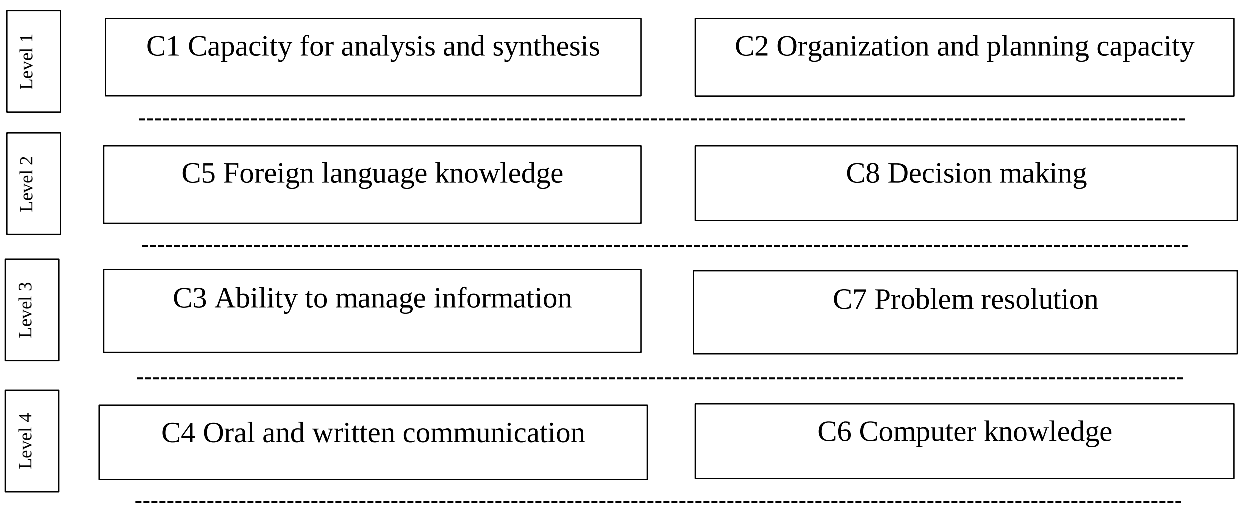

Figure 1: *Hierarchical Structure of Skills to Face the Considered Challenges*

4. Conclusion

In the Agricultural Engineering degree, instrumental skills are the most important. In this work, the classification of this type of skill is analyzed using fuzzy logic. The study is particularized in the degree in Agri-food and Environmental Engineering from the Higher Polytechnic School of Orihuela of the Miguel Hernández University. The results show four levels of relevance. The first includes the capacity for analysis and synthesis and the organization and planning capacity. Foreign language knowledge and decision making are also considered important. At the next level is the ability to manage information and problem resolution. Lastly, oral and written communication and computer knowledge are considered. This type of classifications can contribute to updating university degrees in Agricultural Engineering to increase the probability of success of future graduates in the face of their current and future challenges.

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