Intervention to Cultivate Systemic Thinking and Transdisciplinary Attitudes

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Abstract:

The objective is to encourage the use of transdisciplinary systemic tools (TD-ST) to cultivate transdisciplinary systemic thinking and improvement of skills and attitudes through educational intervention in graduate students. The main findings were a) Attributes of the students that improved days after of the intervention ($p \leq 0.05$) with the highest percentage of variation were happiness (39%), union (41%) and integration (31%), knowledge and appropriation of the tools (50%) and several potentials application (38%). b) The improved attributes were classified as medium changes (attention capacity (0.47), cognitive process (0.46), perceptive function (0.46), linguistic function (0.52), creativity (0.5), use of TD-ST (0.68) and their appropriation (0.65), integration (0.52), joy (0.51) and interest in the use of TD-ST (0.52)), and high changes (union (0.70) and knowledge of the TD-ST (0.75)). c) Students prefer to be taught TD-ST in a creative way using didactic material and real-world, everyday applications. Trainers of transdisciplinary researchers must develop in ourselves and in our students, skills, and attitudes transdisciplinary systemic, basic to the sustainability.

Keywords: Educational intervention, systemic and transdisciplinary skills, transdisciplinary systemic tools.

1 Introduction

UNESCO established education for sustainable development to ensure that students acquire the knowledge and skills necessary to promote it and understand the interactions of the dimensions involved: social,

environmental, and economic (Ekselsa, 2023) [1]. Also reflect on their own actions, considering the impacts from a local and global perspective, and current and future (Tristananda, 2018) [2]. For this, one of the main competencies to be developed by the student as a transition towards sustainability is systems thinking and transdisciplinary attitudes (Tarrant and Thiele, 2016; Ekselsa, 2023) [1, 3], which should be encouraged in schools as an integral part of quality education (Riess and Mischo, 2010, Tristananda, 2018) [2, 4].

Graduates should be prepared in the development of these skills and attitudes (Forum for the Future, 2004; Connell, 2012) [5, 6]. To be able to know the system as a whole, know the elements of the system and the relationships between these elements, detect problems, their causes and propose solutions or their improvement from that global and local vision through the participation of stakeholders, actors and decision makers (Wiek et al., 2011; Scholz, 2015; 2020; Hernández-Aguilar et al., 2018; 2020a; 2020b) [7-12]. Dialoguing with society, as is characteristic in transdisciplinary research; fundamental perspective of mode 2 to produce knowledge. Understanding that science is not only for society, but it is with society (Scholz, 2020) [8]. Hence the importance of their participation and the development of diverse skills of students and teachers to integrate and perform collaboration with both disciplines and stakeholders of the problem, at first with the actors of this and to develop empathy and understanding of the system of study, among others.

In this sense, face current global situation that afflicts humanity, it is necessary to strengthen the characteristic attributes of transdisciplinary researchers in training and their thesis directors or tutors. The researcher must develop characteristics such as critical, creative, and divergent scientific thinking (identifying problems or areas for improvement and proposing solutions), develop transdisciplinary attitudes, virtues and evolve towards systemic thinking (Anes et al., 1994; Nicolescu, 1996; Hernández-Aguilar et al., 2018) [13-14,10]. Systems thinking and transdisciplinary actions are manifested by holistic vision, view on the human being, teamwork, sensitive, and integrative actions, in the different stages of the research process, from empathizing to the problem by approaching it and knowing it in the context of real-world application, the selection of problem itself and the approach of solutions (moments of co-creation), between producers and users of knowledge (Hoffmann et al., 2017) [15] or in general the parties involved in the problem.

However, the level of being sensitive, integrative, and holistic are located at the highest levels of consciousness (level 6, 7 and 8) according to the spiral of consciousness proposed by Wilber according to the value system proposed by Graves (1914-1986) (Prinsloo, 2018; ADH, 2023) [16-17]. Even more relevant is that the attribute of being inclusive is one of the great challenges to be met. It has been reported that only 5% of the world's population is integrative, with decision-making power of only 1%. While the highest percentage of the population (89%) is in levels of consciousness 1-4 (instinctive, tribe, hero, order, scientific achievement) with decision making power of 90.1%.

In the face of global problems and indicators of sustainability and the problem of man's destruction (Hernández-Aguilar et al., 2022) [18]. It is evident the need to evolve consciousness and thinking towards the systemic and transdisciplinary (Beck and Christopher Cowan, 1996) [19]. As one of the ways to achieve the required transformations that lead to survival and sustainability. To have a change or transformation of attitudes fundamentally requires a change of consciousness or level of thinking that leads to new attitudes. One of the challenges of transdisciplinary researchers is to develop it, to work doing the individual and group tasks that allow its evolution (Hernández Aguilar, 2018; Mc Gregor, 2004) [10, 20]. Klein (2004) [21] said, that transdisciplinarity is an essential mode of thought and action, which is necessary to cultivate. It even achieves joy in the living of people trained with the transdisciplinary perspective, simply by seeing things differently (Augsburg, 2014) [22] and succeeding in becoming a transdisciplinary researcher "encauser of hope" as Basarab (1996) [14].

Thus, in this research work, we propose to cultivate and encourage transdisciplinary systems thinking through knowledge and application of transdisciplinary systemic tools (TD-ST) by creative activities with diverse applications, evaluating some skills before, during, at the end, and after the activity. As said by Benson (2007) and Arnold and Wade (2015) [23-24] systems thinking involves the development of analytical and synergistic skills that can help to understand complex systems and their behavior over time. In this sense to make timely decisions, in adequate time. This research also evaluates the emotions of the participants, the

knowledge acquired, the appropriation of the tools and the changes in some transdisciplinary systemic attitudes.

2 Methodology

A creative activity encouraging the use of transdisciplinary systemic tools was carried out in May 2023 in the meeting room of SEPI-ESIME, ZACATENCO (Institution of Higher Education in Mexico) located in the Gustavo A Madero municipality, Mexico City.

2.1 Subjects of study

A focus group was formed with the participation of 20 subjects, including 13 men and 7 women, master's and doctoral graduate students in systems engineering at ESIME-Zacatenco-IPN (who took previous courses in subjects related to systems thinking and the transdisciplinary perspective in research). The students chose the transdisciplinary systemic tool to be used and the presentations were carried out taking a defined time of 15 min per presentation where they had to capture the attention of the audience among which were the same fellow participants, students, and teachers of the study program. The applications for each student and the tools used were the personal decisions of the participating subjects.

The systemic tools were, as can be seen in Table 1, basically the rich vision, the CATWOE (customers, actors, transformation, world view- weltanschhaung, owner, environmental constraints), the dialogic processes, Bronfenbrenner’s ecosystemic models, empathy maps, multidimensional methods such as analytical hierarchization for multi-attribute decision making, sustainability methodology (Mesmis), etc. Applying them in greenhouses, in restaurant services, in road safety education, in health, in soccer coach selection, in breaking paradigms and closed and structured postures, in raising awareness for hand washing in the motorcycle taxi driver sector, students, dance, etc.

2.2 Dynamics of the activity

The participating subjects presented the systemic tool of their choice and an example of its application (free application case). The established criteria were not to use PowerPoint slides, Prezi, Google, or any other similar tool. The intention is to give them the opportunity to develop creativity, develop didactic material, etc. It was raised to be careful in aspects such as: 1) Creativity in teaching, 2) Application and explanation of the tool, 3) Appropriation of the systemic tool and Transdisciplinary perspective, 4) Beneficial emotion produced, 5) Cognitive process and its possible improvement, 6) Awareness generated with the tool and its application, 7) Originality in the application and presentation, 8) For presenting the TD systemic tool in a happy and enthusiastic way, 9) For being participative and provoking integration, 10) For modifying the level of stress, 11) For the effort and time invested in the elaboration of didactic material and Creativity in the teaching of the tool.

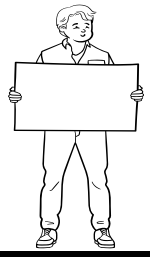
Table 1. Transdisciplinary systemic tools (TD-ST)

Id.	TD-ST	Description	Reference
S1	Rich vision, fish diagram	Development of road safety culture	Lewis (1992), Ishikawa (2013), Delgado et al. (2021) [25-27].
S2	Quality with actor.	Interactive activity with actors-consumers	-
S3	Cognitive development enhancement.	Dance to flow emotions and body, towards openness of thought, balance, brain connections, transdisciplinary look, it all works at the same time.	Drach and Gavelya (2020) [28].
S4	MESMIS. 	Encourage the use of sustainability indicators for the benefit of the community sustainable perspective applied to low-income farmers' greenhouses.	Masera and López-Ridaura (1999) [29].
S5	Imaginative problem solving.	Mechanical games	Reyes (2015) [30].
S6	Dual hybrid model.	Dual-component problem solving based on real scenarios for learning.	Mejía Gallegos (2017) [31].
S7	IKIGAI Model.	An intermediate zone where passion, profession, vocation, and mission converge.	Loewy (2021), Maki (2021) [32-33].
S8	Bronfenbrenner' s Ecosystem Model	Holistic model for the development of the human being and its influences. Applied to motorcycle taxis and the importance of hand washing.	Algood *et al*. (2011). Bronfenbrenner and Morris (2007) [34-35].
S9	Rich Paint.	Rich vision of Psychoacoustics sensitizing the relationship between the physical characteristics of a sound stimulus and the psychological response that it provokes in a subject.	Checkland (1999; 2000; 2010) [36-37].
S10	Analytical Hierarchy	Mexican soccer team coach selection	Saaty (1980). Wind and Saaty (1980) [38,39].
S11	Multi-attribute technique	Application to evaluate progress in training as a transdisciplinary researcher.	Saaty and Vargas (2006) [40].
S12	Maltese cross	Applied to the health of the university community	Vergiú et al. (2023) [41].
S13	Bronfenbrenner ecological model	Oncology case	Shapiro et al. (1998) [42].
S14	Dialogic Process	To promote awareness of health and nutrition	Nupia and Martínez (2015) [43].

N: Number of people, BMI: Body mass index, M: Male, F: Female

Table 1. Continuation. Transdisciplinary systemic tools (TD-ST)

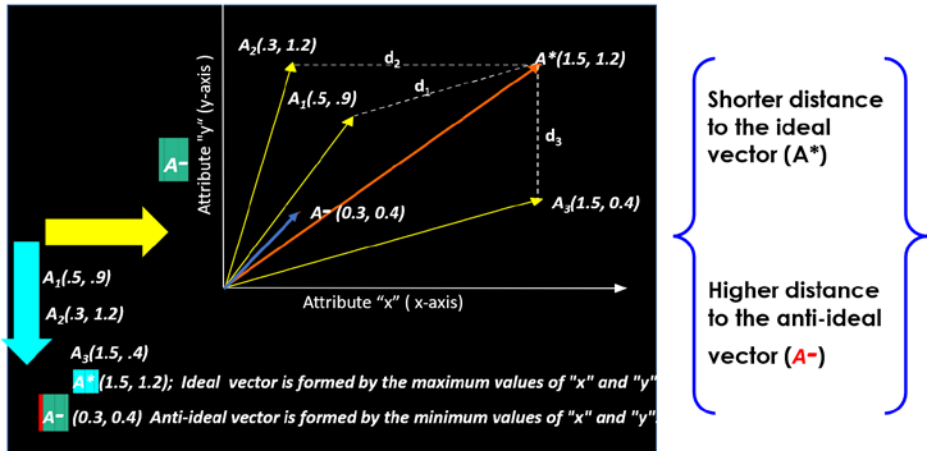
Id.	TD-ST Tool	Application	Reference
S15	CATWOE	Reforestation in agroecosystems	Mendoza (2015) [44].
S16	Rich Paint	To analyze manufactured products and the origin of the materials used	Checkland (2010) [37].
S17	Analytical hierarchization applied in research	In transdisciplinary research and training	Saaty (1980) [38].
S18	Cybernetics	Digital image processing	Forrester (1994), Igno Rosario (2019) [45,46].
S19	Empathy map	Dynamic integrative exercise. Jungle animals	Siricharoen (2021) [47].
S20	Representation by holistic rich vision	Transdisciplinarity applied to the holistic vision of health services.	Sell et al. (2022) [48].



N: Number of people, BMI: Body mass index, M: Male, F: Female

2.3 Evaluation of compliance of criteria and impact produced by TOPSIS.

The evaluation of the impacts produced by the activity of each of the participants was carried out using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, one of the multicriteria decision analysis methods developed by Hwang and Yoon (1981) and Yoon (1987) and Lai et al. (1994) [49-51]- based on the distance to the ideal vector and the anti-ideal vector (Equations 1 and 2) of the alternatives to be evaluated (Figure 1).



$$d = \sqrt{(x * -x1)^2 + (y * -y1)^2} \quad \text{..... (1)}$$

Figure 1. TOPSIS based on vector distances to the ideal and anti-ideal vectors.

Figure 2 shows block diagram of the synthesis of the TOPSIS algorithm. It is possible to observe four steps 1) definition of the rating table and formation of the matrix, 2) normalization of the matrix, each element is divided into the norm of the column vector, 3) weighting of the attributes that characterize the alternatives and multiplication of this weighting of each attribute by the corresponding column. In the present study the weighting was determined through the application of Saaty's algorithm (1980) [38], qualifying the comparisons between the attributes by professors-researchers of the Systems program, to later apply the algorithm and obtain the weights for each one of the attributes, these values are incorporated within the TOPSIS process, to continue as indicated in Figure 3a, with the obtaining of the ideal (A*) and anti-ideal (A-) vectors. In the second stage of the algorithm, the relative proximity (P) is obtained (Figure 2b) from these values and a quotient of these values, from which the weighting is displayed. The higher values are those of higher weighting.

$$d_n = \sqrt{\left(X_1^* - X_1^i\right)^2 + \left(X_2^* - X_2^i\right)^2} + K + \left(X_n^* - X_n^i\right)^2 \quad \text{- - - - - - - - - - - - - - - (2)}$$

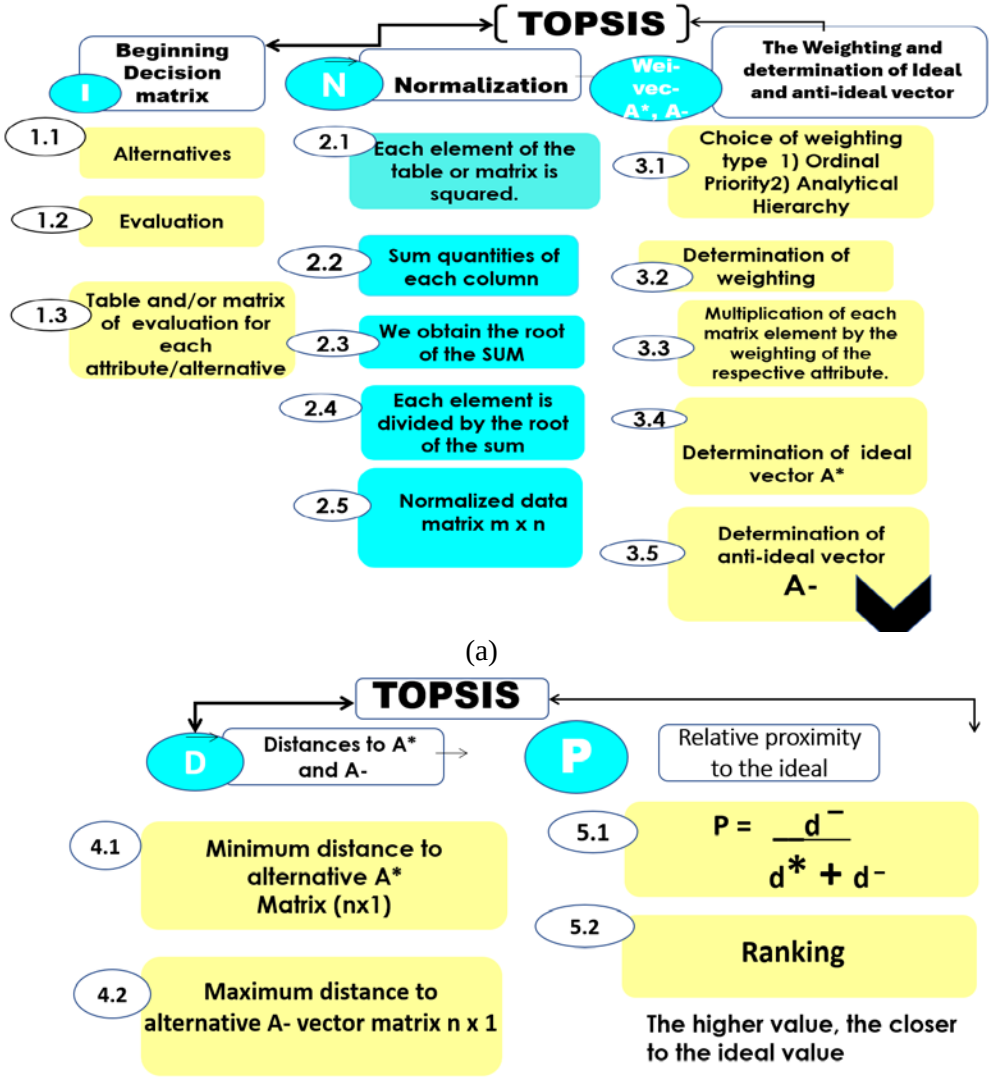


Figure 2. TOPSIS Algorithm a) First stage of the algorithm b) Second stage of the algorithm

2.4 Survey applied.

A survey consisting of 50 questions was applied to find out how the students were before, during, immediately after and days after the activity in their cognitive processes, emotions, use and knowledge of transdisciplinary systemic tools, appropriation of the same and transdisciplinary attitudes.

2.5 Evaluation of changes in evaluated aspects.

Changes achieved or gain achieved (GN) obtained was evaluated by the relationship proposed by Sundayana (2014) [52]. In which a quotient of the differences between the score obtained for the attribute at a time after the intervention is made ($Score\ post$) minus the rating obtained prior to the intervention ($Score\ pret$) between the ideal rating ($Score\ ideal$) minus the pre-intervention qualification ($Score\ pret$). From this we obtain a normalized change whose interpretation is a change 1). not occurred ($-1 \leq GN \leq 0$); 2). No increase or decrease (GN = 0); 3). Low change ($0 < GN < 0.3$); 4). A Medium change ($0.3 \leq GN < 0.7$) and 5). High change ($0.7 \leq GN \leq 1$) (Ekselsa et al., 2023) [1].

$$GN = \frac{Score\ post - score\ pret}{Score\ ideal - score\ pret} \quad \text{..... Eq. (3)}$$

3 Results and Discussions

3.1 Survey applied.

According to the intervention carried out to encourage the use and appropriation of systemic and transdisciplinary tools, statistically significant changes were found in some of the attributes of the cognitive process, emotions, knowledge and use of TD-ST tools, and systemic transdisciplinary attitudes (Figure 3). Figures 3a and 3b show that the attention span, cognitive process, perceptual and linguistic function of the participating focus group improved significantly at the end of the activity about (23, 14, 18, 16 %) and days after the activity (23, 17, 21, 32%) when compared to the ratings obtained by Likert scale before the educational intervention.

The diversity of uses of TD-ST tools increased during the activity (25%), immediately after (35%) and days after the activity (38%). In relation to creativity and the adoption of transdisciplinary systemic tools to life were significantly increased days after by 25 and 34 %, respectively. It should be noted that according to the students' answers, happiness was modified, but not the emotions of sadness, anxiety, and depression, which only showed a slight tendency to improve the situation of this emotion (Figure 3c and 3e).

In the case of happiness (Figure 3c), they were significantly happier immediately after the activity (35%) and days later (39%). Stress of students showed no significant statistical difference, but a tendency to increase during their participation in the activity (Figure 3e).

Knowledge of transdisciplinary systemic tools during, immediately after, and days after the educational intervention increased by 23, 43, and 50% when compared to the knowledge they had before the educational intervention (Figure 3e). On the other hand, although the participants were encouraged to use the transdisciplinary systemic tools, immediately after and days after the intervention their interest was further encouraged, obtaining a score of 4.5, increasing slightly (12%).

Figure 3d shows other evaluated attributes related to the liking for systems thinking and the improvement of transdisciplinary systemic attitudes. About the liking and interest in systems thinking, 22% was improved days after the educational intervention. Likewise, attitudes such as integration and the ability to unite were improved. The ability to integrate days after the educational intervention increased significantly (31%) with respect to how they were before the educational intervention. However, the ability to unite among peers was improved with a significant statistical difference from when the activity was conducted (29 %), immediately after (35 %) and days after (41 %) (Figure 3e).

Thus, the attributes that improved in the highest percentage days after the activity were language function (32%) and attention capacity (23%), happiness (39%), union (41%) and integration (31%), knowledge and appropriation of the tools (50%) and their application potential (38%).

Figure 3f shows the principal component analysis of the attributes and their Likert scale ratings before the intervention, during, at the end of the intervention and days after the intervention. The vector "before" is in quadrant I, and vectors "during", "after", and "days after" are in quadrant II. The angles formed between the vectors "before"-"during", "before"-"after" and "before"-"days after" are increasing (55, 66 and 76°) i.e. the scores obtained in the attributes evaluated before the intervention, during, immediately after and days after are becoming more differentiated. There is a greater angle of separation between the vector "before" and "days after" (76 °), which is related to the changes generated in different attributes due to the educational intervention. It can also be observed that the attributes that are most modified are in quadrant II (attention capacity, integration, linguistic function, Know TD-ST, happiness, use of systemic TD-ST, Unión, adoption of TD-ST, integration).

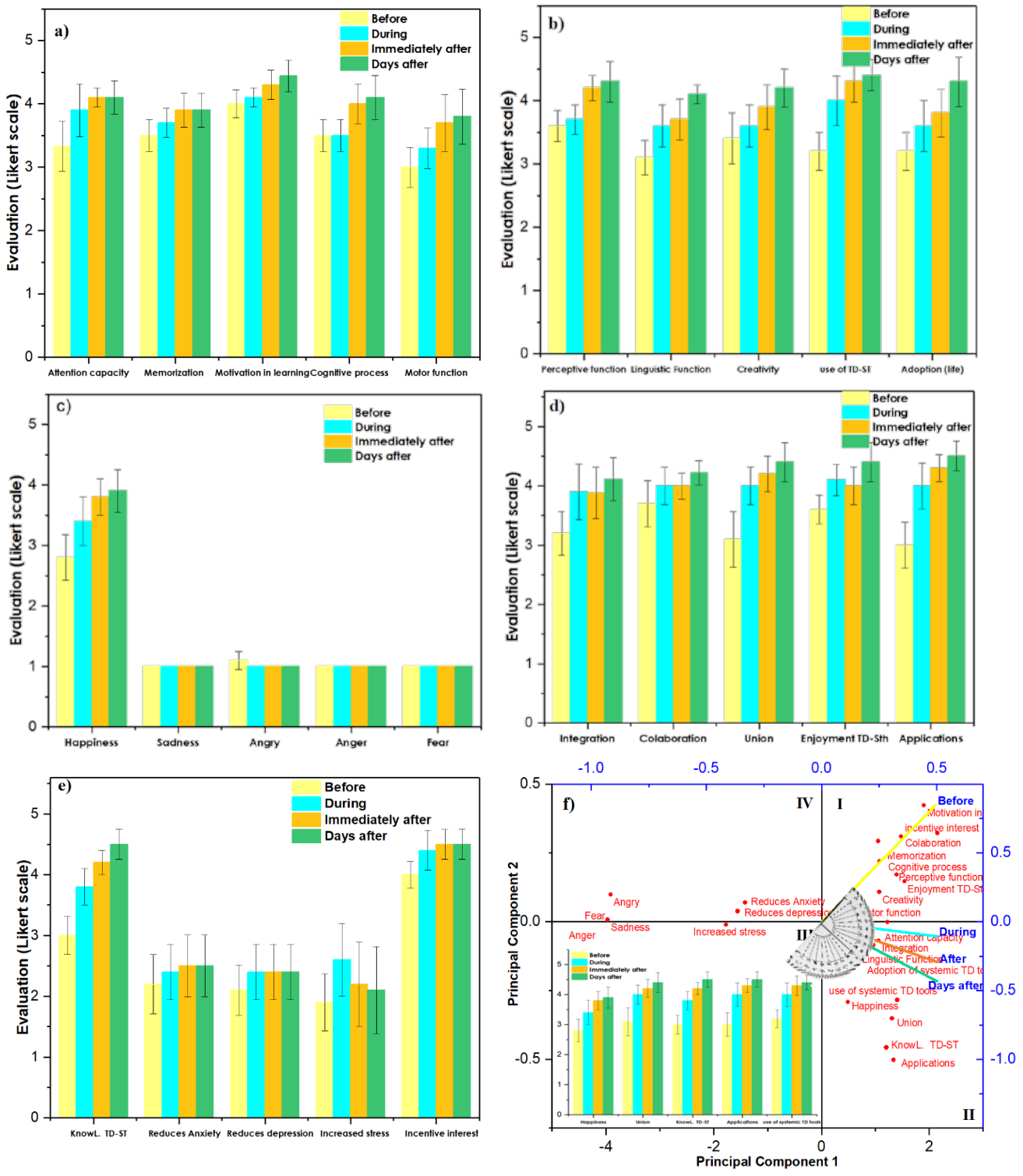


Figure 3. Evaluation according to Likert scale of characteristic attributes of the cognitive process (a and b), emotions (c and e) and transdisciplinary systemic characteristics and knowledge and application of tools (d and e). Likert scale increase 1(😡): None, 2 (😕): little, 3 (😐): neutral, 4 (🙂): very much y 5 (😁): totally.

3.2 TOPSIS

Table 2 shows the scores of the attributes proposed for this method for each participant. By applying the described algorithm of the TOPSIS method, it is possible to observe that the distance of the ideal vector and the distance of the anti-ideal vector are obtained in the lower part; these data were calculated and make up the penultimate and last row of Table 2 (see breakdown of the algorithm in the appendix). In the last column it is possible to observe the value of Pr (relative proximity) according to the equations formulated in the algorithm. Participants S10, S3 and S4. In this case, they are the participants who had the greatest impact and contributed the most to the changes in the attributes evaluated in the participants. In addition, it is possible to observe the weighting given to them by the teachers who were the ones who carried out the weighting of attributes by applying Saaty's technique (1980) [38] (The procedure can be seen in the appendix).

Table 2. Data in the TOPSIS method.

	Attributes											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Pr**
Weihting (%) by Analytical Hierarchy												
	16.7	10.6	19	8.6	7.7	9.2	11.3	3.3	4.7	4.5	4.1	
S1	8.5	8.5	8.6	7.4	8.2	7.8	8.6	8.2	8	8.4	9.2	0.64
S2	8.2	8.4	8.4	8	7.8	7.6	8.2	8.6	9.4	8.6	9	0.59
S3	9	8.8	9	8.6	8.6	8.6	8.8	9.2	9	9	9	0.85
S4	8.6	9.4	9.2	8.4	8.4	8.8	9.2	8.2	7.4	8.4	8.8	0.82
S5	7.6	8	7.4	7.4	7.2	7.4	7.8	8	9	8	7.4	0.31
S6	8	8	7.6	7.2	7.2	7.4	7.4	7.6	7.6	7.6	7.4	0.32
S7	7.4	7.4	7	6.6	6.8	7.2	7.6	7.2	7.4	7	6.8	0.13
S8	7.2	7.8	7.6	7.6	7.2	7.8	7.6	7.6	8	7.6	7.6	0.28
S9	8.6	8.6	8.2	8.6	8.2	8.4	8.2	8.4	8.2	8.6	8	0.64
S10	8.8	8.4	9.2	9.2	8.4	8.6	9.4	9	8.4	8.8	9.4	0.86
S11	7.8	7.8	7.6	7.4	7.4	7	7.4	7	6.8	7.4	7.2	0.27
S12	8	7.2	8	7.4	7.2	6.8	7	7.4	6.8	6.8	7	0.31
S13	7.4	8.4	8.2	7.4	7.2	7	7	6.2	7	7.4	7.4	0.34
S14	8.2	8	7.8	7.4	7.4	7.4	7.6	7.4	7.4	7.8	8.6	0.39
S15	7	7.8	7.4	6.6	7	7	7	7	6.4	7.2	7.2	0.13
S16	8.2	8.6	7.8	7.6	7.6	7.8	7.6	7.4	7.6	7.8	8.4	0.44
S17	8.2	8.8	9	8.2	7.8	8.4	7.4	7.4	8.6	8.2	8.4	0.63
S18	7.6	8.6	8	7.8	7.4	7.8	7.8	7.6	7.6	7.8	8	0.43
S19	8.4	8.2	8.4	8.6	8.4	7.8	8.4	8.6	9.4	8.8	8.4	0.65
S20	8.6	8.2	8.4	7.8	7.4	7.8	8.2	7.6	7.6	7.6	9.4	0.58
Ideal	**0.04**	**0.02**	**0.04**	**0.02**	**0.02**	**0.02**	**0.03**	**0.008**	**0.012**	**0.011**	**0.010**	
Anti	**0.03**	**0.02**	**0.03**	**0.01**	**0.015**	**0.018**	**0.022**	**0.005**	**0.008**	**0.008**	**0.007**	

P**r_** Relative proximity

1) **Creativity in teaching**, 2) Application and explanation of the tool, 3) **Appropriation of the systemic tool and Transdisciplinary perspective,** 4) Beneficial emotion produced, 5) Cognitive process and its possible improvement, 6) Awareness generated with the tool and its application, **7) Originality in the application and presentation,** 8) For presenting the TD systemic tool in a happy and enthusiastic way, 9) For being participative and provoking integration, 10) For modifying the level of stress, 11) For the effort and time invested in the elaboration of didactic material and Creativity in the teaching of the tool.

Figure 4 shows the dendrogram elaborated with the minimum Euclidean distance of the attributes of each participant. In general, it is constituted by two large groups: group 1 formed by 9 participants (1, 20, 2, 19, 9, 17, 3, 10 and 4) and group 2 formed by 11 participants (5, 6, 8, 14, 16, 18, 7, 15, 11, 12, and 13). The group is composed of those who obtained greater relative proximity and this cluster is formed by 3 subgroups A (1, 20), B (2, 19, 9) and C (3, 10 and 4). Participants 1 and 20 presented applications to create a culture of road safety and in the health sector, participants 2, 19 and 9 presented exercises integrating listeners as participants and 9 raised awareness on the importance of sound in people and finally, participants 3, 10 and 4 presented an integrating and fluency exercise with dance (3), participant 10 presented an exercise with a problem of the moment in a soccer team in the country, election of a soccer team coach using a multidimensional decision technique and participant 4 presented a model application of a sustainable methodology for poor greenhouse producers. Thus, these are the applications that had the greatest impact, the latter subgroup having the best evaluations with respect to all the others. In this research it was demonstrated that students are motivated when they apply the tools with real world cases and in a creative way and using didactic material.

It is important to point out the importance of cultivating the fine arts in students. In this intervention one of the participants used dance to develop openness, flow, and expression. In general, it would be important for students in transdisciplinary training to develop some of the fine arts (architecture, dance, sculpture, music, painting, and poetry; and eloquence). The fine arts cultivated in the students would also allow them to create harmony and beauty. Paraphrasing Ruy Castro on Tom Jobim's death (1994): "Every time Antonio Carlos Jobim opened the piano, the world got better. For a few minutes it became a more harmonic, melodic, and poetic world. All individual or collective misfortunes seemed small because at that moment there was a man dedicating himself to producing beauty. Whatever resulted from his gesture of opening the piano - a note, a chord, a song - came so charged with excellence, sensitivity and wisdom that, exposed to his creation, all of us, his listeners, also improved as human beings."

Today we need to improve ourselves as human beings and join to come up with solutions in the face of an increasingly divided world. Nicolescu Basarab mentions that to unite different people, it is necessary to evolve, whether spiritually, religiously, or culturally. The fine arts could also complement the development of individual students and teachers to strengthen their evolution towards human development.

On the other hand, the use of real-world case studies can be effective in motivating students in various disciplines. Mustoe (1999) [53] and Soares (2013) [54] highlight the positive impact of real-world applications on student motivation in engineering and logic programming, respectively. Ates (2013) [55] focuses on management education for computer engineering students and finds that case-based learning increases student retention and motivation.

It is possible to say that the intervention brought about changes in mood, cognitive and linguistic attitudes, appropriation of systemic tools, their knowledge and use, and diversification of techniques and applications. The attitudes that tended modified are attitudes related to a problem of systemic thinking and awareness such as integration skills and the ability to unite. Thus, the intervention could support the development of systemic and transdisciplinary skills.

Studies conducted by the fundamentals of training and experiential development according to Benson (2007) [23] indicate that people remember more when they carry out something it is mentioned that they remember 20% of what they hear, 50% of what they see and 80% of what they do. As Confucius (551-479 B.C.) said:” They told me and I forgot, I saw it and I understood it, I did it and I learned it”.

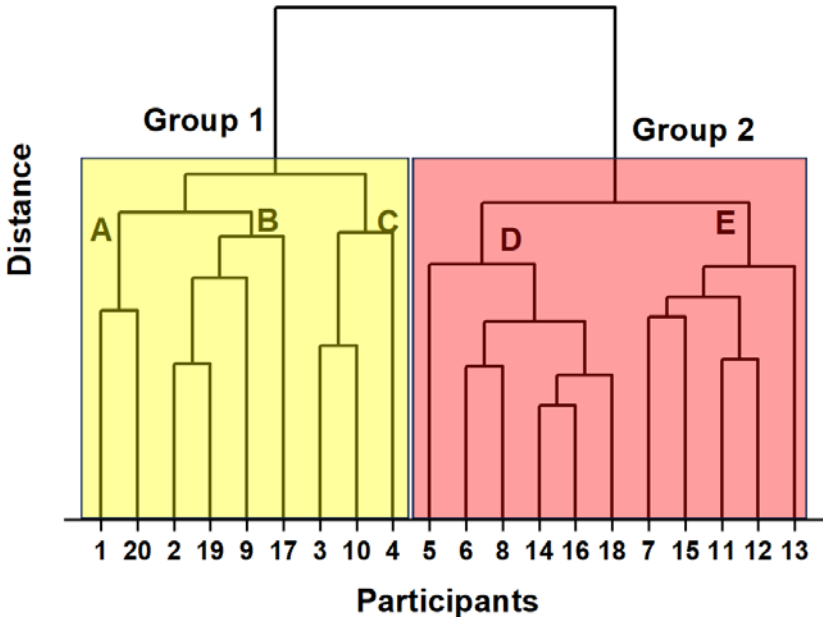


Figure 4. Dendrogram of participants

Teaching interventions to improve systems thinking skills in sustainability courses, shows that a long-term integrated approach is effective (Cornell, 2012) [6]. The activities carried out with the students at the end of the semester have prevailed mainly those of integration, collaboration, union, and employment of diversity of systemic tools and skills to analyze systems, but it is part of the continuous practice when doing tasks related to their thesis projects, where they have to make representations and interrelations of the factors that can affect a specific problem. The use of transdisciplinary systemic tools could support the development of skills that are so difficult to obtain. Some authors have reported the use of systemic tools in the creation of learning laboratories for sustainable development (Nguyen, 2011) [56]. The development of systems thinking and the use of its tools is linked to sustainability in the world.

On the other hand, in education and research for sustainability, the transdisciplinary perspective is required, which is based on interdisciplinarity and goes beyond, by moving education to the world outside the university (Scholz, 2006) [57]. The skills to be developed in graduate students is also to collaborate and integrate the knowledge of academic experts with practical or traditional (empirical) knowledge of stakeholders or outsiders. Figure 5 shows a stakeholder map, a classification of large groups that could be the community, community, civil society, or international organizations (Ginige et al., 2018) [58] among others, to achieve knowledge co-production i.e. collaboration between academics and non-academic agents (Carolan, 2006) [59].

Thus, the transdisciplinary perspective encourages the inclusion of the ways of thinking and knowledge of people outside the academic world, which is added to achieve the integration of knowledge and its co-production. The impulse toward this type of education and research perspective is necessary because academic knowledge alone cannot solve the growing and complex problems of society (Fischer, 2001) [60].

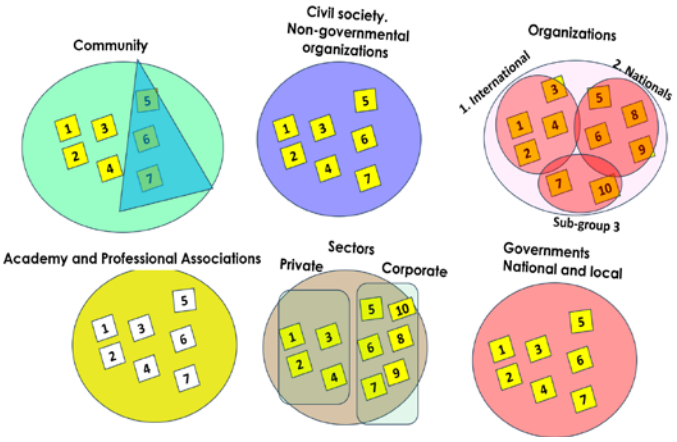


Figure 5. Stakeholder classification map based on Hampshire et al. (2022) [61].

Despite the relevance of developing these systemic and transdisciplinary skills, it is a challenge within the TD research perspective. Hung (2008) [62] mentions that systems thinking is one of the most important higher order skills in advanced learning, but the most difficult to master. According to Kali et al., (2003) [63] possessing knowledge about the holistic aspect of a system does not foster the application of systems thinking, nor the general awareness to approach solutions by looking at the whole and its connections, including all types of knowledge, sometimes evolving awareness requires life experience.

That is why learning it, living it, and making it part of life in the academy is very complex. However, students in training can advance in systemic skills and transdisciplinary attitudes, such as those observed in this research. The most relevant changes were classified as medium and high changes.

Among those that had medium changes ($0.3 \leq GN < 0.7$) were the aspects related to cognitive process and emotions as in the evaluated attributes: Attention capacity (0.47), cognitive process (0.46), perceptive function (0.46), linguistic function (0.52), creativity (0.5). Likewise, the use of TD-ST (0.68) and the appropriation of TD-ST tools (0.65), integration (0.52), joy (0.51), and interest in the use of TD-ST (0.52) were encouraged. Regarding this last attribute, the focus group had already evaluated it before the intervention with one of the highest scores on the Likert scale applied, that is, they were already encouraged in the use of TD-ST, but despite this, there was an increase in the students' interest in the use of TD-ST. Finally, it is important to mention the attributes classified with the highest changes ($0.7 \leq GN \leq 1$): union (0.70) and knowledge of the TD-ST (0.75).

The union among students could be a first exercise for understanding and tolerance among them, necessary attributes in transdisciplinarity. These attributes can later transfer among empiricists and with other disciplines. This is one of the most important attributes for researching to achieve union. In transdisciplinarity, the union between disciplines, the union of sciences, and the union between people is sought. In this intervention, it was possible to change the ability to unite in the participant focus group. Likewise, this research shows that students, in addition to the digital media used in the current era, also have greater learning when didactic materials are designed in a physical way, which achieves greater interest and understanding. In this way, despite the development of digital media, these could continue to be complemented with creative ideas to teach transdisciplinary systemic tools.

In this sense, in the face of the challenges of humanity, the role of education in formative stages as transdisciplinary researchers goes beyond graduating them. As Mc Gregor (2015) [64] says, students must be helped to develop higher-order cognitive and communicative skills, which include, among others, logical, flexible, critical, and creative thinking. They should also learn complex reasoning, complex thinking, integrative thinking, problem-posing, and problem-solving. Ideally, higher, and postgraduate education should lay the foundation in the student-in-training for lifelong reflection and deep learning, and meaning in life (Chan et al., 2014; Hernández, 2018) [65, 10].

An advance in this direction could be to get used to using systemic tools for systems analysis, visualization in time of system variables, tools for decision making, systemic, sustainable and transdisciplinary

methodologies, and empathy maps and stakeholders among many other tools that would help them in their training, in their thesis projects and once they graduate in their development and resolution of work problems and that transcends in their lives. Thus, it is necessary to continue promoting the development of systemic skills and transdisciplinary attitudes in the classroom. Mimoun-Sorel (2016) [66] emphasized the need for teachers to adopt a transdisciplinary attitude in the classroom to initiate a transformation within the existing educational system. Hammer (2001) [67] focused on introducing transdisciplinary elements into disciplinary courses to enhance students' awareness of disciplinary metaphors. Overall, educational interventions can play an important role in fostering systemic skills and transdisciplinary attitudes among students and educators.

As already reported, it is very important to develop awareness, i.e. environmental awareness, which could be developed by analyzing the system in all its parts and in the whole and its impacts inside and outside the system. In a study conducted with students at the high school level in Indonesia to develop systems thinking skills, it was found that students are at a pre-conscious level on the environmental issue before making educational interventions (Ekselsa et al. 2023) [1]. Learning systems analysis is one stage of realizing and entering awareness, another stage will be the acts and decisions based on the acquired awareness. According to the results in this research are also modified some cognitive factors, capabilities, emotions, attitudes. As noted above, but more work must be done to further improve the skills, awareness and transformation towards systemic, scientific thinking and transdisciplinary attitudes, necessary to propose solutions to the problems addressed in graduate research projects and in their future development as professionals.

Systemic tools could foster systemic development and transdisciplinary attitudes, so it would be convenient to continue promoting and encouraging their use in universities and undergraduate and graduate institutes in Mexico City and other contexts in Mexico and the world. Not only at a higher level but also from early education to improve society over time.

In this way to continue rescuing what Plato (427 B.C.-347 B.C.) (Athenian philosopher, disciple of Socrates) said hundreds of years before Christ.

That education is a process of improvement and beautification of the body and spirit, highlighting three main functions of education:

The formation of the citizen.
The formation of the virtuous man; and
The preparation for a profession.

The virtuous man in these times is relevant to strengthen, to co-construct a better world and to be promoters and decision makers for life and peace.

4 Conclusions

Educational interventions developing creative activities with students where they apply and explain transdisciplinary systemic tools using didactic material and real-world case examples helps to develop systemic skills and transdisciplinary attitudes.

This study evidenced the change of attributes in a focus group of graduate students. The angle of separation of vectors (which represent the assessed attributes) increased as the intervention activity progressed and days after.

The relevant changes found in this study were of two types of classifications: strong and medium. The attributes classified with high changes are union (0.70) and knowledge of the TD-ST (0.75). Regarding the changes classified as medium changes were attention capacity (0.47), cognitive process (0.46), perceptive function (0.46), linguistic function (0.52), creativity (0.5), the use of TD-ST (0.68) and the appropriation of TD-ST tools (0.65), integration (0.52), joy (0.51) and interest in the use of TD-ST (0.52).

Thus, the attributes that improved in the highest percentage days after the activity were language function (32%) and attention capacity (23%), happiness (39%), union (41%) and integration (31%), knowledge and appropriation of the tools (50%) and their application potential (38%).

Transdisciplinary systemic skills and attitudes can be encouraged within academic activities such as extra-class activities or in the classroom. As trainers of transdisciplinary researchers, we need to cultivate transdisciplinary systemic skills and attitudes in ourselves and in our students.

Incorporating strategies for teaching transdisciplinary systemic tools in a creative, didactic way and focused on real-world everyday cases will be important to stimulate interest in the tools and promote the development of systemic thinking and transdisciplinary attitudes as basic elements towards sustainable actions and decisions.

Authors' Contribution: CHA had the idea for the research, proposed the methodology, organized, and conducted the research and manuscript preparation. RRG collaborated in field research, FADP critically revised and edited the text and results, EJMO collaborated in field research and manuscript, LMHS collaborated in field research. All authors reviewed and finally approved the manuscript.

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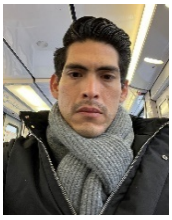

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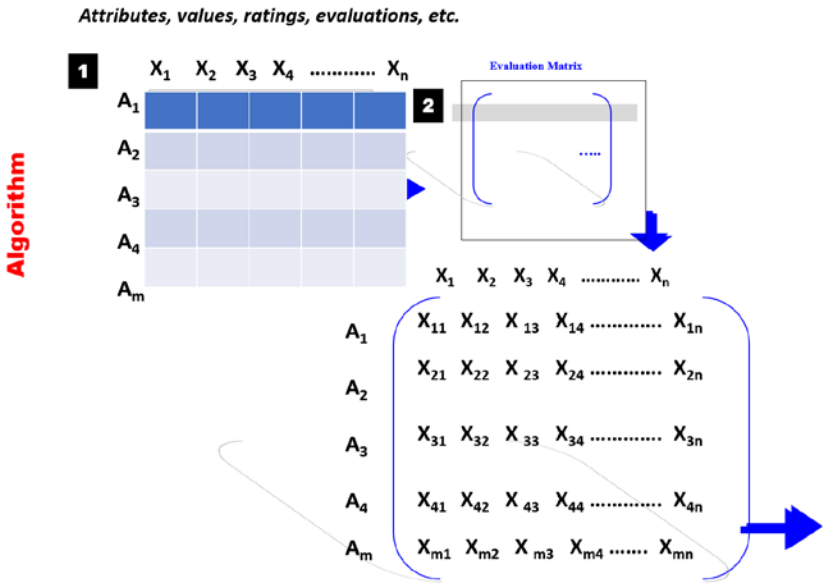
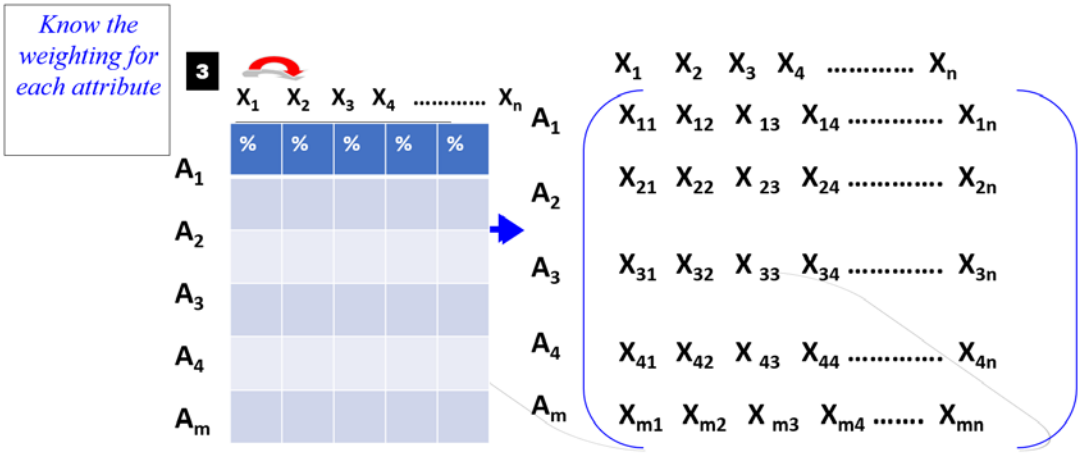
ANNEX "A" Development of the TOPSIS method, with weighting of attributes through analytical hierarchization.

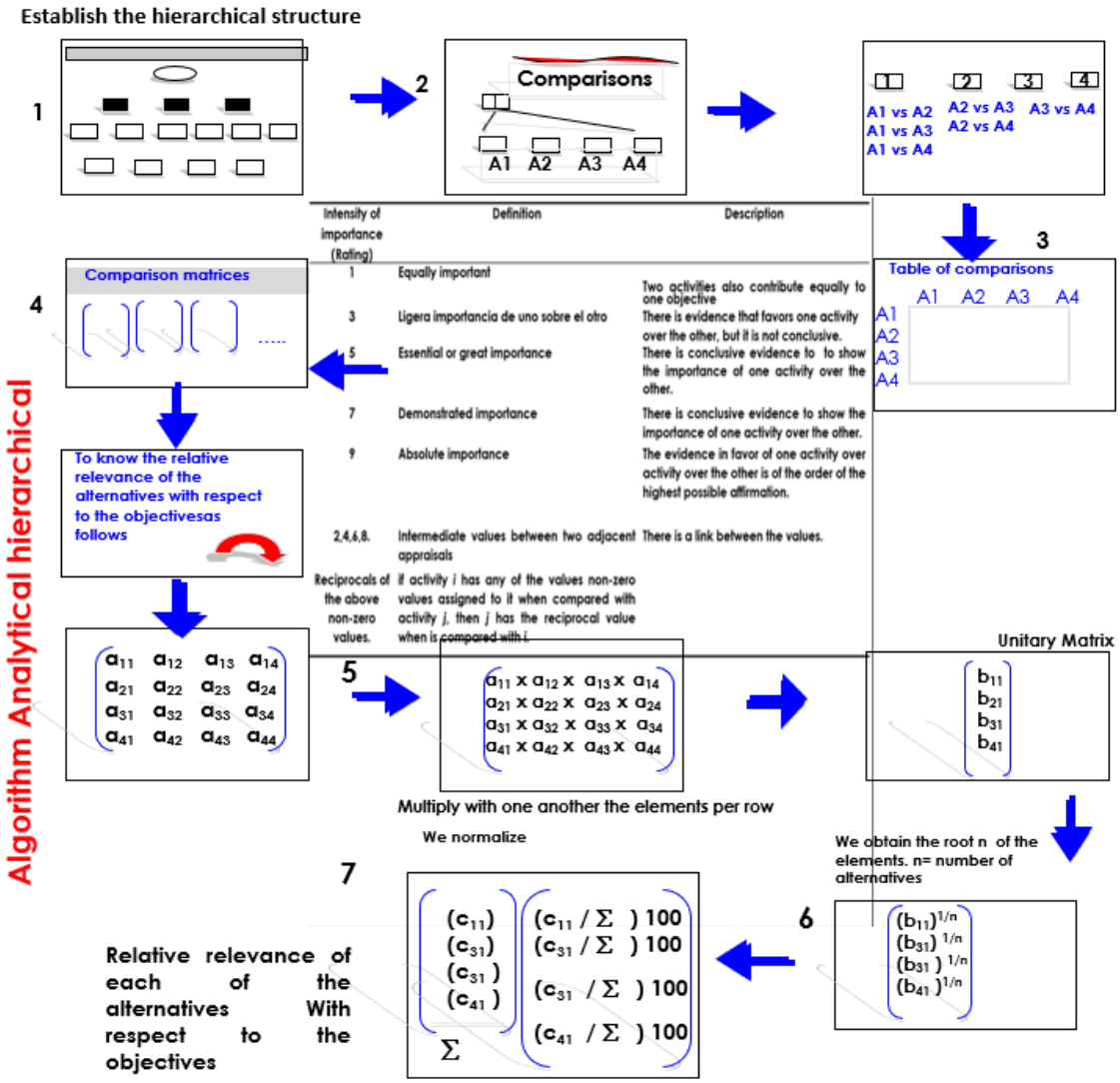


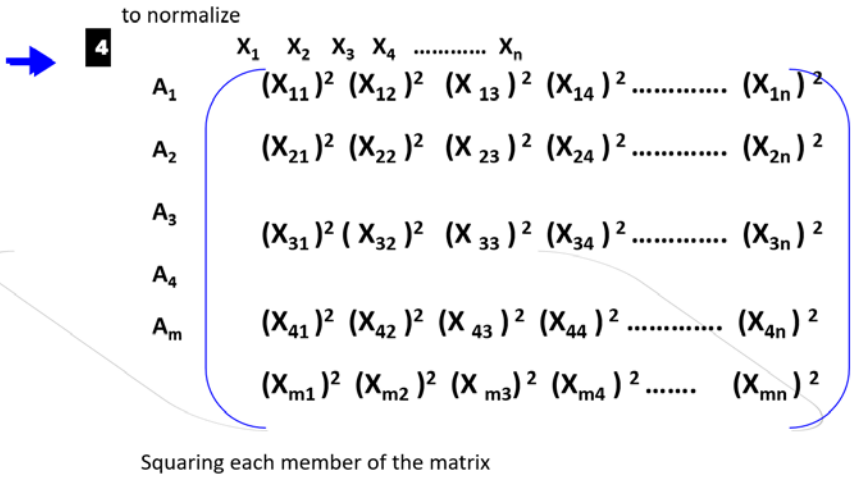
Subjects	Attributes										
	1	2	3	4	5	6	7	8	9	10	11
Weighting	16.69	10.61	18.98	8.61	7.72	9.22	11.33	3.37	4.75	4.53	4.13
S1	8.5	8.5	8.6	7.4	8.2	7.8	8.6	8.2	8	8.4	9.2
S2	8.2	8.4	8.4	8	7.8	7.6	8.2	8.6	9.4	8.6	9
S3	9	8.8	9	8.6	8.6	8.6	8.8	9.2	9	9	9
S4	8.6	9.4	9.2	8.4	8.4	8.8	9.2	8.2	7.4	8.4	8.8
S5	7.6	8	7.4	7.4	7.2	7.4	7.8	8	9	8	7.4
S6	8	8	7.6	7.2	7.2	7.4	7.4	7.6	7.6	7.6	7.4
S7	7.4	7.4	7	6.6	6.8	7.2	7.6	7.2	7.4	7	6.8
S8	7.2	7.8	7.6	7.6	7.2	7.8	7.6	7.6	8	7.6	7.6

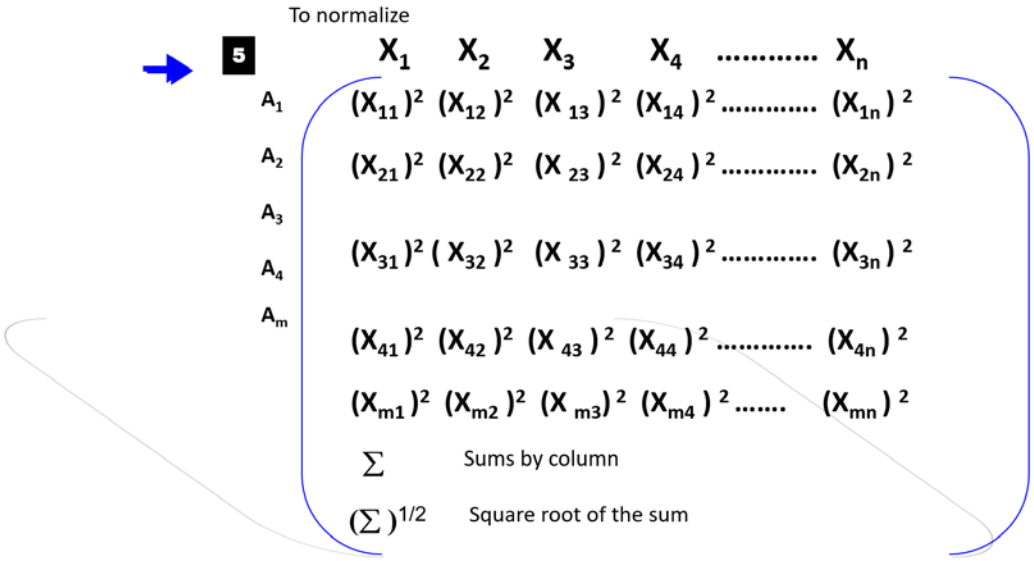
S9	8.6	8.6	8.2	8.6	8.2	8.4	8.2	8.4	8.2	8.6	8
S10	8.8	8.4	9.2	9.2	8.4	8.6	9.4	9	8.4	8.8	9.4
S11	7.8	7.8	7.6	7.4	7.4	7	7.4	7	6.8	7.4	7.2
S12	8	7.2	8	7.4	7.2	6.8	7	7.4	6.8	6.8	7
S13	7.4	8.4	8.2	7.4	7.2	7	7	6.2	7	7.4	7.4
S14	8.2	8	7.8	7.4	7.4	7.4	7.6	7.4	7.4	7.8	8.6
S15	7	7.8	7.4	6.6	7	7	7	7	6.4	7.2	7.2
S16	8.2	8.6	7.8	7.6	7.6	7.8	7.6	7.4	7.6	7.8	8.4
S17	8.2	8.8	9	8.2	7.8	8.4	7.4	7.4	8.6	8.2	8.4
S18	7.6	8.6	8	7.8	7.4	7.8	7.8	7.6	7.6	7.8	8
S19	8.4	8.2	8.4	8.6	8.4	7.8	8.4	8.6	9.4	8.8	8.4
S20	8.6	8.2	8.4	7.8	7.4	7.8	8.2	7.6	7.6	7.6	9.4



The weights can be calculated using the ordinal using the ordinal priority approach or the analytical the analytical hierarchy process, etc.

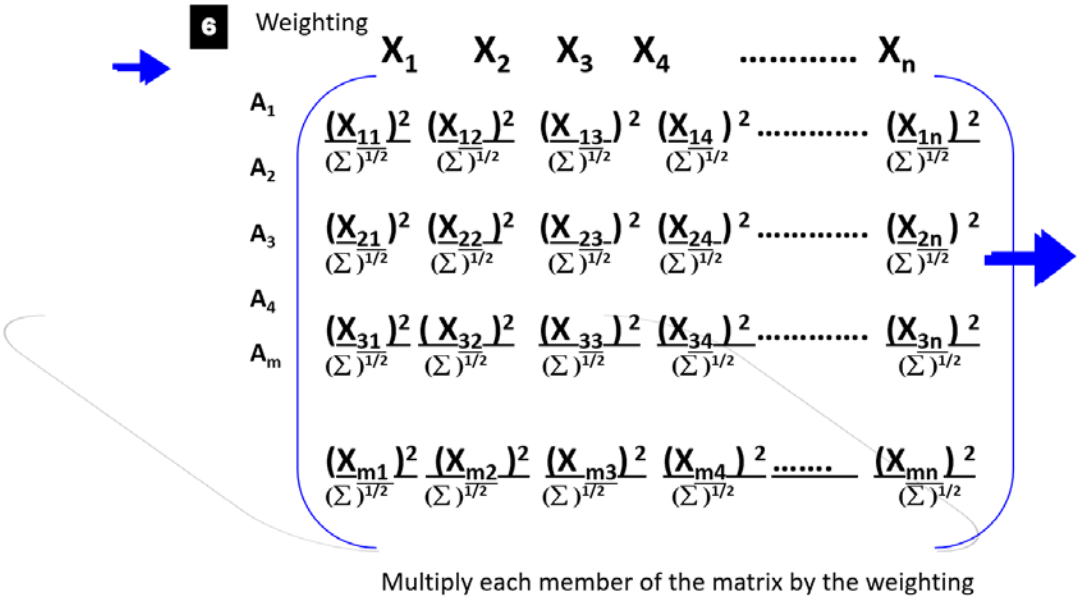

Establish the hierarchical structure
1
2
Comparisons
A1 A2 A3 A4
A1 vs A2
A1 vs A3
A1 vs A4
A2 vs A3
A2 vs A4
A3 vs A4
3
Table of comparisons
A1 A2 A3 A4
Intensity of importance (Rating)
Definition
Description
1 Equally important
Two activities also contribute equally to one objective
3 Ligera importancia de uno sobre el otro
There is evidence that favors one activity over the other, but it is not conclusive.
5 Essential or great importance
There is conclusive evidence to to show the importance of one activity over the other.
7 Demonstrated importance
There is conclusive evidence to show the importance of one activity over the other.
9 Absolute importance
The evidence in favor of one activity over activity over the other is of the order of the highest possible affirmation.
2,4,6,8. Intermediate values between two adjacent appraisals
There is a link between the values.
Reciprocals of the above non-zero values.
if activity i has any of the values non-zero values assigned to it when compared with activity j, then j has the reciprocal value when is compared with i.
4
Comparison matrices
To know the relative relevance of the alternatives with respect to the objectivesas follows
Algorithm Analytical hierarchical
5
Unitary Matrix
Multiply with one another the elements per row
We normalize
We obtain the root n of the elements. n= number of alternatives
6
7
Relative relevance of each of the alternatives With respect to the objectives


to normalize
4
X1 X2 X3 X4 ..... Xn
A1
A2
A3
A4
Am
(X11)2 (X12)2 (X 13)2 (X14)2 ..... (X1n)2
(X21)2 (X22)2 (X 23)2 (X24)2 ..... (X2n)2
(X31)2 (X32)2 (X 33)2 (X34)2 ..... (X3n)2
(X41)2 (X42)2 (X 43)2 (X44)2 ..... (X4n)2
(Xm1)2 (Xm2)2 (X m3)2 (Xm4)2 ..... (Xmn)2
Squaring each member of the matrix

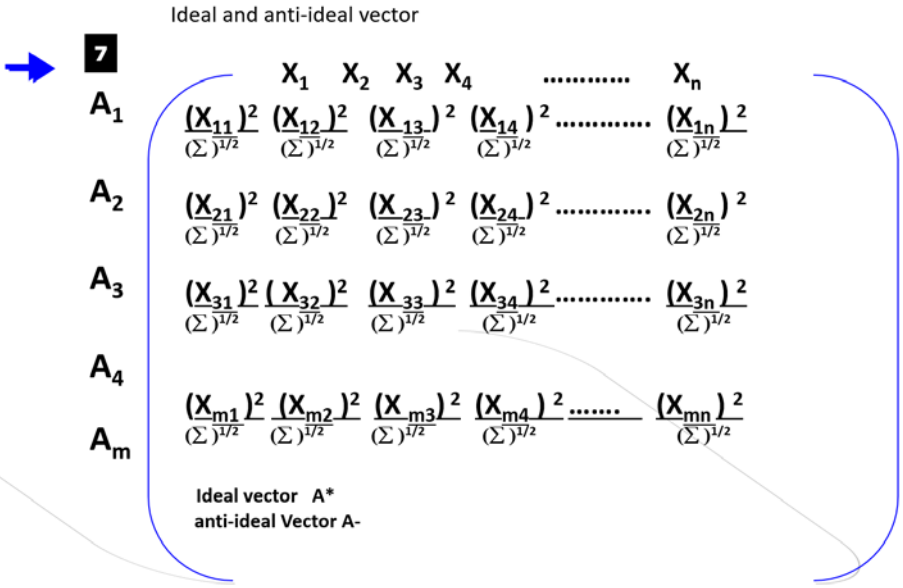

To normalize
5
X1 X2 X3 X4 ..... Xn
A1
A2
A3
A4
Am
(X11)2 (X12)2 (X 13)2 (X14)2 ..... (X1n)2
(X21)2 (X22)2 (X 23)2 (X24)2 ..... (X2n)2
(X31)2 (X32)2 (X 33)2 (X34)2 ..... (X3n)2
(X41)2 (X42)2 (X 43)2 (X44)2 ..... (X4n)2
(Xm1)2 (Xm2)2 (X m3)2 (Xm4)2 ..... (Xmn)2
∑ Sums by column
(∑)1/2 Square root of the sum

Subjects	Attributes										
	1	2	3	4	5	6	7	8	9	10	11
Weighting	16.69	10.61	18.98	8.61	7.72	9.22	11.33	3.37	4.75	4.53	4.13
S1	72.25	72.25	73.96	54.76	67.24	60.84	73.96	67.24	64	70.56	84.64
S2	67.24	70.56	70.56	64	60.84	57.76	67.24	73.96	88.36	73.96	81
S3	81	77.44	81	73.96	73.96	73.96	77.44	84.64	81	81	81
S4	73.96	88.36	84.64	70.56	70.56	77.44	84.64	67.24	54.76	70.56	77.44
S5	57.76	64	54.76	54.76	51.84	54.76	60.84	64	81	64	54.76
S6	64	64	57.76	51.84	51.84	54.76	54.76	57.76	57.76	57.76	54.76
S7	54.76	54.76	49	43.56	46.24	51.84	57.76	51.84	54.76	49	46.24
S8	51.84	60.84	57.76	57.76	51.84	60.84	57.76	57.76	64	57.76	57.76
S9	73.96	73.96	67.24	73.96	67.24	70.56	67.24	70.56	67.24	73.96	64
S10	77.44	70.56	84.64	84.64	70.56	73.96	88.36	81	70.56	77.44	88.36
S11	60.84	60.84	57.76	54.76	54.76	49	54.76	49	46.24	54.76	51.84
S12	64	51.84	64	54.76	51.84	46.24	49	54.76	46.24	46.24	49
S13	54.76	70.56	67.24	54.76	51.84	49	49	38.44	49	54.76	54.76
S14	67.24	64	60.84	54.76	54.76	54.76	57.76	54.76	54.76	60.84	73.96
S15	49	60.84	54.76	43.56	49	49	49	49	40.96	51.84	51.84
S16	67.24	73.96	60.84	57.76	57.76	60.84	57.76	54.76	57.76	60.84	70.56
S17	67.24	77.44	81	67.24	60.84	70.56	54.76	54.76	73.96	67.24	70.56
S18	57.76	73.96	64	60.84	54.76	60.84	60.84	57.76	57.76	60.84	64
S19	70.56	67.24	70.56	73.96	70.56	60.84	70.56	73.96	88.36	77.44	70.56
S20	73.96	67.24	70.56	60.84	54.76	60.84	67.24	57.76	57.76	57.76	88.36
Σ	1306.81	1364.65	1332.88	1213.04	1173.04	1198.64	1260.68	1220.96	1256.24	1268.56	1335.4
$\Sigma^{1/2}$	36.14	36.941	36.50	34.82	34.2	34.621	35.50	34.94	35.44	35.61	36.54

Subjects	Attributes					
S1	0.235132522	0.230095585	0.235560748	0.212468308	0.239418354	0.225294308
	0.242212203	0.234673005	0.225711495	0.235843428	0.25175734	
S2	0.226833727	0.227388578	0.230082592	0.229695468	0.22773941	0.219517531
	0.230946519	0.246120469	0.265211007	0.241458748	0.246284354	
S3	0.248963846	0.238216606	0.246517062	0.246922628	0.251097299	0.248401416
	0.247845045	0.263291664	0.253925432	0.252689388	0.246284354	
S4	0.237898786	0.254458647	0.251995219	0.241180241	0.245257827	0.254178194
	0.259110729	0.234673005	0.208783133	0.235843428	0.240811369	
S5	0.210236137	0.216560551	0.202691807	0.212468308	0.210220994	0.213740754
	0.219680835	0.228949273	0.253925432	0.224612789	0.202500469	
S6	0.221301197	0.216560551	0.208169964	0.206725921	0.210220994	0.213740754
	0.208415151	0.217501809	0.214425921	0.21338215	0.202500469	
S7	0.204703607	0.200318509	0.191735493	0.189498761	0.19854205	0.207963977
	0.214047993	0.206054346	0.208783133	0.19653619	0.186081512	
S8	0.199171077	0.211146537	0.208169964	0.218210694	0.210220994	0.225294308
	0.214047993	0.217501809	0.225711495	0.21338215	0.207973455	
S9	0.237898786	0.232802592	0.224604435	0.246922628	0.239418354	0.242624639
	0.230946519	0.240396737	0.231354283	0.241458748	0.218919426	
S10	0.243431316	0.227388578	0.251995219	0.264149788	0.245257827	0.248401416
	0.264743571	0.257567932	0.23699707	0.247074068	0.257230326	
S11	0.215768667	0.211146537	0.208169964	0.212468308	0.216060466	0.202187199
	0.208415151	0.200330614	0.191854771	0.20776683	0.197027484	
S12	0.221301197	0.194904496	0.219126278	0.212468308	0.210220994	0.196410422
	0.197149468	0.211778078	0.191854771	0.190920871	0.191554498	
S13	0.204703607	0.227388578	0.224604435	0.212468308	0.210220994	0.202187199
	0.197149468	0.177435687	0.197497559	0.20776683	0.202500469	
S14	0.226833727	0.216560551	0.213648121	0.212468308	0.216060466	0.213740754
	0.214047993	0.211778078	0.208783133	0.218997469	0.235338383	
S15	0.193638547	0.211146537	0.202691807	0.189498761	0.204381522	0.202187199
	0.197149468	0.200330614	0.180569196	0.20215151	0.197027484	
S16	0.226833727	0.232802592	0.213648121	0.218210694	0.221899938	0.225294308
	0.214047993	0.211778078	0.214425921	0.218997469	0.229865397	
S17	0.226833727	0.238216606	0.246517062	0.235437854	0.22773941	0.242624639
	0.208415151	0.211778078	0.242639858	0.230228109	0.229865397	
S18	0.210236137	0.232802592	0.219126278	0.223953081	0.216060466	0.225294308
	0.219680835	0.217501809	0.214425921	0.218997469	0.218919426	
S19	0.232366257	0.221974565	0.230082592	0.246922628	0.245257827	0.225294308
	0.236579361	0.246120469	0.265211007	0.247074068	0.229865397	
S20	0.237898786	0.221974565	0.230082592	0.223953081	0.216060466	0.225294308
	0.230946519	0.217501809	0.214425921	0.21338215	0.257230326	



Multiply each member of the matrix by the weighting



S1	0.039245976	0.024434643	0.044717468	0.018297425	0.018501748	0.020780111
	0.027452257	0.007918473	0.010738718	0.010705485	0.010417449	
S2	0.037860823	0.024147176	0.043677527	0.019781	0.017599223	0.020247287
	0.026175408	0.00830474	0.012617993	0.010960377	0.010190983	
S3	0.041554562	0.025297042	0.046797351	0.021264575	0.019404272	0.022911404
	0.028090682	0.00888414	0.012081058	0.011470162	0.010190983	
S4	0.039707693	0.02702184	0.047837292	0.02077005	0.01895301	0.023444227
	0.029367531	0.007918473	0.009933314	0.010705485	0.009964517	
S5	0.035090519	0.022997311	0.038477822	0.018297425	0.016245437	0.019714464
	0.024898559	0.007725339	0.012081058	0.0101957	0.008379253	
S6	0.036937389	0.022997311	0.039517763	0.0178029	0.016245437	0.019714464
	0.02362171	0.007339072	0.010201782	0.009685915	0.008379253	
S7	0.034167085	0.021272513	0.036397939	0.016319325	0.015342913	0.019181641
	0.024260134	0.006952806	0.009933314	0.008921237	0.007699854	
S8	0.03324365	0.022422378	0.039517763	0.01879195	0.016245437	0.020780111
	0.024260134	0.007339072	0.010738718	0.009685915	0.008605719	
S9	0.039707693	0.024722109	0.042637586	0.021264575	0.018501748	0.022378581
	0.026175408	0.008111606	0.011007186	0.010960377	0.009058652	
S10	0.040631128	0.024147176	0.047837292	0.02274815	0.01895301	0.022911404
	0.030005955	0.008691007	0.011275654	0.01121527	0.010643916	
S11	0.036013954	0.022422378	0.039517763	0.018297425	0.016696699	0.018648817
	0.02362171	0.006759672	0.00912791	0.009431022	0.008152786	
S12	0.036937389	0.02069758	0.041597645	0.018297425	0.016245437	0.018115994
	0.02234486	0.007145939	0.00912791	0.008666345	0.00792632	
S13	0.034167085	0.024147176	0.042637586	0.018297425	0.016245437	0.018648817
	0.02234486	0.005987138	0.009396378	0.009431022	0.008379253	
S14	0.037860823	0.022997311	0.040557704	0.018297425	0.016696699	0.019714464
	0.024260134	0.007145939	0.009933314	0.009940807	0.009738051	
S15	0.032320215	0.022422378	0.038477822	0.016319325	0.015794175	0.018648817
	0.02234486	0.006759672	0.008590974	0.00917613	0.008152786	
S16	0.037860823	0.024722109	0.040557704	0.01879195	0.017147961	0.020780111
	0.024260134	0.007145939	0.010201782	0.009940807	0.009511584	
S17	0.037860823	0.025297042	0.046797351	0.020275525	0.017599223	0.022378581
	0.02362171	0.007145939	0.011544122	0.010450592	0.009511584	
S18	0.035090519	0.024722109	0.041597645	0.019286475	0.016696699	0.020780111
	0.024898559	0.007339072	0.010201782	0.009940807	0.009058652	
S19	0.038784258	0.023572244	0.043677527	0.021264575	0.01895301	0.020780111
	0.026813833	0.00830474	0.012617993	0.01121527	0.009511584	
S20	0.039707693	0.023572244	0.043677527	0.019286475	0.016696699	0.020780111
	0.026175408	0.007339072	0.010201782	0.009685915	0.010643916	

IDEAL	0.041554562	0.02702184	0.047837292	0.02274815	0.019404272	0.023444227
	0.030005955	0.00888414	0.012617993	0.011470162	0.010643916	

anti-ideal	0.032320215	0.02069758	0.036397939	0.016319325	0.015342913	
	0.018115994	0.02234486	0.005987138	0.008590974	0.008666345	0.007699854

No. Participante	Distancia A*	Distancia A-	Pr $P = \frac{d^-}{d^* + d^-}$
S1	0.00781659	0.01407504	0.64294165
S2	0.00877311	0.01284276	0.59413574
S3	0.00327155	0.01860583	**0.8504598**
S4	0.0041378	0.01872961	**0.81905265**
S5	0.01495822	0.00700683	0.31899917
S6	0.01457294	0.00703313	0.32551625
S7	0.01880423	0.0028174	**0.13030453**
S8	0.01544148	0.00628934	**0.28942033**
S9	0.0077798	0.01394424	0.64188046
S10	0.00339236	0.019431	**0.85136453**
S11	0.01546028	0.00597384	**0.27870708**
S12	0.01573423	0.00740034	**0.31988233**
S13	0.01514626	0.00780706	0.34012764
S14	0.0130494	0.00861295	0.39760005
S15	0.01903359	0.00297493	**0.13517181**
S16	0.01205238	0.00965302	**0.44472903**
S17	0.00868692	0.01473341	0.62908629
S18	0.01231179	0.00911356	0.42536335
S19	0.00763234	0.0141055	**0.6488915**
S20	0.00922539	0.01274236	**0.58004835**