A Concurrent Approach to STS

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Introduction

The Industrial Revolution has been considered as the new age in History due to the deep social, economical and political transformations that it has caused. On the one hand, the mechanization of the means of production replaced handcrafted labor, greatly increased the availability of goods, and enriched very much the capitalist businessman. On the other hand, it sprang up serious social and environmental problems, such as unemployment, rural exodus, and pollution, which demanded institutional, cultural and political transformations[1,2]. Nowadays, we are the witnesses of a new revolution. The generalized use of computers and computerized systems have been changing again the means of production, and also, personal relations. Once more, the course of History has been modified, at this time by the so-called "information revolution", which has been altering lifestyles, educational practices, production relations, etc[3]. And, the main "engine" of these processes has been the discoveries in science that make possible the development of new technologies, which give support to a massive industrial production and promoting several transformations in social relations. But, this process brings new advances to science itself, generating a vicious circle. At the same time, as consequence, social, environmental, economical, and political problems have come along, bringing up crisis and instability to the social order.

Presently, one of the greatest challenges to researchers in social areas is to understand the complex imbrications/overlaps amongst the variables of this historical process and to find out ways to allow "harmonious solutions". However, what do "harmonious solutions" mean to each one? Would be there a general consensus about that? The definition of what means a "harmonious solution" will depend on the ideological aspects of the people involved in the analysis of problems.

In the last years, aiming to give some perspectives of solution to these problems, the STS (Science, Technology and Society) approach has developed an educational proposal that intends to teach students and teachers new attitudes to cope with those issues. The focus of STS is to know about the relationship amongst science, technology, and the culture of a society, aiming at some "harmonious solutions". Also, environmental factors are frequently being taken into account, as well as economical issues. One of the most important aspect in STS educational

approach is to develop in students a critical thinking. For that, we regard as essential to use means to make relational reasoning putting together several ideas seeking for finding out the mutual influences.

The STS approach is relatively recent in Brazil. In spite of the emphasis given to Mathematics, Physics, and Technical knowledge, during several years, engineering curriculum in Brazil has tried to include subjects such as Biology, History, Law Studies, Economy, among others, to provide a more encompassing view for students. Nevertheless, there was not an effective concern to connect/integrate the subjects and to make critical reflections. So, the students did not understand the reason of such subjects in the curriculum, and frequently neither the teacher. Some updates in curriculum were made and we could notice that there was not a general understanding about how teachers/professors have to be qualified to deal with an integrative approach of subjects according to the STS proposal. In addition, we have perceived that a number of our engineering students does not like of those non-technical matters, frequently calling them of "cosmetic" ones. They used to demonstrate some opposition to read and to reflect about social themes. Also, we have observed that they prefer visual issues (equations, flowcharts, drawing, abacus, graphics, built up circuits and components, etc.).

Then, to favor a relational reasoning, which takes in account these issues and can motivate our engineering students, we are proposing to use cognitive maps (CMs) to analyze STS situations. And CMs have another interesting aspect that became an interesting tool to be applied in STS teaching/learning in engineering courses, that is its mathematical basis. As STS aims to promote a critical reflective thinking, we consider that for engineering students a mathematical instrument would be an attractive way to motivate a multi-relational reasoning specially if it is used with computer based applications.

Generally, a framework of STS implies in a set of concepts or ideas, which are put together for making cause and effect reasoning. "CMs are a power tool which allows users to represent and reason on causal relationship as reflected in realistic dynamic systems"[4]. Also, CM can be taken as a reflective tool assuming a constructivist view of knowledge[5]. This latter view considers that knowledge change dynamically. In fact, CM depicts a static representation of knowledge that can be used to understand some situation allowing an insightful vision of a moment that is under consideration. However, in due time, new information can be added to the map or even it can be modified to follow the progress of the knowledge concerning a situation. In this way, the STS' dynamics could be modeled expressing the changes in the situation that is being investigated.

Thus, the objective of this paper is to show how we could use cognitive maps to make an STS approach that offer valid outcomes, motivate our students, and allow a degree of visualization of the real world. For that, this paper is organized as follows. Firstly, it is approached some aspects of STS, which we consider that are important to take into account. Such aspects are explained and justified according to authors' point of view and from readings of various authors. Secondly, a review of cognitive maps is shown highlighting the modeling of concurrence among information as well as its mathematical representation. Thirdly, a simple and small example is proposed to illustrate the proposed methodology. It is important to emphasize that such example does not intend to be a "universal model of reality" but just a way to exemplify the relational

reasoning promoting by CMs. Finally, we comment about some possibilities of using this methodology.

Concurrent Aspects of STS

STS basically seeks to analyze the interrelationship between human action in scientific and technological fields, and the transformations that such actions produce in nature, cultures and societies[6-8]. The agents of those transformations are individuals and/or groups that lead their actions to achieve that material transformation according to their *desires*, *beliefs* and *values*, which were established through culture and/or religion.

Desires are especially related to individual human basic needs and instinctive drives. They are taken here as an impulse toward something that promises enjoyment or satisfaction in its pursuit[9]. It is a driver of behavior. Murray[10,11] considered several human needs that could be taken as desire, for example, desire for power and domination, desire for acceptance, and desire for achievement. Some authors[12,13] considered desire for power the strongest desire of human beings. So, we think to understand people's behavior and the dynamic of societies, at least some psychological drives have to be taken into account. They are important psychological motivational factors that compel people to action, directing behavior to search for specific achievements.

Beliefs are socially constructed ideas, which define subjectively what is real or non-real, and "who", "what", "where", "why" things are[14,15]. They organize and structure our knowledge about reality. Religious fundamentalism and some cultural patterns are example of beliefs shared by people.

Values are cognitive constructs concerning what is important to each individual and/or societies, leading our judgment about what is good or bad, right or wrong, etc.[14,16]. Values are related to what is important and what is worth spending time with, paying attention, and endeavoring to keep or achieve. These aspects are, in general, learned by means of education, cultural, religious and familiar practices. Values work like abstract goals, which align other more concrete ones in a hierarchical way. As example of values we could mention honesty, freedom, justice and peace.

Finally, beliefs and values are associated with the ideology or the worldview of a society and their representation into individual minds. Often ideological aspects are not explicit but they underlie people's behavior as individuals or groups justifying and legitimating their actions upon others and the environment[3,17]. Such aspects influence people's perception, judging, and decision-making about the happenings. Also, ideological aspects influence the advances in science and technology, and in political and social doctrines.

For that reason, we consider very important to take into account desires, beliefs and values in Science, Technology and Society (STS) approaches. In fact, those aspects motivate individuals and societies to define actions, rules, ethical codes and moral procedures that legitimate actions and achievements in all areas. Then, it is necessary to put those subjects together with economical aspects (such as competitiveness, productivity, and profitableness), social issues (such as unemployment, social mobility, and poverty), environmental questions (such as

exploitation of natural resources, pollution, and agriculture), political actions (such as war, economic and cultural imperialism), etc., to understand the social dynamics that move science, technology and society in an interconnected manner. For that, we propose here to use Axelrod's cognitive maps (CMs) that allow carrying out a concurrent analysis of socio-economical reality.

Cognitive Maps to Model Concurrence

We present a way to analyze the STS dynamic based on cognitive maps (CMs) proposed by Axelrod[18]. Through such tool we are able to model social mechanisms underlying STS, regarding several aspects that are interrelated, distinguishing oppositions and synergy among aspects, and even predicting consequences of some simulated situations. This kind of analysis makes possible to have a broaden vision about many questions. It allows stimulating critical consciousness through the requirement of making direct relationships among information, and at the end of the process, investigating the indirect relationships obtained.

Axelrod proposed CMs to analyze social, political and economical issues. Such maps are based on the idea of *causality*, that is, the relation between a cause and its effect or between regularly correlated events or phenomena. He observed that people make evaluations about complex political alternatives in terms of the consequences that a particular choice could cause in the outcome of the process under investigation, and, at the end, in terms of the sum of the effects of each decision upon the result of such process. He stated that, in reality, this causal analysis is built inside human language itself and it was very difficult to reason completely through other means, even though it would be tried. He suggested representing the concepts used by decision makers by points (nodes), and the causal links, which make relationships of every concept with one another, by edges (arrows). This results in a representation like an oriented graph. Thus, if we give weights (values) to those links, we have a cognitive map, as shown in Figure 1.

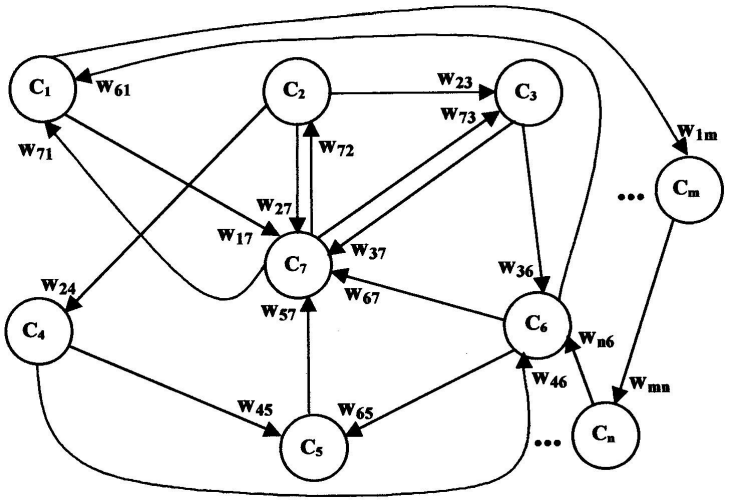

Figure 1 – Cognitive Map.

Nodes C_i represent concepts. Edges w_{ij} represent relationships among those concepts and their weights or, in other words, the interrelationship among considered concepts. Axelrod asserted

that, in such representation, the real potential of this approach based on CMs arises and becomes relatively simple to verify how the concepts act upon each other. This allows a general view of the entire scenery, which someone is trying to model or to understand. The nodes symbolize ideas, concepts, political alternatives, several causes and effects, the goals, and even the decision maker's final target. The edges show the causal relationships among those concepts or ideas or, in other words, how the concepts interfere each other. It is done through two basic laws of interaction of parts, which are, for example, "cause" or "not cause". However, in a "cause" case, we need to inform if the action of a given concept C_i is in direction of strengthening or weakening the other(s) concept(s) C_j.

To construct a CM, the opinions of several specialists about a pair of concepts could be combined through a process called a vote procedure (the most voted opinion wins), what is done when we use a questionnaire. But, if the relationships were obtained, for example, from a text written by a specialist about a particular subject, we need to find the intersection between his/her different opinions about a particular pair of concepts. All possible combinations are shown in Table 1. Note that an ambivalent relation ("a") is not directly obtained from the specialists' assertions, but it can arise when we combine their opinions about a particular relationship.

Moreover, the system becomes more complex when we have indirect effects. For example, if a concept C_i affects C_j and C_j affects C_k, how does concept C_i affect concept C_k? To answer this question, we simply have to multiply the edge weights w_{ij} and w_{jk}. If the exact numerical values of relationships w_{ij} and w_{jk} are known, we need to do a standard multiplication. But, if we have only signals or others nonnumeric values as shown in Table 1, the multiplication rules must be the following:

1. Positive times anything is that thing;
2. Zero times anything is zero;
3. Ambivalent times anything (except zero) is ambivalent;
4. Negative times negative is positive;
5. Multiplication distributes over union. For example, (–) • (~~p~~) = (–) • (– ∪ 0) = ((–) • (–)) ∪ ((–) • (0)) = (+) ∪ (0) = ~~n~~;
6. Multiplication is symmetric. For example: (–) • (~~p~~) = (~~p~~) • (–).

Another important situation occurs when we have two or more paths between any concepts C_i and C_k, passing through different nodes, and we wonder the total influence of C_i upon C_k. In this case, all we have to do is a simple addition, governed by these rules:

1. Zero plus anything is that thing;
2. Ambivalent plus ambivalent is ambivalent;
3. Positive plus positive is positive and negative plus negative is negative;
4. Positive plus negative is universal, that is, positive, negative or zero;
5. Addition distributes over union;
6. Addition is symmetric.

Symbol	Logical combinations	Explanation
+	Positive	Concept C_i strengthens concept C_j
–	Negative	Concept C_i weakens concept C_j
0	Zero (null)	Concept C_i does not affect concept C_j
~~n~~	Nonnegative, that is, zero or positive	Concept C_i does not weaken concept C_j
~~p~~	Nonpositive, that is, zero or negative	Concept C_i does not strengthen concept C_j
m	Nonzero, that is, positive or negative	Concept C_i affect s concept C_j
u	Universal, that is, positive, negative or zero	Concept C_i can or cannot affect concept C_j
a	Ambivalent, that is, the empty set	It is not clear if concept C_i affects concept C_j

Table 1 – Values that can be assumed by concept relationships.

Finally, to come up with useful information from a map, we must obtain the effect of all concepts (nodes) upon the concept (node) in which we are interested. With a little training, it is possible for someone, through mental calculation, to combine the concepts with the aid of the previous rules, until getting the total effect upon the desired concept. Then, politics/actions that produce total negative or non-positive influence should be discarded. Politics/actions with null (zero) influence upon the final result should be ignored, and those with non-negative results should be reserved for new studies. Those that result in non-zero, universal or ambivalent are inconclusive. Finally, those that resulted in a positive global effect must be chosen, because they will be reinforcing the desired outcome.

However, for huge maps, it can be a hard work to infer about it using only mental calculation. It is necessary that we develop a mathematical model, which could be implemented by a computer. In this case, we need initially to assemble a matrix that represents the action of a concept upon the other ones. That is, a matrix that shows how the concept of the row i acts over the concept of the column j. This matrix is called "valency matrix" or "weighted edges connection matrix", and it is represented here by [**W**]. The valency matrix of the Cognitive Map from Figure 1 is shown in Table 2. The next step is working with this matrix to obtain the mathematical model.

Concepts ⇓ ⇒	⇓ Effect C_1	C_2	C_3	C_4	C_5	C_6	C_7	...	C_m	C_n
⇓ Cause C_1	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}	w_{16}	w_{17}	…	w_{1m}	w_{1n}
C_2	w_{21}	w_{22}	w_{23}	w_{24}	w_{25}	w_{26}	w_{27}	…	w_{2m}	w_{2n}
C_3	w_{31}	w_{32}	w_{33}	w_{34}	w_{35}	w_{36}	w_{37}	…	w_{3m}	w_{3n}
C_4	w_{41}	w_{42}	w_{43}	w_{44}	w_{45}	w_{46}	w_{47}	…	w_{4m}	w_{4n}
C_5	w_{51}	w_{52}	w_{53}	w_{54}	w_{55}	w_{56}	w_{57}	…	w_{5m}	w_{5n}
C_6	w_{61}	w_{62}	w_{63}	w_{64}	w_{65}	w_{66}	w_{67}	…	w_{6m}	w_{6n}
C_7	w_{71}	w_{72}	w_{73}	w_{74}	w_{75}	w_{76}	w_{77}	…	w_{7m}	w_{7n}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋯	⋮	⋮
C_m	w_{m1}	w_{m2}	w_{m3}	w_{m4}	w_{m5}	w_{m6}	w_{m7}	…	w_{mm}	w_{mn}
C_n	w_{n1}	w_{n2}	w_{n3}	w_{n4}	w_{n5}	w_{n6}	w_{n7}	…	w_{nm}	w_{nn}

Table 2 – Valency Matrix of the Cognitive Map corresponding to Figure 1.

The multiplication of two matrices [**X**] and [**Y**] of order n results in a third matrix [**Z**] of order n, in which each element z_{ij} is given by the expression:

$$z_{ij} = \sum_{k=1}^{n} x_{ik} \cdot y_{kj} \qquad 1$$

If [**X**] = [**Y**] = [**W**], we have [**Z**] = [**W**^{2}], where:

$$z_{ij} = w_{ij}^{[2]} = \sum_{k=1}^{n} w_{ik} \cdot w_{kj} \qquad 2$$

Then, observing Equation 2, we can conclude that each element $w_{ij}^{[2]}$ of the resultant matrix [**W**^{2}] represents the indirect effect of the concept C_i upon the concept C_j through every path composed by exactly two edges, i.e., there is exactly one node between the nodes i and j. In other words, each product $w_{ik} \cdot w_{kj}$ expresses the indirect effect of the node i upon the node j crossing some node k. Adding the effects of all paths between the nodes i and j passing through all intermediary nodes k, we have the total indirect effect of the node i upon node j considering all, and only, the paths of length two. Now, if we multiply [**W**^{2}] by [**W**] obtaining [**W**^{3}], we have the effects of the node i upon the node j, considering all, and only, the paths of length three (two intermediary nodes). If we continue the process until power $(n-1)$, we will get the indirect effects of the node i upon node j considering all, and only, the paths of the maximum possible length $n-1$ ($n-2$ intermediary nodes). After that, to obtain the total influence of the node i upon the node j, considering all paths of all lengths, we need to combine (add) every partial matrix through Equation 3:

$$[\mathbf{T}] = \sum_{q=1}^{n-1} [\ \mathbf{W}^q\ ] \qquad 3$$

The matrix [**T**] can be called "total effects matrix", and each element t_{ij} gives us the global effect of the node i upon the node j, considering all direct and indirect effects, that is, it informs us about the way how concept C_i influences the concept C_j, and it can be used to generate information about the global effect of every politics upon a specific desired outcome. Also, matrix [**T**] can be used to study the structure of the cognitive map. At the end, according to Axelrod, a cognitive map is "acyclic" when, and only when, all of the main diagonal entries of its total effect matrix are zero, that is, no concept or variable has an effect upon itself. And a cognitive map is "balanced" if, and only if, it has not universal, non-zero, or ambivalent entries in the matrix [**T**], that is, if the global affect of every concept or variable upon another concept or variable is not indeterminate.

Done that, we are able to represent and to reason with incomplete definitions, or lack of them, or linguistic imprecision, in mathematical terms. We can mathematically model a complex system and individual beliefs and we can mathematically deal with someone's true beliefs and what moves his/her actions. Once the properties of the parts (nodes) and the interaction laws among those are known, we can make inferences about the complete cognitive map and about the reality that it represents, for example, obtaining answers for questions like these: How would a person make a particular choice among several alternatives? Will it be possible to predict about future attitudes? How could the change of a concept or belief influence the other ones? How would that change modify the way of thinking or acting of that individual? That is, we are interesting in knowing things like this: How does the decision making process of a person works?

STS Dynamics

We present here a small example to illustrate the STS dynamics based on CMs. It is a sample of the capacity of this tool for modeling, which could be used to teach and learn STS in a broader sense, as it was mentioned previously. Nine concepts related to STS and connected aspects were chosen. The weights of the edges were defined based on common sense thoughts and authors' beliefs. This example just models a way of thinking about these subjects mirroring the reality under authors' point of view. Other people could have different opinions choosing different connections, weights or concepts. What we intend here is just to exemplify how a CM is able to put together information related to each other by means of cause and effect relationships. Also, the weight of edges depends on the context that it is being analyzed. Here, a global/world context was taken into account. The chosen concepts and their suggested definition can be seen in Table 3. The authors propose these definitions to make some constraint in the meaning, because these concepts have a broad semantic structure associated to each one.

Concept	Definition
1. Desire for power/domination	"Needing to have impact, control, or influence over another person, or world at large"[11]. Nietzsche believed that the strongest of the human species desire is not only to survive, but also to gain power over others[13].
2. Social values	Honesty, freedom, peace, better life quality for everyone, and democracy. Social values depend on each culture and the ones proposed consist of Western values.
3. Capitalist business ideals	Competitiveness, productivity, profitableness, consumerism.
4. Imperialism	The policy, practice, or advocacy of extending the power and dominion of a nation especially by direct territorial acquisitions or by gaining indirect control over the political or economic life of other areas[9]. We can cite as examples: religious fundamentalism, lack of respect for cultural differences, war, and economic and cultural imperialism.
5. Environmental problems	Exhaustion of natural resources, pollution, extinction of animals and plants.
6. Social problems	Unemployment, lack of social mobility, bad income distribution, violence, famine, poverty.
7. Science	Knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method[9].
8. Economic stability	Inflation under control, currency stability, low interest rates.
9. Technology	Devices and procedures developed by people.

Table 3 – Chosen concepts and their definition.

It is important to emphasize that these set of concepts just stand for an example, which expresses the thoughts of authors. It does not intend to be a "universal" or "generalized" model. What is important here is the *process of modeling* rather than the obtained model. The process of modeling allows the relational reasoning, which make possible insights into the situation under analyzing. This example just aims to show the process of modeling provided by CMs, which is applied to analyze a STS hypothetical situation.

To obtain the CM of the proposed example, all suggested concepts were related two-by-two, according to the definitions in Table 3. This process generated the CM shown in Figure 2. In sequence, the matrix [**W**] can be assembled according to the information in Figure 2. This matrix is shown in Table 4. Only direct relations between concepts were sought for because indirect ones will be obtained by map interconnections. Nine concepts make up to 81 two-by-two interconnections.

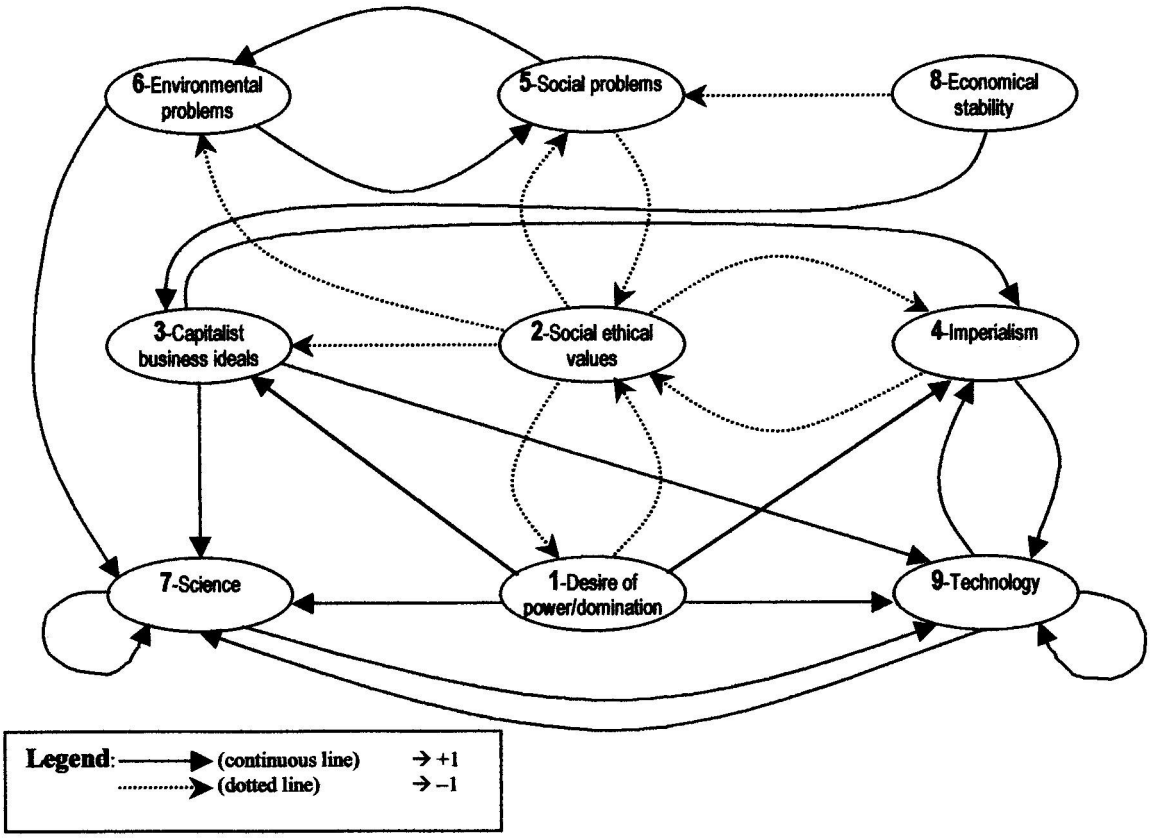

Figure 2 – Example of Using of Cognitive Map.

Figure 2 and Table 4 represent the direct relationship between the chosen concepts, that is, the author's beliefs. From those, it can be observed that, in author's thoughts, *Desire for power and domination* strengthens *Capitalist business ideals*, *Imperialism*, *Science* and *Technology*, and it weakens *Social ethical values*. *Social ethical values* weaken *Desire for power and domination*, *Capitalist business ideals*, *Imperialism*, *Social problems*, and *Environmental problems*. So,

Social ethical values act like a moderator favoring the decrease of social and environmental problems. *Capitalist business ideals* strengthen *Imperialism*, *Science* and *Technology*. *Imperialism* strengthens *Technology* and weakens *Social ethical values* (because it does not promote *freedom* and *democracy*). *Social problems* strengthen *Environmental problems* and weaken *Social ethical values*. *Environmental problems* strengthen *Social problems* and *Science* (that tries to solve such problems). *Science* strengthens itself and *Technology*. *Economical stability* weakens *Social problems* and strengthens *Capitalist business ideals* (because investors feel more confidence in economical context). And *Technology* strengthens *Imperialism*, *Science* and itself.

	1	2	3	4	5	6	7	8	9
1	0	-1	+1	+1	0	0	+1	0	+1
2	-1	0	-1	-1	-1	-1	0	0	0
3	0	0	0	+1	0	0	+1	0	+1
4	0	-1	0	0	0	0	0	0	+1
5	0	-1	0	0	0	+1	0	0	0
6	0	0	0	0	+1	0	+1	0	0
7	0	0	0	0	0	0	+1	0	+1
8	0	0	+1	0	-1	0	0	0	0
9	0	0	0	+1	0	0	+1	0	+1

1. Desire for power and domination
2. Social ethical values
3. Capitalist business ideals
4. Imperialism
5. Social problems
6. Environmental problems
7. Science
8. Economical stability
9. Technology

Table 4 – Valence matrix corresponding to Figure 2

Some of these relationships probably represent common sense thoughts. Other could be questioned. The first step of the process of modeling with CM is to take the concepts as isolated points, what was done. The next step is to apply the CM method to calculate the interrelationship among the concepts, that is, to obtain the integration of information.

A program was developed in FORTRAN language to calculate a matrix [**T**] (Equation 3). The mathematical analysis of results of mutual influence is explained next.

Analysis of outcomes

Applying Equation 3 to the matrix shown in Table 4, we obtain matrix [**T**] shown in Table 5, which represents the sum of all direct and indirect influences on each node/concept. This matrix was normalized in percentage terms in relation to the highest value to facilitate the interpretation of outcomes. The performed analysis will not consider the absolute value of the numbers, but it will make a relative evaluation trying to interpret the numbers in qualitative terms.

Analyzing the rows, we have the influence of a concept upon the others. In this sense we can take the rows from Table 5 and make an analysis considering the most meaningful outcomes. *Desire for power and domination* has high influence upon *Technology* and *Science* and little less upon *Imperialism.* Also it weakens a little *Social ethical values*. *Social ethical values* weaken *Technology*, *Science* and *Imperialism*. Such influence could be understood as a kind of "social control" over these concepts. It is interesting to observe that it works in opposition to *Desire for power and domination. Capitalist business ideals*, *Imperialism*, *Environmental problems*,

Science and *Technology* have similar profile, that is, a moderate influence in increasing the strength of *Science* and *Technology* and a little less in *Imperialism*. *Technology* has an influence very similar to *Science* but a little stronger. *Economical stability* does not have a meaningful influence upon the other concepts. It could be inferred that its influence depends on other factors that were not modeled in this map. So, *Desire for power and domination* and *Social values* are the concepts that have the most influence upon the others.

	1	2	3	4	5	6	7	8	9
1	12	-33	17	59	19	19	85	0	100
2	-12	34	-17	-59	-20	-20	-85	0	-99
3	6	-15	8	28	9	9	40	0	47
4	7	-18	9	32	11	11	45	0	53
5	6	-15	8	27	10	10	39	0	45
6	3	-9	4	16	5	5	23	0	27
7	3	-9	4	16	5	5	24	0	28
8	0	1	0	1	-1	-1	1	0	1
9	6	-15	8	28	9	9	40	0	47

1. Desire for power and domination
2. Social ethical values
3. Capitalist business ideals
4. Imperialism
5. Social problems
6. Environmental problems
7. Science
8. Economical stability
9. Technology

Table 5 – Direct and indirect influences in each node/concept.

Analyzing columns, we have the influence that a concept receives from the others. In this sense, we can take the columns from Table 5, and make an analysis considering the most meaningful outcomes. So, *Desire for power and domination* practically does not receive influence of others. *Social values* receive a moderate influence of itself strengthening it, and of *Desire for power and domination*, weakening it. *Capitalist business ideals*, *Social problems* and *Environmental problems* just receive a mild influence of the others. *Imperialism, Science* and *Technology* have a similar profile, milder in the two firsts and stronger in the latter. For these three concepts, there is a considerable influence of *Desire for power and domination*, strengthening them, and of *Social ethical values*, weakening them, and also a mild influence of *Capitalist business ideals*, *Imperialism, Social problems* and *Technology*. *Economical stability* does not receive influence of the other concepts as we can see in Figure 2.

Some aspects of this latter analysis could seem obvious, however, other are not so. For example, *Economical stability*, which is often pursued by government, practically does not influence the other concepts. Probably, if this were put with other set of concepts, for example *market credibility* or *foreign investments*, it would have a more meaningful influence. Also, we can observe that, in this proposed model, *Social problems* strengthen indirectly *Science* and *Technology*.

In CM technique what is important is to model a situation and to analyze the outcomes, interpreting what the map really represents. Also, this reflection can bring out some limitations of the model or of the used database. Then, changes can be proposed. For example, new concepts could be added, subtracted, or even the old ones could be redefined. New weights could be given to the edges. And the process could be repeated until the user of this method achieves the level of

reflection that he/she desires. But, the outcomes obtained here were considered enough to attain the goals of this paper.

Conclusion

The STS approach aims to understand the complexity of the relationships among science, technology and society. In this sense, it tries to promote critical thinking regarding value, ethical, moral, cultural, historical, political and economical dimensions of problems and issues, therefore, broadening the view of situations. For that, methodologies and tools for analyzing and reflecting have to be used to favor a complete reasoning. Here it was shown a mathematical tool for modeling situations in which science and technology can be put together with social and economical issues. The developed example brought up several aspects that were not explicit at first, as for example; the moderator role of "social ethical values" and the strength of individual/social drive "desire for power and domination", the little influence of "economical stability" in concepts that were regarded, etc. In fact, the proposed model of interrelationships represents the beliefs of the authors. Other people could have different thoughts about such concepts. It expresses a point of view upon a situation/issue or problem. However, once it is expressed, it is easier to reflect about the subject, to see its multi-facets, imbrications, and limitations of the proposed model (concepts and links), and even to use common sense thoughts to interpret what the numbers are showing to us. Possible incoherencies in the outcomes could be succeeded of an incomplete model (lack of some concept(s)) or ambiguous definition of concepts. The meaning of concepts is often associated to context or concerning the direction of an action, for example "imperialism" could be a big thing to those who impose it but a bad one to those who are subdued. So, a critical assessment of each map is necessary to mirror better reality and to reflect about our own beliefs.

A CM is a very flexible and easy to use simulation tool. It can be used to model a situation (simplified or even complex) by means of a graph representation. The process of modeling with this tool activates the relational reasoning favoring a critical reflection. It accounts for direct and indirect effects of causal relations in each concept giving an idea about the whole functionality of the system. The mathematical treatment of a map is simple to be implemented by computer programming. Simple maps, with few nodes, can be calculated by hand. It is recommended that the interpretation of results be based on the qualitative relation among numbers (much/less/most/least) instead of the analysis of absolute numeric values. Due to theses features, the CM is an interesting tool to model STS matters, especially in the context of engineering education.

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