
Capacity building: a course on sustainable development to educate the educators

Capacity
building

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Abstract

Purpose – The purpose of this paper is to present information about a team-teaching course on sustainable development (SD) for educators in an institution of higher education, Monterrey Campus of ITESM in México.

Design/methodology/approach – Four faculty members were invited to work together with the Sustainable Campus Programme coordinator in the process of developing the “Educate-the-Educator’s” SD course. The course was structured using lectures, readings, class role play activities, homework, and general discussion. Additionally, a workshop-format was woven throughout the course; its function was to help the educators incorporate SD issues within their own courses.

Findings – It was found that a multi-disciplinarily developed and delivered course is an effective vehicle for educating educators on SD. Documentation of some facets of the learning process further helped the “students” and the course leaders to better understand the whole learning process.

Originality/value – The paper’s value rests on the interconnected structure, showing resonance with the triple bottom line, as well as many other dimensions linked with sustainable development. This structure increased the course participants’ comprehension of sustainability. Furthermore, the use of concept maps and digraph theory to evaluate “faculty participants”’ comprehension of the interconnections and dimensions of SD proved to be a successful innovation.

Keywords Training, Education, Sustainable development, Mexico

Paper type Research paper



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Introduction

For the last decade there has been an increasing momentum for educators in all academic fields to incorporate concepts, values and approaches of sustainable development (SD) into their curricular activities. Similarly, many governments and enterprises are facing similar challenges/opportunities. Consequently, it is essential that institutions of higher education ensure that their educators and administrators are not only knowledgeable but also committed to making SD an integral part of all curricular activities of present and future students.

In this context, Tecnológico de Monterrey (ITESM) has incorporated sustainable development concepts within its new mission and vision statements, which are to be fully implemented by 2015. Specifically, the Mission states that Tec faculty are responsible for:

... preparing people with integrity, ethical standards and a humanistic outlook, who are internationally competitive in their professional fields; at the same time, they will be good citizens committed to the economic, political, social and cultural development of their community and to the sustainable use of natural resources (www.itesm.mx/2015/english/index.html).

This means that the institution must take actions to ensure that the concept of SD is incorporated into our professional education, and that SD must be part of all institutional activities.

Fortunately, the United Nations established the Decade of Education for Sustainable Development (DESD)[1] that started in January 2005, with the goal of supporting the incorporation of SD into courses and curricula throughout the World. Hence, both the Mission of Tec de Monterrey and the United Nation's ideological support provide momentum to our educational activities.

Criticism about sustainable development is directed to its ambiguity and inefficacy to solve complex problems that future generations will face. Jickling (1994) plays down the role of SD in education, stating that it is only a set of ideas that will be in fashion for a while, without necessary depth or implementation. But SD has to be approached from an interdisciplinary stance, with a strong critical component towards un-sustainability, in order to generate discussion and action awakening (Warburton, 2003). Because of the latter, this education for SD should effectively combine a conceptual framework and autonomous discovery through the acquisition of sustainable practice, and this must happen first at a personal level before it can be expected at a global level (Warburton, 2003).

This gap between theory and practice has led this paper's authors to develop an "Educate-the-Educators" course which first reviews the origin and meanings of SD concepts and second involves faculty learners in converting their courses to be more actively and thoroughly engage their students in learning to become "Change Agents for SD" through their academic experiences. To accomplish such empowerment, the faculty are challenged and supported in making a personal commitment to teach students to include SD in their professional and personal lives.

Following the arguments of Dale and Newman (2005), the main effort was to make learners capable of understanding and developing new responses to dynamic situations. This was accomplished by providing a wide range of content that illustrated interconnections and interdependencies that underline "dynamic" responses instead of "fixed" ones (Warburton, 2003).

According to some case study reports, different approaches and strategies for incorporating SD into the curricula have been tried by university faculty (e.g. Steiner, 2006). A relevant approach takes into consideration transdisciplinarity, which provides the complex, multidimensional focus into case studies. There have been attempts to permeate university life with SD (Moore, 2005), also attempts have been made to evaluate SD understanding and comprehension (Lourdel *et al.*, 2005, 2007; Ferrer-Balas *et al.*, 2006; Segalàs *et al.*, 2006). The later authors have proposed a method to assess understanding regarding sustainable development for students by using concept maps, which facilitates evaluation of comprehension through time.

A report on SD embedding at the engineering department of the University of Cambridge, (Fenner *et al.*, 2005) emphasizes that one must understand the process of change in order to successfully introduce SD concepts into courses and curricula. Approaches and strategies to overcome the typical barriers to change are presented by Lozano (2006). The barriers are grouped in three levels:

- (1) resistance to the idea of SD itself;
- (2) resistance to involving deeper issues; and
- (3) deeply embedded resistance to change.

Education of faculty members can partially overcome the first two barrier levels.

It is on this task, i.e. “capacity building of faculty to teach SD”, that this part of our campus SD efforts have been focused.

It is increasingly evident that “capacity building of educators,” must be considered to be the cornerstone of transforming universities to become effective in empowering their students to become change agents for SD in their professional and personal lives after their university experiences. If those who teach in HE are not versed in, conscious about and committed to SD, they cannot explain these concepts to their students and/or to incorporate such concepts into their research.

In the “Educate-the-Educator’s” work at Tecnológico de Monterrey (Monterrey Campus) is part of a holistic programme that covers every aspect of the institution. For a more detailed description of all other facets of the Sustainable Campus Programme (see Lozano *et al.*, 2006). The Sustainable Campus programme presented in this document underscores that not only academic issues need to be addressed when a higher education institution works to incorporate sustainability.

Background to this new, multi-disciplinary “Educate-the-Educators” course

In January 2003 faculty at the Monterrey Campus developed a three-day “Educate-the-Educators” course about SD. This course was designed to increase their awareness, to provide the foundation of a common language regarding SD and to provide tools and literature to help them to modify their courses. In that way, they could increasingly integrate the holistic approaches that are essential for student empowerment, so that communities can be transformed into sustainable societies.

This course was given four times. Approximately 100 dedicated faculty members took one of the courses.

Analyses of feedback from the faculty showed that although the three primary facets of SD (people, planet and profits or economics, ecology and society) were addressed, they were not appropriately integrated. This was apparently due to the way

the course was prepared and delivered. Consequently, the educators could not develop adequate insight into how to integrate all three facets into their own courses.

This is especially important because SD is based on interconnections and complexity, which means that decisions made in certain spheres have implications beyond the discipline or societal/ecological context within which it is made. Consequently, after further analyses of the results of the first four short-courses on SD for educators, the organizing team decided to thoroughly restructure the course to ensure that it be more integrated and interconnected. In this way, educators will more effectively learn how to integrate all dimensions of SD dimensions into their courses as interconnected elements.

All academics who have sought to work in this multi-disciplinary context know it is challenging to accomplish holistic integration of such diverse dimensions of knowledge into their courses and curricula but at the same time it is exciting and essential to do so.

In order to make progress in this complex system, several conditions must be fulfilled.

First, the course content should be structured so that the educators gain insight into the complex web of connections of the TBL, as well as of the other essential concepts of SD.

Second, a dedicated group of educators must be empowered to work as a team to design the general goals and objectives as well as the specific course content of the integrated SD course for the educators. Of course, they must then be dedicated to teaching the course and be supported to work as a team, much as a philharmonic orchestra would perform a symphony.

Third, a support activity to the SD course should be designed to help educators incorporate SD themes, problems, case studies, projects, etc., into their courses. To accomplish this objective, a workshop was developed to address these practical aspects as the course developed.

Finally, it was essential to develop a way to assess the progress that the newly educated educators made in understanding SD concepts, vision and complexity. Details about these four aspects are presented in the following sections.

1. The new course's structure, content and methodology

1.1 Structure linking relevant issues as the foundation of the course

The new course was based on the idea that certain drivers have pushed us onto our currently unsustainable societal path. This framework can be used to attract and to engage educators to become versed in SD and to be empowered to teach it. The course was used to engage educators willing to prepare and learn how to educate within the SD framework. A map of interconnected concepts in the course is presented in Figure 1. This figure shows the many interconnections among the relevant concepts of SD.

A set of drivers causally linked to our current unsustainable path were identified. These drivers include: anthropocentrism, resource appropriation, consumerism, human population growth, wealth generation oriented towards short term profits, etc. Many of these drivers are an expression of cultural values adopted by our present day society; hence, education must become an effective tool to modify or alter these unsustainable attitudes, values, policies, practices and technologies.

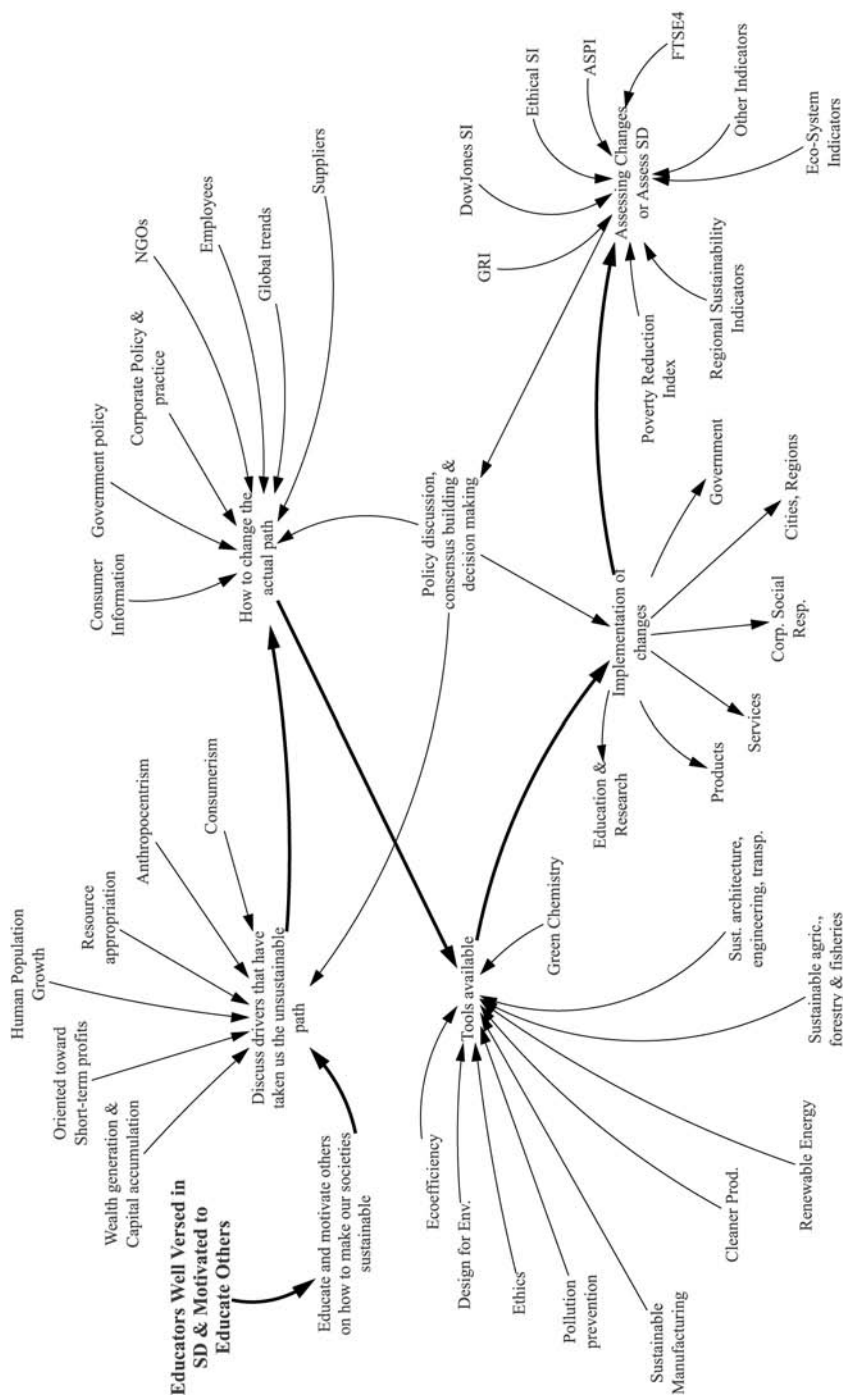


Figure 1. Diagram representing the interconnections among concepts and elements that help faculty members become effective SD educators

It is important to take into account the following insights derived from the book *Collapse* (Diamond, 2005):

First of all, a group may fail to anticipate a problem before the problem actually arrives. Second, when the problem does arrive, the group may fail to perceive it. Then, after they perceive it, they may fail even to try to solve it. Finally, they may try to solve it but may not succeed.

This quote is highly relevant for present and future generations. Past societies have chosen unsustainable pathways. Many of our current ones seem to be making similar mistakes! According to Diamond there have been societies that did not make the necessary changes and thus disappeared. On the other hand, he also emphasised that those that elected to make the necessary changes succeeded in becoming sustainable. It is within this context that the course was planned and developed.

Having agreed that these drivers have moved us away from sustainability; then we need to shift the discussion towards the ways that can help us change our path. Many factors need to be understood, such as global trends in natural resources use, energy demand, climate change, population growth, poverty, spreading diseases such as HIV/AIDS, terrorism, species losses, habitat destruction, changing scientific knowledge, and changing values. These are all relevant, especially from the perspective of the Earth's carrying capacity.

Further, it is essential for educators, students and all of society to be empowered to contribute to the essential changes. That means that members of NGOs, Governments, corporations, citizens, in general, must be involved in envisioning and in actualizing sustainable societies.

If educators are not helped in doing this they may continue to teach their students the typical "business as usual" themes, and the students, when they enter their post university lives will make decisions that follow the unsustainable paths. This course was designed to help educators to contribute more effectively to this transformational process.

During the last 15 years, many concepts, tools, and knowledge have been discovered. These need to be incorporated into the curricula of institutes of higher learning. The objective of this "Educate-the-Educator" is to address the diverse issues of SD. We believe that this is essential to help the educators to be able to focus more deeply on the concepts and tools for both future professional life, and also for institutions of higher education (Lozano-Ros, 2003).

The following list provides some of the concepts and tools that are relevant for helping educators to help their students help societies to take the SD paths instead of the alternative paths:

- climate change;
- eco-efficiency;
- green and sustainable chemistry;
- sustainable, green engineering;
- design for the environment;
- sustainable manufacturing;
- sustainable architecture;

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- sustainable mobility;
 - sustainable agriculture, forestry and fisheries;
 - ecologically sustainable resource management;
 - cleaner production and sustainable consumption;
 - renewable energy and energy efficiency;
 - pollution prevention and integrated product policy;
 - the polluter pays principle;
 - ethics;
 - ethical investment;
 - ethical employment;
 - corporate social responsibility; and
 - human population control.

Educators need to understand that these concepts and tools need comprehensive integration into the new SD courses and curricula. These courses can help their students become knowledgeable and empowered to help move society onto SD pathways. In order to accomplish this, educators must be supported in their teaching of SD.

Our institution educates future professionals that will be working in industry, services, local, state and federal governments, and NGOs. Some will become entrepreneurs, so the course provided a context to underline the importance of the future graduates' responsibilities in these different realms, in order to prepare a sustainable future.

But it is necessary to assess and evaluate sustainable development. A general context for this assessment should address the following issues:

- Societal, ecological, economic, political and ethical parameters that should be studied and monitored in order to assess if “progress” is being made or not.
- Such monitoring must be made based on the selection and use of appropriate indicators over a long time-frame for each category and for cross-cutting issues so as to effectively monitor the process and the results of the process toward SD.
- Additionally, of course, frequent sharing of the results with all stakeholder groups must be done along efforts to continue on stakeholder involvement and empowerment to ensure that the process continues to be democratic and equitable and that it continues to ensure that both short and long-term foci are addressed properly.

Figure 1 highlights some indicators useful for this assessment such as the Global Reporting Initiative (www.globalreporting.org/Home), or from the business perspective, the Dow Jones Sustainability Indexes (www.sustainability-index.com/).

Stakeholders need to participate in society to change the direction away from an unsustainable path. This is a relevant context in the new course, which also has to be addressed in different ways in the courses and curricula of higher education institutions. Thus, policy discussion, consensus building and decision making

processes can close the feedback loop for all the previously mentioned issues. This is shown in Figure 1 with the interconnected feedback linkages.

1.2 The first structure of the new SD course

Based on the structure given in 1.1, a draft was generated for a course that considered the following themes.

An introductory discussion from an historical perspective was proposed showing various relevant examples: the need to take into account the triple bottom line; actual trends in natural resource appropriation and use (mainly material and energy flow in the market); how to modify these trends towards more sustainable ones; and finally the tools to promote this change.

However, after several discussions, the course structure was modified slightly in order to better represent the lecturers’ point of view, as well as to our Campus and Mexican reality.

1.3 The final structure of the new course with activities to incorporate SD concepts into specific educators’ courses and curricula

Discussion among the team led to a final structure consisting of six modules, shown in Table I, which includes the general theme and a brief description of the modules’ goals and activities.

Module	Theme	Goals	Activity
1	Introduction	To introduce basic concepts of SD and its evolution. To enhance awareness of how we relate to the environment	Game on resource management with different inputs
2	Interconnections: Society-Economy-Environment	To identify SD and the triple bottom line, as well as its interconnections with a simulation exercise	Role-playing game to provide solution to actual local problems
3	Actual trends	To analyze the impact of human actions on the planet and the consequences of not reversing actual trends	Tragedy of the commons simulation through a fishing exercise game. Ecological “footprint” calculation. Personal commitments pledge
4	Tools to promote change 1	To show tools in successful cases, from the point of view of public policy, of sustainable management of natural resources	From the economic perspective: evaluation of emissions generated from personal consumption of electricity and fuel
5	Tools to promote change 2	To show tools in successful cases that foster sustainability from the perspective of citizens and entrepreneurship	Concept maps showing interconnections of economic, social, and environmental issues in local events
6	Activities designed for Tec courses	To provide tools and materials to teach and motivate students to become agents of change for sustainability	Final presentation of designed activities to be incorporated in each educator’s course

Table I.
Final course structure

Module 1 includes an introduction to SD concepts. It traces the evolution from development *per se* towards sustainable development, and discusses the recent academic mandates in various World Summit declarations. Explanations are provided for the concepts of multidisciplinary, intergenerational, and multi-dimensionality, and the section is closed with the UN Decade of Education for SD. A presentation is offered on great global problems and how human beings are part of ecosystem Earth, using a video named “SOS Earth” produced by SEMARNAT (Mexican Environmental & Natural Resources Ministry). Case analysis of unsustainable development, from Mesopotamia and the Mayas to South Africa and Río Tunal, contrast historical and recent examples. Module 1 concludes with a simulation exercise for various economies that start from a different resource basis.

Module 2 addresses interconnections of SD in concrete and real situations. Educators attending the course, engage in a role playing exercise about specific local projects (wood production, real estate development, industrial park), with roles including the public sector, business leader, civil society, scientific community member, and citizen.

Module 3 analyses the impact of human actions on the planet, and the consequences of maintaining present trends. It starts with a visual presentation of the human footprint at the end of the second millennium, using satellite photographs across the planet for the last 25 years (UNDP, 2005), as well as an economic explanation of resource appropriation. Then the implication of social aspects on SD are discussed, including population, health, poverty, and education. The Millennium Development Goals provide the context. Next, pesticide pollution and deforestation are analyzed. Finally, the participants calculate their ecological footprints and share personal commitments to reduce them.

Module 4 analyses the role of public policy and international organizations regarding sustainable management of natural resources. It reviews the achievements, challenges and advances made under various international agreements (Montreal and Kyoto protocols). Following that discussion, successful cases and approaches to the sustainable management of natural resources (Costa Rica) and organic agriculture are exemplified. After that, the discussion is shifted to environmental economics with value attributed to the environment and payments required for ecological service.

Finally, the details of the past, present and future dimension of the Sustainable Campus Programme (in Monterrey Campus) are shared by outlining the goals, objectives, results, challenges, and opportunities for improvement. The module concludes by asking the participants to assign monetary value for the pollution they have generated through their personal consumption of electricity and gasoline, i.e. fuel.

Module 5 considers several strategies and successful cases for fostering SD from the perspective of business and the individual citizen. It starts with the issue of fair trade followed by integral waste management; emphasis is placed on the European experience, as well as on Curitiba, Brazil’s sustainable transportation example. Finally various business strategies are presented and special emphasis is given to eco-efficiency, cleaner production, social responsibility and design for the environment. The module ends with introduction to and experimenting with concept maps (Warfield, 1994; Lourdel *et al.*, 2005, 2007; Macris and Georgakellos, 2006) related to local events. Participants are asked to provide the connections from the TBL perspective, e.g. local events such as: car racing, the Book Fair, etc.

Module 6 provides tools for teaching and motivating students to become “Change Agents for SD.” The following activities were proposed for students: generating sustainability indicators, information search and analysis, reflection exercises, case study. The module concludes with each teacher’s presentation of the SD concepts, tools and approaches to be incorporated into his/her course for teaching SD. This activity was initiated in module 3 and follow up was provided in each subsequent module by the course lecturers. A brief description will be given in the next section.

2. Dedicated group of educators engaged in the preparation and teaching of the new SD course for educators and attending educators’ disciplinary background

In 2003 the first course on SD for educators was developed with experienced lecturers chosen to guide the course. This course was based on the TBL. The professors could effectively portray each dimension. However, that group of lecturers was not able to continue working on the initial course, to make it more integrated and to show the interconnectedness among themes. Therefore, a new team of dedicated educators was sought on campus to carry on this initial effort. The criterion was that the professors be outstanding in their own disciplines, and also be willing to work as members of a joint, multi-disciplinary team to develop and to teach the new course. As a result of the search, a team of four educators was selected. The disciplines of the four faculty members includes: environmental economics, international relations, forestry, and plant pathology. This group was considered able to effectively present the concepts of the TBL as essential to the SD transformation that is needed to help educators on their SD journeys.

A pilot offering of the new was given in May 2006 with educators from the Division of Management and Finance. Then from September to October 2006, the newly designed course was offered to the Campus Faculty, with participating educators from management, engineering, law, industrial design and education.

As the course evolved, the educators began to broaden their perspective instead of conceiving of issues from the typical restricted vision from their own disciplines. This became evident in the various role plays, presentations, and group discussions used in the course. Although apparent to participants and lecturers, the challenge would be how to assess this change in attitudes, perspectives and values. This is expanded on within the following section.

3. Assessment to monitor the re-educated educators’ understanding of SD concepts and their progress within the new course

3.1 Concept maps as tools for assessing the progress of the changes in understanding of those attending the new course

A concept map is a powerful graphic representation of information. It consists of concepts visually related by pointed arcs or arrows, linked to phrases. It is beyond this work scope to delve into concept maps characteristics, the reader is referred to Novak, 1998; also the various International Conferences on Concept Mapping and the web site of the Institute for Human and Machine Cognition (<http://cmap.ihmc.us/>) are a good bibliographic source.

Nevertheless, these tools cannot guarantee commitment and participation of the educators as a result from the new course (Warfield, 1994; Lourdel *et al.*, 2005, 2007; Macris and Georgakellos, 2006; Kühtz, 2007).

The course generated increased awareness of SD problems and sparked a rich interchange of opinions. Those educators who brought previous knowledge of SD also shared their experiences and helped others to incorporate SD concepts into their specific courses, and this peer coaching was an important part of the new course. The participants with less experience regarding SD searched for ways their discipline could provide support for sustainability. Though the tasks proposed could not happen overnight, the experience was worthwhile for these educators.

Using cognitive maps to assess SD learning, Lourdel *et al.* (2005) puts the concepts appearing in the maps therein under a total of six semantic categories:

- (1) *Category 1* includes the words relative to social and cultural aspects.
- (2) *Category 2* concerns the environmental aspects.
- (3) *Category 3* concerns the economic, scientific and technical aspects.
- (4) *Category 4* is relative to the principles of Sustainable Development (durability, principles of precaution, prevention, solidarity, and future generations) and the reference to complexity, temporal and spatial dimensions.
- (5) *Category 5* includes procedural rationality and political aspects.
- (6) *Category 6* refers to actors and stakeholders. It is assumed that the reference to actors is related to the understanding of the participative dimension.

The last category gathers all the words that are not included within other groups.

The authors decided to slightly modify the categories and expand them to eight, while Category 3 was divided to separate economic issues from scientific and technical aspects, and a category for Education was included. Our final list, then, was conceived as follows:

- (1) Social and cultural issues.
- (2) Environmental issues.
- (3) Economic issues.
- (4) Scientific and technological issues.
- (5) Future generations, durability, precautionary principle, prevention, complexity.
- (6) Law, policies and procedural rationality.
- (7) Stakeholders and actors, participatory dimension.
- (8) Education.

At the beginning of the course, in order to assess participants' comprehension of SD, they were asked to sketch a concept map based on the words "sustainable development" and then repeat the assignment at the end of the course (Lourdel *et al.*, 2005, 2007).

These maps were processed by counting the number of concepts that the educators put in the maps and the concepts were classified according to the 8 categories explained above[2].

Subsequently, the average numbers of concepts was calculated for each category, as well as the average for the total number of concepts in all the data. See Tables II and III for a summary presentation of the initial and final data.

A typical concept map is shown in Figure 2.

A simple statistical analysis of data in Tables II and III gives the total number of concepts a value of 8.5 and 15.0 for the initial and final respectively. A “t” test analysis with 95 per cent confidence shows that the final average is greater than the Initial average. This means that educators attending the course relate a greater number of concepts to SD at the end of course than at the beginning.

To graphically present the data in Tables II and III for the whole group or for individual cases, radar graphs were prepared (See Figure 3 and Lourdel *et al.*, 2005), to clearly depict changes in awareness in the participants from the beginning to end of the course.

Other graphical presentations were tried, such as pie charts (Ferrer-Balas *et al.*, 2006) but radar graphs seemed to represent the evolution of participant comprehension in a simpler, graphical way.

These radar graphs depict the evolution of the Educators’ awareness from the course’s beginning to the end in eight semantic categories. Figure 3 shows the group results. These show that, on the average, the number of concepts increased from the beginning to the end, as would be expected.

Table II.
Data collected from the initial concept maps. Number of concepts for each category

Initial data Category	Educator number												
	10	4	2	11	13	1	9	5	8	12	6	3	7
Social and cultural issues	1	3	2	0	4	2	1	4	2	0	1	2	0
Environmental issues	12	5	5	8	1	3	3	2	4	7	5	2	3
Economic issues	2	5	2	1	2	2	0	1	0	0	0	0	1
Scientific and technological issues	0	0	0	0	0	0	4	0	0	0	0	0	0
Future generations, durability, prec, princ., complex	2	0	0	0	0	1	0	0	1	0	0	0	0
Law, policies and procedural rationality	0	0	0	0	1	0	0	0	0	0	0	0	0
Stakeholders and actors, participatory dim.	0	0	0	0	0	0	0	0	0	0	0	0	0
Education	0	1	1	0	1	0	0	0	0	0	0	0	0
Total	17	14	10	9	9	8	8	7	7	7	4	4	4

Table III.
Data collected from the final concept maps of 10 course participants. Number of concepts for each category

Final data Category	Educator number										
	13	12	8	9	7	14	5	3	1	6	
Social and cultural issues	7	6	5	4	1	3	2	4	2	1	
Environmental issues	11	11	6	6	10	5	7	5	1	1	
Economic issues	5	5	5	4	3	4	4	1	1	1	
Scientific and technological issues	1	0	0	1	0	0	1	0	0	0	
Future generations, durability, prec., princ., complex	0	0	0	0	1	0	0	0	0	0	
Law, policies and procedural rationality	0	0	1	0	0	3	0	2	0	2	
Stakeholders and actors, participatory dim	0	0	0	0	0	0	0	0	0	0	
Education	2	1	1	1	0	0	0	1	1	0	
Total	26	23	18	16	15	15	14	13	5	5	

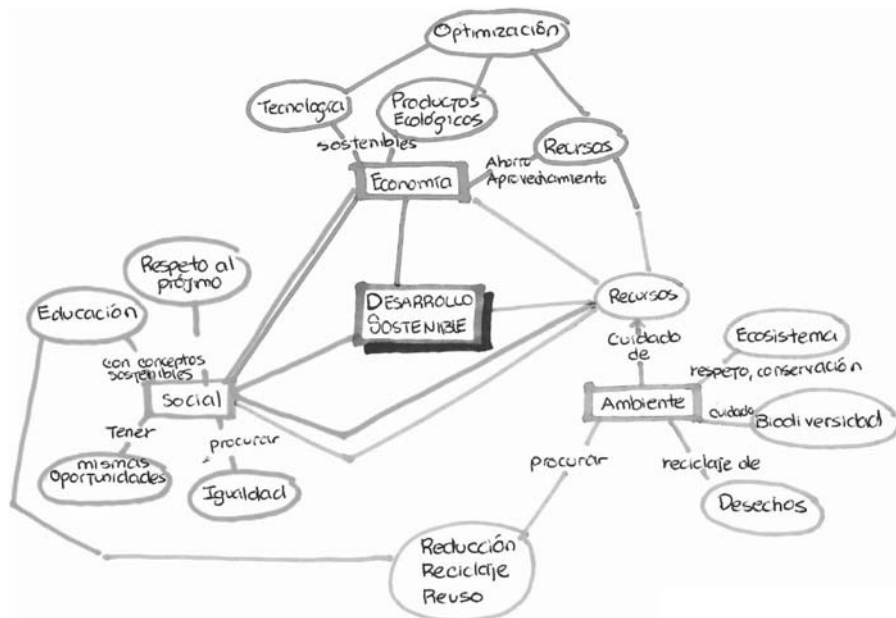


Figure 2.
Educator 9 final concept map

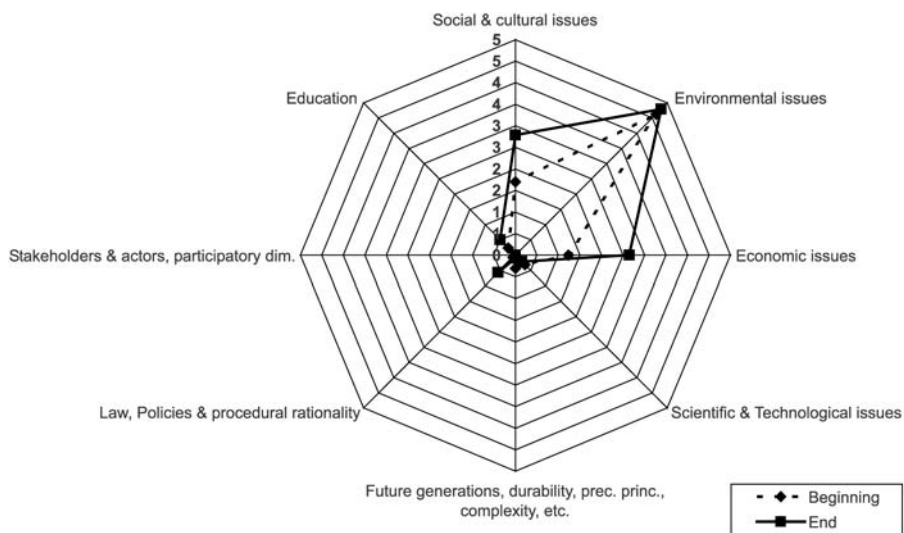


Figure 3.
The average number of concepts in the maps for each semantic category for the group of educators compared at beginning and end

Even though the lectures in the new course focused on the eight semantic categories as an intrinsic part of SD, emphasizing their interconnectedness, the graph in Figure 3 does not show this. It does show increased use of the number of concepts for the TBL at the end of the course.

Since course content and lectures were designed to emphasize connectivity, the triple bottom line was a strong foundation for the course. The educators who attended the course were truly engaged in the discussions, and frequently commented that they were able to see things from a different perspective. The radar graphs show that the learners improved in their understanding of the elements of the TBL. Their use of the concepts increased from beginning to end, but the interconnections are not as evident in the concept maps, even though participants addressed those interconnections in their discussions of the lectures. These results show the need to improve the course, in order to substantially expand the course focus beyond TBL, by emphasizing much more about education, law and policy, future generations and so forth.

Herein lies a challenge: to help educators to more fully comprehend that issues are connected and do not exist separately from one another. It is not enough for them to be proficient in their discipline with respect to SD. There was an attempt in the course to provide both depth and breadth of comprehension of SD, but the results of the analysis motivated the course team to make further modifications in certain parts of the course content and procedures.

A thorough analysis of the results is provided in order to enhance the “learner’s” comprehension in the other categories as well as to emphasize the needed interconnectedness, to benefit future courses. This has led to discussions with top management in the institution to request more help so faculty can more effectively embark on and to continue on the path of educating for SD.

As a corollary from Figure 3 there is a need to teach educators to expand their perspectives beyond the TBL, and that the inputs and discussions in the course did not achieve this. Sustainability is more than the societal, economic and ecological dimensions. Further studies should be used to follow up on educators to help them in their journey to SD. A process for follow-up is being discussed at various levels within the whole multi-campus system of Tecnológico de Monterrey.

Reviewing some of the individual radar graphs helped the team to understand the attitudinal changes and changes in knowledge that occurred for individual educators from the beginning to the end of the course. A single example of an individual radar graphs is shown in Figure 4. It is clear that educator eight substantially increased his knowledge about SD, and as a result included a greater number of concepts than what they presented at the beginning of the course.

Educator eight has expanded his/her awareness from 7 to 18 concepts

Not all educators showed an increase in awareness as a result of the course.

This example, as well as those not shown, challenges us to re-consider if “student” comprehension of the TBL was enhanced by taking the course. Clearly, a much more comprehensive goal needs to be set for the course, to address the many other dimensions more thoroughly.

3.2 Concept maps, directed graphs and complexity as tools for evaluation of effectiveness of educator learning in SD

Discussion of the data in the previous section provides a simplified view of the knowledge generated; concept maps are more elaborate than the simple enumeration of concepts in various semantic categories. By analysing the maps using graph theory, specifically as directed graphs or digraphs, a greater insight into the educators’ progress can be gained.

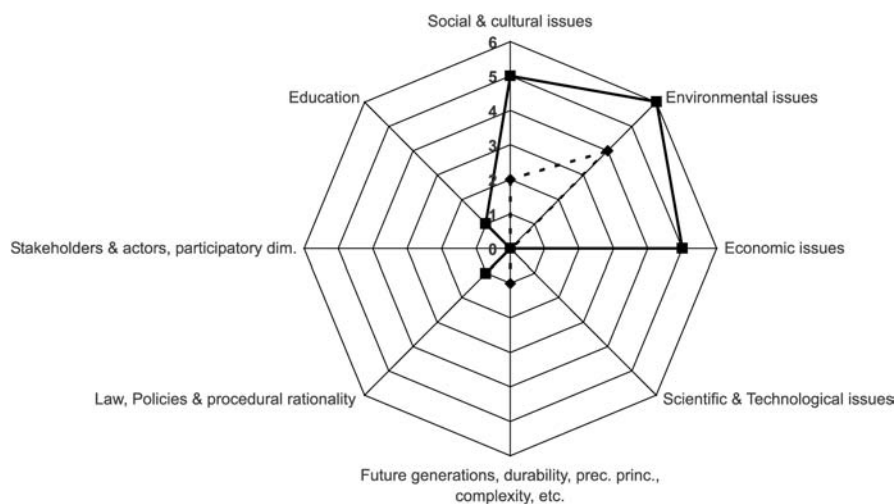


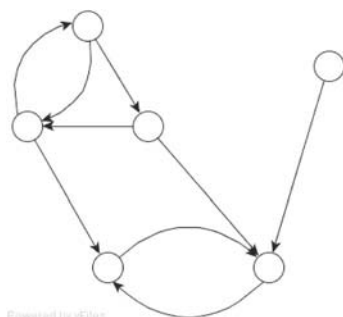
Figure 4. A comparison from the beginning to the end of Educator 8. The average number of concepts written in the concept maps for each semantic category

The authors decided to use the graph theory approach, because it can render information on connectedness, structure, complexity, as well as clustering among concepts, further down it will be explained with more detail, as well as providing references where this has been used elsewhere.

A graph is a set of vertexes (nodes) joined by arcs (edges), while a digraph has direction associated to the arcs, Harary (1962) see Figure 5.

For example Macris and Georgakellos (2006) have used graphs as a new teaching tool; this paper uses them for the intrinsic property relationships that they show, which are relevant to such concepts as complexity, arborescence, and direction given to connections, etc.

Analysing concept maps under a different light can help assess if the educational goals were achieved, as well as provide information on concept comprehension, and changes in understanding of the complexity of SD. As stated by Warfield (1994) “a map is an enlargement of a digraph, where each vertex is replaced by an associated prose statement”.



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Source: Harary (1962)

Figure 5. An example of a digraph

One way to start addressing this evaluation issue is to use graph theory, and specifically directed graph theory. This has been used in several disciplines to address different problems. For example, Warfield (1989, 1994) used them for electrical engineering problems, as well as societal and organizational problems; Himmelblau and Bischoff (1968) has applied them to chemical process diagram analysis, while Mah (1990) has used them for chemical process structures and information flows. Lourdel *et al.* (2005, 2007) has used them to evaluate students' understanding of SD. Segalàs *et al.* (2006) and Ferrer-Balas *et al.* (2006) have used them to evaluate learning in SD.

Graphs can be of different types; according to Warfield (1994), there would be isolated elements, arrays, linear maps, multi-linear maps, cycles, hierarchy maps, multilevel maps (hybrids). Macris and Georgakellos (2006) calls them complete graphs, networks, trees, mazes, flow charts, etc. Harary (1962) provides another classification for them. The various classification schemes can provide information on different issues, in the context of the present work they can be used to portray complexity in the structure, as well as interconnectedness among concepts for example. The reader is referred to the various references for the sake of brevity.

The importance lies in the mathematics used in graph theory which could provide useful information on the graphs (Harary, 1962; Bondy and Murty, 1976; McCabe and Butler, 1989; McCabe and Watson, 1994). The present document focuses on a simple metric to calculate complexity, as well as provision of analyses of some basic features that are in the concept maps, when treated as digraphs. Also the concepts of partitions, planarity, spanning trees, and sub-trees provide further information regarding structure; for definitions of these concepts see Harary (1962) and Warfield (1994).

Software programming can be treated in certain aspects as a graph, and Thomas McCabe in 1976 (Van Doren, 2007) showed that such representation can be used to calculate what has been known as the cyclomatic number.

In order to evaluate complexity we can use the cyclomatic number (defined herein as Cy), used in software programming as a metric. Cyclomatic number is equal to $A - V + C$ (arcs minus vertices plus connected components). For digraph in Figure 6, $Cy = 38 - 28 + 1 = 11$.

Hence, further processing information from the original hand-drawn concept map in Figure 2, renders the diagram in Figure 6. If the concept statements are hidden, we thus end with a digraph. If nodes are reordered under certain procedure a hierarchical layout is obtained providing structural information on the digraph, see Figures 7 and 8. For processing concept maps, the software yEd 2006-2007 from yWorks was used (www.yworks.com/en/products_yed_about.htm).

3.3 Have there been changes in the maps drawn at the course's beginning and end?

The answer does provide a measure of knowledge acquired, at least for the duration of the course. The initial and final results for Educator 9 are shown in Figures 7 and 8. The initial and final cyclomatic numbers are 1 and 8.

It is clearly seen that the final map of Educator 9 expanded to address more of the semantic categories shown in Section 3.1, and fulfils the course's goal of emphasising the TBL.

The change is notorious from Figure 7 to Figure 8 (showing an increase in environmental, economic, social issues). It can be seen that more concepts in

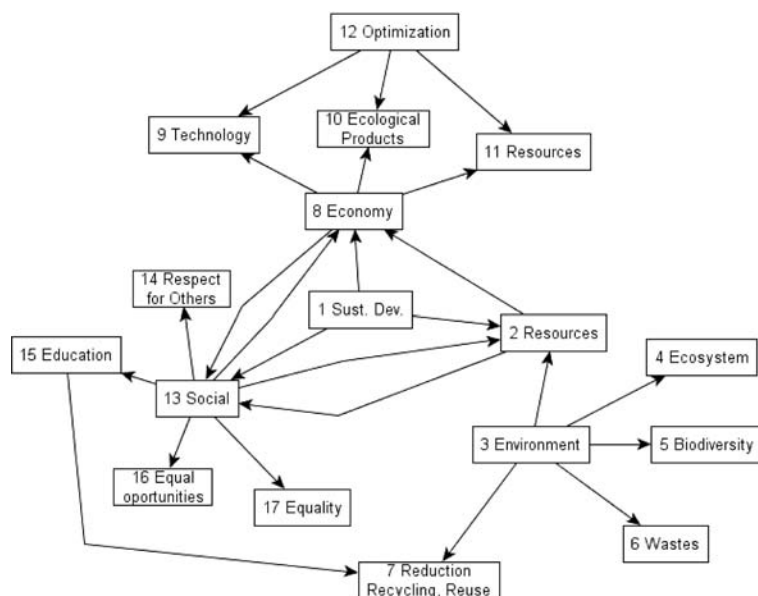


Figure 6.
The final concept map for
Educator 9 (basic
diagram), which can be
considered as a digraph

technology were found initially, while the final graph shows a more balanced set of concepts, at least regarding the TBL.

Table IV shows the results of processing the data for eight out of 12 educator's digraphs ordered in decreasing number of concepts. It was decided to exclude from Table IV and further analysis, those digraph results that contained less than four concepts. Because the basic concept was SD, the remaining three belonged to the TBL; hence those concept maps provided no additional information or complexity for this context.

At this point, it is relevant to make a distinction between a hybrid digraph and a tree digraph, the former corresponds to Warfield's multilevel map, while the latter to a multi-linear map (Warfield, 1994). Therefore, from here on the maps will be referred to as hybrid or tree digraphs, see Figure 9 (a) and (b). This difference can be used to compare the following maps in Figure 10 to those in Figures 7 and 8.

It is important to address another concept that provides information on deeper interconnectedness in concept maps. That is when a concept map can be portrayed as a tree digraph (see Figure 10). Hence, no arcs have been drawn to interconnect concepts between branches; the digraph extends only from a specific branch, and the author has not considered the cross-cutting influence of the possible concepts; in other words, there is a linear connection between concepts in the tree branches, for those without any cycles or interconnecting arc between branches, as could happen in a hybrid digraph. The importance for this type of digraph lies in the fact that concepts are connected linearly within one branch, and having no connection with concepts in other branches, for example one branch is related to economic concepts, while another one is related to environmental concepts, without them influencing each other, as it normally happens from the SD point of view, this can clearly be shown in Figure 10. Hence a tree

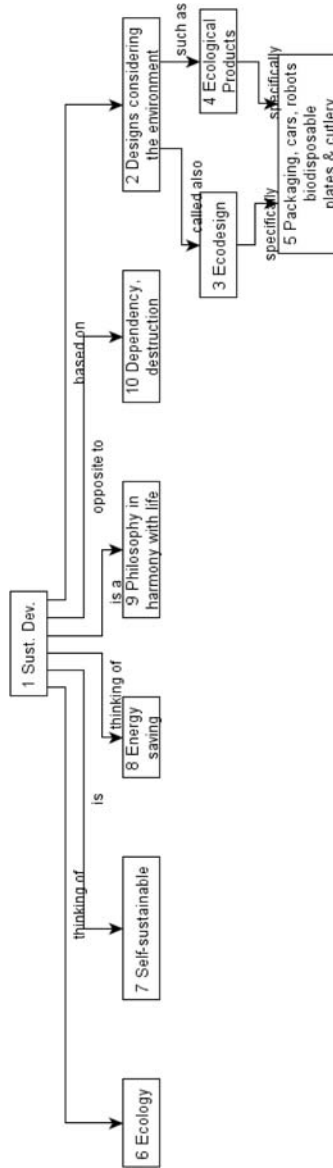


Figure 7.
Educator 9 initial digraph

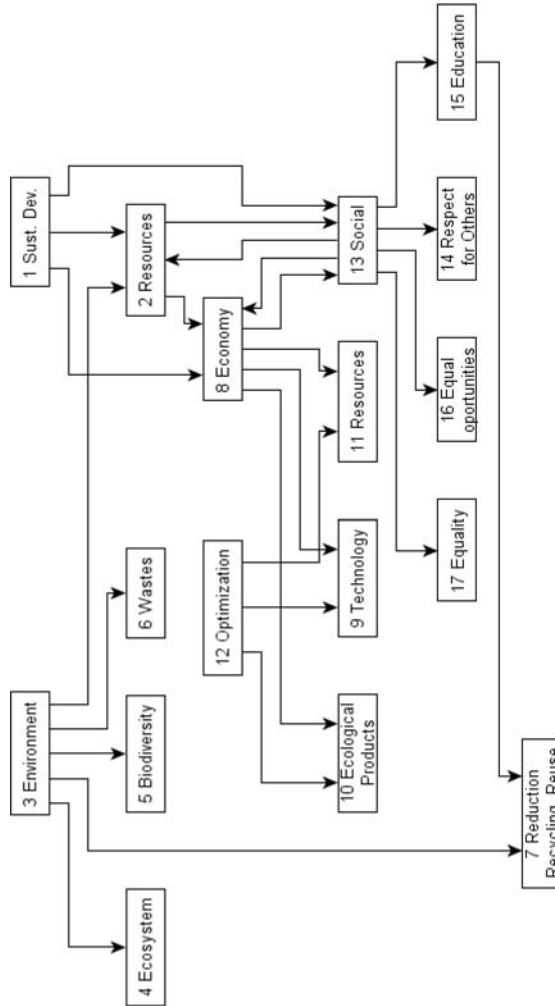


Figure 8. Educator 9 final digraph

digraph can show that the interconnectedness complex structure that is sought with a thorough understanding of SD has not been achieved.

Normally, a tree digraph, having no interconnection between branches, has a cyclomatic number of zero, meaning that concepts between each TBL branch, as well as the other dimensions are not interacting among themselves. This is the case for the last four data in Table IV, where these maps can be classified as trees.

Also high cyclomatic numbers do not provide a full picture of digraph complexity because high interconnection with fewer concepts can happen, such as is shown in Figure 11, which has a cyclomatic number = 9. That is the reason these types of digraphs (those with less or equal than four concepts) were excluded from the analysis.

To summarise, there were mainly hybrid and tree digraphs generated by those attending the course, either at beginning or end. There was a group of maps whose digraphs were classified as trees, and their cyclomatic number had a value of zero, an example of which is shown in Figure 10. There was another group of maps that can be classified as a hybrid digraph, and their cyclomatic number was larger than zero, an example is shown in Figure 8.

Finally there was a group of maps which included four concepts, some highly connected, but provided no insight whatsoever into the existence of concepts beyond the TBL. These were excluded from further analysis; an example is shown in Figure 11. The reason to exclude them is that they do not provide any information about knowledge evolution, except mentioning the TBL. Using concept maps can provide an insight into a person perception of the various concepts that are relevant to the phrase taken as the starting point, hence those maps that portrayed only four concepts were extremely simplified, of course they were taking into consideration the TBL, but nothing else.

Therefore, the cyclomatic number needs to be complemented in order to generate a stronger tool for analysis. This can include the restriction of a minimum number of concepts to be included in the analysis, as mentioned in the previous paragraph.

Table IV.

Final digraph assessment data, excluding results from maps with fewer than four concepts

Final	A	G	J	B	K	C	I	H
Concepts (nodes)	28	24	19	17	15	14	12	10
Connecting arcs	38	34	18	24	14	13	11	9
Partition	3	3	4	2	3	3	3	3
Cyclomatic number [Cy]	11	11	0	8	0	0	0	0

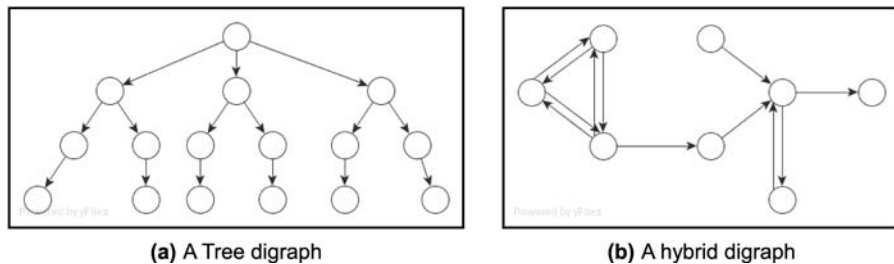


Figure 9.
A tree digraph; A hybrid digraph

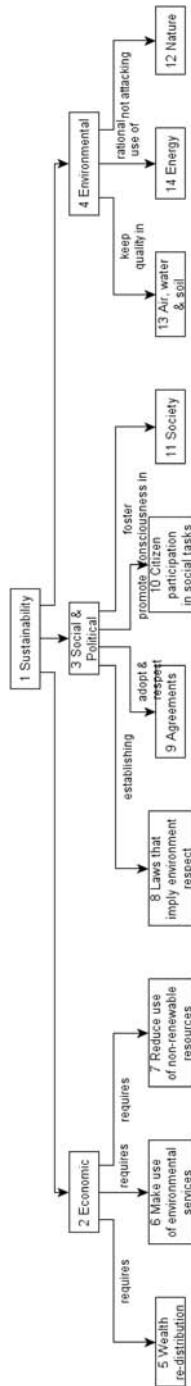
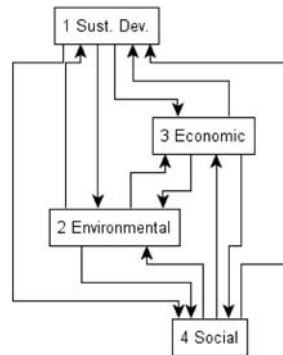


Figure 10. Final hierarchical map for Educator C

Figure 11.
Final digraph for
Educator F



Also the partitions generated from the mathematical adjacency matrix representation of a digraph is another method to further analyse map structure, they can provide information on the concepts that are clustered, as well as the concepts that are used as bridges between concept clusters.

Summary and conclusions

To foster SD in higher education in Higher Education, to be an active part of the global effort within the UN Decade of Education for SD, and to help implement the Vision and Mission of Tecnológico de Monterrey for 2015, the design and planning of a course on SD for educators was achieved by a multidisciplinary team of lecturers.

A pilot was offered to nine educators and the comprehensive course was given to 14 educators.

The course design was based on the following concepts:

- Drivers that have taken us through an unsustainable path.
- Ways to change our current path.
- Changes needed in the educational realm, tools that have to be considered.
- Implementing the changes.
- Assessment or evaluation of sustainable development.

In order to assess the knowledge and concepts acquired by the “faculty who took the course”, the tool of concept maps was applied at the course’s beginning and end.

Tools employed to analyse results were based on concept maps:

- (1) First concepts were clustered along eight semantic categories, by expanding on Lourdel’s six categories (Lourdel *et al.*, 2005, 2007; Segalàs *et al.*, 2006; Ferrer-Balas *et al.*, 2006); hence Lourdel’s economic, scientific and technical aspects category was divided into an economic category and a scientific and technical aspects category, while a new education category was added. Simple statistical tests were applied to the data in order to have a basic evaluation, consisting of averages and *t* tests.
- (2) Second, using graph theory and a complexity metric; maps were further processed and evaluated to obtain various metrics related to the degree of acquired knowledge.

The purpose of the course was to educate educators on how to educate their students in the full range of SD, with a special emphasis on the TBL. That the TBL understanding was accomplished can be inferred from the radar and column charts (Figures 3 and 4).

However, educators need to understand the interconnected and complex web, so papers by Lourdel *et al.* and Segalàs *et al.* would, as well as this work findings suggest that we should modify the course to eventually reach the future students of the participants. Besides the assessment of concept maps for educators that attended the course, digraph theory was used to evaluate the complexity concept maps, structures, and partitioning.

The team teaching course was designed to build capacity among Monterrey Campus educators on educating their students in SD. The course was based on the TBL and was expanded with further concepts related to SD; interconnectedness was emphasised throughout. Educators increased their understanding of SD. An assessment method was based on concept maps, first using statistical evaluation for concepts portrayed in relation to SD, second using digraph theory with complexity values, and finally, using digraph structure.

Based on the results, it is clear that further work to modify and enhance the course is needed, especially to show a more robust interconnectedness among all SD concepts. Moreover, a follow up assessment should be carried out to help consolidate the educators' work in SD with a set of courses to deepen sustainability in specific disciplines. The new 2015 Vision and Mission statements endorse the value of this journey towards sustainability.

Notes

1. After the Johannesburg Summit 2002, in December that year, the United Nations approved a resolution to declare 2005-2014 as the Decade of Education for Sustainable Development.
2. Some of the attending educators were given more time to elaborate their final concept map.

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