Conceptual maps: measuring learning processes of engineering students concerning sustainable development

J. Segalàs*, D. Ferrer-Balas and K.F. Mulder

*a UNESCO Chair of Sustainability, Technical University of Catalonia, Barcelona, Spain; b Cities, Centre for sustainability, Technical University of Catalonia, Barcelona, Spain; c Technology Dynamics and Sustainable Development, Delft University of Technology, Delft, The Netherlands

(Received 21 December 2007; in final form 27 March 2008)

In the 1990s, courses on sustainable development (SD) were introduced in technological universities. After some years of practice, there is increased interest in the evaluation of the most effective ways for teaching SD. This paper introduces the use of conceptual maps as a tool to measure the knowledge acquired by students when taking a Sustainability course. Pilot measurements have been made to evaluate the concepts and their interrelations in order to evaluate the students’ learning. These measurements were carried out using a sample of more than 700 European students. To measure the learning outcomes of courses, the evaluation is done twice. Before the course starts, the students’ previous knowledge on sustainability is measured; once the students have completed the course they are evaluated again. By comparing conceptual maps drawn by each student, the improvement of the students’ knowledge is evaluated. This paper shows the measuring process, and points out the suitability of using conceptual maps for research in education. Moreover, the correlation between the learning outcomes the pedagogical techniques used in each course may indicate the effectiveness of the pedagogical strategies in education for sustainable development.

Keywords: conceptual maps, learning, sustainable development, measuring, pedagogy

1. Introduction

Sustainable development (SD) is recognised to be the path to amend the un-sustainabilities of our society. To follow the SD paradigm we need a fundamental, transformative shift in thinking, values and action by all society’s leaders, professionals and the general population. To quote Albert Einstein, ‘The significant problems we face cannot be solved at the same level of thinking we were at when we created them’.

In this context higher education institutions have the responsibility to educate graduates that have achieved the moral vision and the necessary technical knowledge to assure the quality of life for the future generations. This implies that SD will be the framework in which higher education has to focus its mission (Corcoran et al. 2002).
Many international conferences and meetings have drawn attention to the importance of education for sustainability in higher education. From these events a great number of declarations and agreements have been signed: Stockholm declaration, Tbilisi declaration, Talloires Declaration, Halifax Declaration, Chapter 36 of the agenda 21 in Rio Declaration, Swansea declaration, Kyoto Declaration, CRE-Copernicus Charter, Declaration of Barbados, The Earth Charter, Thessaloniki Declaration, Lüneburg Declaration, Declaration UBUNTU, United Nations Decade of Education for Sustainable Development (2005–2014) and, more specific, the Barcelona Declaration on engineering education in sustainable development.

Following the guidelines established by these declarations, there have been different approaches to introduce sustainability into the engineering curriculum of universities. From specific courses on SD, through specialisations on SD, to embedding SD in all ‘conventional’ engineering courses (Mulder et al. 2005).

Specific courses are needed to give the basic understanding of the challenges associated with SD; to deliver tools and models for dealing with dynamic and complex systems; and to attain a feeling of how things are interconnected. However the specific SD courses delivered at universities today have mainly an environmental focus (Holmberg and Samuelsson 2006).

This work explores the learning processes in specific courses on SD that are being taught in some European technological universities. Nevertheless teaching SD is rather challenging, because it’s not merely transmitting knowledge, but also learning on critical thinking, complexity, values and ethics. When measuring learning processes induced by teaching SD courses, some questions arise:

- Which is the starting level of knowledge and assumptions on SD of students?
- Which is the optimal way of teaching SD to engineering students?

In particular, this paper analyses the SD understanding of students when enrolling to an SD course and evaluates the improvement they achieve during the course. Moreover, by comparing different pedagogical strategies used in the courses, it highlights the most effective way to teach SD in this kind of specific learning courses.

2. Conceptual maps as an educational research tool

Concept maps (Cmap) were initially developed as a data analysis tool in 1972. Cmap are graphical tools for organising and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line referred to as linking words or linking phrases, specify the relationship between the two concepts (Novak and Cañas, 2006). In recent years concept mapping has become a powerful tool which is frequently applied in different contexts in science education. Teachers ask their students to describe their knowledge by means of specific terms and explain connections between them. Researchers ask students to construct concept maps to gain information about students’ conceptions of various topics in science (Iuli and Helldén 2004).

Concept mapping stimulates learners to articulate and externalise the actual state of their knowledge. Novak and Gowin (1984) noted that concept mapping is a creative activity, in which the learner must exert effort to clarify concept meanings in a specific domain knowledge, by identifying important concepts, establishing the concepts relationships, and denoting their structure (Gouli et al. 2004). Cmaps are shown to be excellent in assessing students’ prior knowledge, which is of great importance since prior knowledge is a determining factor in subsequent learning (Gouveia and Valdares 2004).
In this work concept mapping is applied to evaluate the knowledge acquired on SD by engineering students that take specific courses on sustainability. The study analysed over 700 engineering students from European Technological Universities, who took specific courses on SD. The results obtained allow, on one hand, to evaluate the students initial knowledge on SD and identify their misunderstandings and gaps – very useful information to improve the courses – and on the other hand, to evaluate the changes produced by the courses in the students understanding of sustainability.

3. Methodology

Using conceptual maps to evaluate knowledge on SD has already been applied by other authors in higher education (Legrand 2000, Lourdel et al. 2007, Jaen and De Pro 2006, Ahlberg 2004, Gregorio and Freire 2006). This work introduces a new perspective because its aim is to validate pedagogical strategies used in SD courses.

Students are asked to draw a conceptual map about concepts that are relevant to sustainability twice: before taking the course and after taking it. This study has been carried out among students of different engineering specialities from three universities (Kiev Polytechnic Institute [KPI], Delft University of Technology [TUD] and Technical University of Catalonia [UPC]) of three countries (Ukraine, The Netherlands and Spain). In order to make a comparable analysis the same procedure was followed.

Table 1 Shows the characteristics of the courses analysed: university, Number of ECTS credit points; when the study was carried out; speciality of the students and the pedagogy used in the course.

<table>
<thead>
<tr>
<th>Course</th>
<th>University</th>
<th>ECTS</th>
<th>Year</th>
<th>Elective/ Compulsory</th>
<th>Students engineering speciality</th>
<th>Pedagogy used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable Technology</td>
<td>KPI</td>
<td>3</td>
<td>2007</td>
<td>Elective</td>
<td>Various (Master + PhD)</td>
<td>Lecturing Role play</td>
</tr>
<tr>
<td>Energy III project</td>
<td>TUD</td>
<td>8.5</td>
<td>2006</td>
<td>Compulsory</td>
<td>Mechanical engineering (Bachelor)</td>
<td>Part of Project Based Learning plus 2 lectures/workshops</td>
</tr>
<tr>
<td>Sustainability &amp; Technology (1)</td>
<td>UPC</td>
<td>5</td>
<td>2005</td>
<td>Elective</td>
<td>Various (Bachelor + Master)</td>
<td>Distance course</td>
</tr>
<tr>
<td>Sustainability &amp; Technology (2)</td>
<td>UPC</td>
<td>5</td>
<td>2005</td>
<td>Elective</td>
<td>Various (Bachelor + Master)</td>
<td>Distance course</td>
</tr>
<tr>
<td>Technology &amp; Environment</td>
<td>UPC</td>
<td>5</td>
<td>2006</td>
<td>Elective</td>
<td>Various (Bachelor)</td>
<td>Cooperative learning Role play Presentations</td>
</tr>
</tbody>
</table>

Table 1. Courses analysed characteristics.
to assess the students’ previous knowledge of sustainability. Once the students have completed
the course they are asked to draw another Cmap, so the teacher can evaluate the improvement in
students’ knowledge.

When evaluating Cmaps some aspects should be framed (Ruiz-Primo 2004). On the one hand,
in order to evaluate the width understanding of the concept sustainability, the concepts drawn by
the students are clustered in categories. On the other hand, to weigh up the complexity associated
to sustainability the interrelations between the categories are analysed.

The first practical question that appears: how to group the concepts? Under what categories?
There are different taxonomies of categories for SD. The aim of our study is to find out the best way
to teach sustainability, so we expand the taxonomy developed by previous authors (Lourdel 2004,
Carrera 2007) in order to be more precise when analysing the courses and keep the possibility
of a higher disaggregated analysis. Table 2 shows the different categories’ taxonomy and their
relation.

As seen in Table 2, the categories used in our analysis are:

- Category 1. Environmental aspects (Pollution, degradation, conservation, biodiversity, ecolog-
ical footprint)
- Category 2. Resources scarcity (un-renewable resources, run out of materials, . . .)
- Category 3. Social impact (quality of life, health, . . .)
- Category 4. Cultural & Values aspects (related to ethics, consciousness, . . .)
- Category 5. Future generations (the temporal dimension)
- Category 6. Unbalances (the equity dimension)
- Category 7. Technology (BAT, Industry, efficiency, clean-technologies, energy . . .)
- Category 8. Economical aspects (role of economy, fair trade, consumption, . . .)
- Category 9. Education aspects (role of education, rise of awareness, . . .)
- Category 10. Actors and stakeholders (role of governments, NGOs rules, laws, international
agreements, . . .)

The analysis of conceptual maps can be quantitative or qualitative (Ruiz-Primo 2004, Lourdel
2004). In our study we use the quantitative analysis (number of concepts per category and num-
ber of links between categories). Two dimensions are evaluated: the categories defined, and the
connectivity between them.

The category relevance (CR) provides information about what one course group of students
think sustainability is more related to. It evaluates the distribution of concepts among categories.
This information is essential in order to identify the misunderstanding of students and allows the
teachers to redefine the structure and focus of the course. CR is calculated as the average of the percentages of items for each category of all the students of one course.

The complexity indicator (CO), evaluates how rich and connected students see the concepts they relate to sustainability. To obtain this value two factors are multiplied:

\[ CO = NC \times L_{Ca} \]

where:

NC is the average number of concepts per student in the group, and \( L_{Ca} \) is a relative measure of the connections between different categories. It is normalised by the number of categories and the number of students, and therefore calculated as follows:

\[ L_{Ca} = \frac{NL_{\text{int-ca}}}{(NCa \times NS)} \]

where:

\( NL_{\text{int-ca}} \) is the total number of links inter-category of one group (the sum of all the links counted in each Cmap), \( NCa \) is the number of categories, and \( NS \) is the number of students of the group.

This two indicators are evaluated before and after the students took the courses, and as can be seen it has to be noticed that are values that refer to an entire group average conception, not individually.

In the examples shown in Figure 1 (a) and (b), and taking in account that there is only one student in this group, the values would give the values shown in Table 3:

![Figure 1. Theoretical representation of a Cmap (a) before and (b) after the course.](image)

<table>
<thead>
<tr>
<th>Variable</th>
<th>(a) Before</th>
<th>(b) After</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>C1 (57%)</td>
<td>C1 (33%)</td>
</tr>
<tr>
<td></td>
<td>C2 (29%)</td>
<td>C2 (17%)</td>
</tr>
<tr>
<td></td>
<td>C7 (14%)</td>
<td>C7 (17%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C9 (8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C10 (25%)</td>
</tr>
<tr>
<td>CO</td>
<td>2.8</td>
<td>14.4</td>
</tr>
<tr>
<td>NC</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>( L_{Ca} )</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>( NL_{\text{int-ca}} )</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>( NCa )</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>NS</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Different variables calculation for the example of Figure 1.
4. Results and discussion

The results of the Cmaps drawn by the students are shown in the next tables and figures. Figure 2 illustrates graphically the values of the CR indicator for all the courses and all the ten categories. Table 4 shows the values of the CO indicator for all the courses and all the ten categories. The Sample column indicates the number of students which participated in the research: the first is the number of students which developed the Cmap before taking the course and in brackets the number of students that did it after taking the course. Figure 3 illustrates the results graphically.

Figure 2. Category relevance before and after taking the courses.
The analysis of the CR before the courses shows for all of them that students consider sustainability very much related to Environment and Technology categories, which can be considered the hard engineering ones from the taxonomy. This lack of significance of the ‘soft’ categories should be modified by the courses on SD offered in the engineering curriculum. Nevertheless, the study of the Cmaps after taking the courses shows that this misunderstanding is only partially adjusted, and that these categories are still the most relevant. While environmental category keeps its high level, technology only diminishes slightly.

It is interesting to notice that the institutional category increased significantly in almost all courses (especially for policies, less for education), while the group of the social ones only shows a small raise for values and unbalances, and an undefined trend for the others.

The complexity indicator shows an important increase in the interrelationship among categories when comparing the results before and after taking the courses. This increase is visible in both
Table 4. Complexity indicator for all the courses.

<table>
<thead>
<tr>
<th>Course</th>
<th>Sample before (after)</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NC</td>
<td>Lc2</td>
</tr>
<tr>
<td>Sustainable Technology</td>
<td>38 (28)</td>
<td>8,4</td>
<td>0,35</td>
</tr>
<tr>
<td>Energy III</td>
<td>32 (26)</td>
<td>6,7</td>
<td>0,04</td>
</tr>
<tr>
<td>Sustainability &amp; Technology (1)</td>
<td>224 (227)</td>
<td>6,3</td>
<td>0,13</td>
</tr>
<tr>
<td>Sustainability &amp; Technology (2)</td>
<td>208 (36)</td>
<td>7,2</td>
<td>0,24</td>
</tr>
<tr>
<td>Sustainability &amp; Technology (3)</td>
<td>35 (43)</td>
<td>8,4</td>
<td>0,34</td>
</tr>
<tr>
<td>Technology &amp; Environment</td>
<td>30 (31)</td>
<td>13,2</td>
<td>0,27</td>
</tr>
</tbody>
</table>

Figure 3. Evolution of the complexity indicator for each group before and after the courses.

indexes: the average number of concepts per students more than doubled (it increased from 9.4 to 19.6) while the relative number of links inter-category ($L_{ca}$) increased by a factor of 3. Overall, the complexity factor increases by a factor of 6, which shows a clear shift on the conceptualisation of sustainability by the students.

Comparing the results obtained from the different courses, it is difficult to see any direct trend in function of the type of course. More research is being conducted in order to identify any relationship between the teaching method and the results obtained. In any case, it is interesting to underline the important increase seen in the course S&T(1) and in course Energy III, which needs to be explored.

The results show that the distance courses present a lower increase of complexity, reflecting that this aspect may be more easily skilled in the face-to-face courses.

5. Conclusions

The main result of the study is that the complexity of the students’ sustainability image increases substantially, thus showing that the main learning outcomes of the current SD courses is the capacity to connect concepts in a systems’ perspective more than to identify these concepts in a more balanced way.

The analysis of the results shows that when teaching SD to engineering students an important need to emphasise social and institutional aspects, as well as the ‘soft’ knowledge related to sustainability. Indeed, the students’ a priori conception is that sustainability is mainly linked to Environment and Technological aspects, and the courses seemed not to succeed in highlighting
the importance of the social side. Especially the Ethical, Unbalances and Future generations categories keep at very low rates. An additional result is that a redefinition of the role of technology on sustainability is needed, from a source of environmental problems to a challenge to avoid and solve them.

These two requirements have been taken into account in two new learning projects at UPC: a new course on SD and the ‘European Project Semester’ programme (Segalas et al. 2007). These two new programs are aimed to improve the learning of SD among engineering students. Next step of our research will focus on following the concept maps of the students that will participate on them, in particular to be able to compare the results between clearly different learning methods.

The analysis shows that the more active the learning process is, the more change we observe in both indicators: category relevance distribution and complexity. Although the present work does not show a direct correlation, the hypothesis of the authors is that such types of learning strongly favour education for SD. Nevertheless this is a subject for further study.

Acknowledgements

The authors would like to acknowledge the UNESCO Chair of Sustainability and Delft University of Technology academics who have helped us to pass the Cmap questionnaire to their students. We also would like to thank the Kiev Polytechnic institute for participating in the study. We are also grateful to all the students who have taken part in the survey.

References


About the authors

Jordi Segalàs (1967) works as a senior lecturer at the School of Engineering of Vilanova i la Geltrú of the Technical University of Catalonia (UPC). He received his engineering degree from Technical University of Catalonia. Since 2000 he has been working in curriculum greening policies and actions plans at the Technical University of Catalonia. He is leading the Education for Sustainable Development research group at the UNESCO chair for Sustainability. Since 2005 he has been working in TEMPUS (trans-European cooperation scheme for higher education) projects in relation to higher education for sustainable development. He is the director of the Catalan Research Network of Education for Sustainable Development and the Vice-Dean for International Relations and Sustainability at the School of Engineering of Vilanova i la Geltrú. (Jordi.Segalas@upc.edu)

Didac Ferrer-Balas (Barcelona, 1974) graduated as an industrial and materials engineer in 1997. He obtained a doctorate in materials science in 2001 from the Technical University of Catalonia (UPC). In year 2000, he was appointed as the Coordinator of the Environment Plan of UPC. Since 2005, he is the technical director of the Center for Sustainability, with 16 people, and a wide number of projects in curriculum development, sustainable education, management, research and communication. In 2004, he was in charge of the organisation of the second Engineering Education in Sustainable Development (EESD) conference, and also participated in the committee of the following EESD conferences in Lyon (2006) and Graz (2008). He has coordinated various publications and published several articles on the experiences of UPC. He is very interested in sharing experiences and cooperating with other universities around the world and therefore is active in EMSU, RCE, AGS and EESD networks among other. (didac.ferrer@upc.edu)

Karel F. Mulder (1956) works as associate professor at the department of Technology, Policy & Management of Delft University of Technology, in the group Technology Dynamics and Sustainable Development. He received an engineering degree from Twente University, and a doctorate in Business Administration from Groningen University in 1992. He was in charge of a project to include Sustainable Development in all engineering curricula at Delft University of Technology from 1997–2005 and initiated the European Engineering Education in Sustainable Development network. He wrote Sustainable Development for Engineers, A handbook and Resource Guide, Sheffield: Greenleaf, ISBN-10: 1-874719-19-5. (K.F.Mulder@tudelft.nl)