Càtedra UNESCO de Sostenibilitat
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ENGINEERING EDUCATION FOR A SUSTAINABLE FUTURE

PhD Dissertation

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To everyone who is working for a better future for all.

To Dirk-Jan Peet[1] (1974-2008)

The great aim of education is not knowledge but action.

Herbert Spencer

English philosopher (1820 - 1903)

Education without values, as useful as it is, seems rather to make man a cleverer devil.

C. S. Lewis

English essayist & juvenile novelist (1898 - 1963)

[1] On November 22nd 2008 Dirk-Jan Peet died at the age of 33 because of cancer. Dirk-Jan worked in the Technology Dynamics and Sustainable Development group at TU Delft for 10 years. He showed great dedication and commitment in introducing sustainability to engineering education at Delft University of Technology and he actively participated in the EESD community.

Abstract

In today's world social context, in which a considerable number of contrasting signs reveal that our society is currently contributing to the planet's collapse, "a new kind of engineer is needed, an engineer who is fully aware of what is going on in society and who has the skills to deal with societal aspects of technologies" (De Graaff et al., 2001).

Higher education is the essential instrument to overcome the current world challenges and to train citizens able to build a more fair and open society (Alvarez, 2000). Thus higher education institutions have the responsibility to educate graduates who have achieved an ethical moral vision and the necessary technical knowledge to ensure the quality of life for future generations (Corcoran et al, 2002).

In relation to graduating sustainable engineers, three main questions have been developed to guide this research:

1. Which Sustainability (SD) competences must an engineer obtain at university?
2. How can these competences be acquired efficiently?
3. Which education structure is more effective for the required learning processes?

The first main question is a "*What*" question, and focuses on which competences (knowledge/understanding, skills/abilities and attitudes) an engineer graduating in the 21st century should have in relation to SD. The second main question is a "*How*" question and focuses on how can the education processes make this learning achievable through the proper pedagogical strategies. The last main question is a "*Where*" question and looks at the perspective of the curriculum and the organizational structure needed to apply the optimal didactics to achieve the goal of graduating sustainable engineers.

The focus of this research requires a theoretical-practical approach in which both pedagogical strategies and SD competences are studied in parallel. An assessment tool that measures the two subjects and their relationship is developed and case studies are run in 10 SD courses at 5 European technological universities, where nearly 500 students have participated. Moreover, the different approaches to introduce SD in the curriculum of 17 technological universities are analysed, and 45 experts on teaching SD to engineering students have been interviewed.

In relation to the key questions, the findings of this research are the following.

When graduating the engineering students should have acquired the following SD competences: critical thinking, systemic thinking, an ability to work in transdisciplinary frameworks, and to have values consistent with the sustainability paradigm. Moreover, following the requirements of the EHEA, a common framework to define, describe and evaluate SD competences at European level is needed.

Most students, after taking a course on SD, highlight the technological role of sustainability in terms of technology as the solution to environmental problems. Therefore SD courses need to place more emphasis on the social/institutional side of sustainability.

There is a direct relationship between transdisciplinary and systemic thinking learning.

Students achieve better cognitive learning as more community-oriented and constructive-learning pedagogies are applied. Multi-methodological experiential active learning education increases cognitive learning of sustainability. In addition, the role of the teacher is very important for SD learning in terms of implicit learning of sustainability values, principles and critical thinking.

There are four main strategies to increase EESD in universities: a specific SD course, a minor/specialization in SD, a Master on SD or Sustainable Technologies and the embedment of SD in all courses. Nevertheless the main barrier to embedding SD in all courses is the lack of comprehension to SD within the faculty. The individual approach (Peet et al., 2004) has shown to be successful to overcome this barrier.

There is a need of clear top-down leadership in the ESD process, which must promote the bottom-up approach. Additionally, ESD processes are reinforced when they encompass not only education but also all the key areas of the university: research, management, and society outreach.

This thesis is organised as follows. The introduction in **chapter 1** is followed by the state of the art and literature review in competences that engineers should have when graduating in **chapter 2**. **Chapter 3** introduces the pedagogical strategies for SD and develops a theoretical and methodological exploration of these strategies, which presents the pros & cons and learning outcomes of the most common pedagogical strategies in engineering. **Chapter 4** describes the curriculum structures that catalyse the process of sustainable education. **Chapter 5** presents the development of the conceptual research framework, propositions and case studies research methodologies. A comparative SD competence analysis of three European leading SD technological universities is presented in **chapter 6**. **Chapter 7** introduces the methodology framework to evaluate the knowledge on SD acquired by students; this methodology is later applied in **chapter 8** to 10 case studies related to SD courses taught in 5 European technological universities. From the results of the interviews with 45 experts from 17 European technological universities, **chapter 9** analyses the best pedagogical practices for SD learning and **chapter 10** analyses the curriculum structure that most facilitates the introduction of SD learning in technological universities. **Chapter 11** compares the different cases analyzed and evaluates the propositions developed in chapter 1. Finally, in **chapter 12** conclusions are drawn and recommendations for technological higher education institutions are provided.

Resum

En el context social global actual, en el què un nombre considerable de senyals inequívocs indiquen que la nostra societat està contribuint al col·lapse del planeta, " és necessari un nou tipus d'enginyer, un enginyer que sigui plenament conscient del que està succeint a la societat i que tingui les habilitats necessàries per fer front als aspectes socials de les tecnologies "(De Graaff et al., 2001).

L'educació superior és un instrument essencial per superar els reptes del món actual amb èxit i per formar ciutadans capaços de construir una societat més justa i oberta (Álvarez, 2000). Per tant, les institucions d'educació superior tenen la responsabilitat d'educar els futurs titulats amb la finalitat que adquireixin una visió moral i ètica i assoleixin els coneixements tècnics necessaris per assegurar la qualitat de vida per a les generacions futures (Corcoran et al, 2002).

Amb l'objectiu d'assegurar que els futurs titulats siguin enginyers sostenibles, tres qüestions fonamentals han guiat aquesta investigació:

1. Quines competències en sostenibilitat ha d'adquirir un enginyer a la universitat?
2. Com poden aquestes competències ser adquirides d'una manera eficient?
3. Quina estructura educacional és més eficaç per facilitar els processos d'aprenentatge requerits?

La primera pregunta es refereix a "Què?", és a dir, a quines competències relacionades amb la sostenibilitat (coneixements, habilitats i actituds) ha de tenir un enginyer que es gradua en el segle 21. La segona qüestió es refereix a "Com?" i es centra en com els processos educatius poden fer possible l'aprenentatge de les competències en sostenibilitat a través de les estratègies pedagògiques adequades. L'última pregunta es refereix a "On?" des de la perspectiva de quin pla d'estudis i quina estructura organitzativa són necessaris per poder aplicar la didàctica més òptima per graduar enginyers amb competències en sostenibilitat.

Aquesta recerca s'ha enfocat des d'una vessant teòrico-pràctica en què tant les estratègies pedagògiques com les competències en sostenibilitat s'han estudiat en paral·lel. Amb aquesta orientació, s'ha dissenyat una eina d'avaluació que mesura aquests dos aspectes i la seva relació, i que s'ha aplicat a 10 casos d'estudi formats per cursos de sostenibilitat de 5 universitats tecnològiques europees, en els quals hi han participat, en total, més de 500 estudiants. Per completar l'estudi, s'ha analitzat la introducció de la sostenibilitat en els plans d'estudi de 17 universitats tecnològiques, i s'han entrevistat 45 experts en educació de sostenibilitat en l'enginyeria.

En relació a les preguntes clau, els resultats de la investigació han estat els següents:

En el moment de titular-se, l'estudiantat d'enginyeria hauria d'haver adquirit les competències següents: pensament crític, pensament sistèmic, ser capaços de treballar en un entorn transdisciplinari, i tenir valors en consonància amb el paradigma de la sostenibilitat. D'altra banda, d'acord amb els requisits de l'EEES, també cal establir un marc comú per definir, descriure i avaluar les competències en sostenibilitat a nivell europeu.

Després d'haver realitzat un curs en sostenibilitat, la majoria de l'estudiantat segueix prioritzant el rol tecnològic de la sostenibilitat, pel que fa a la tecnologia com la solució als problemes ambientals, sense

gairebé considerar els aspectes socials. Per tant, els cursos sobre sostenibilitat han d'emfatitzar més la part social i institucional de la sostenibilitat.

Existeix una relació directa entre l'aprenentatge de la transdisciplinarietat i el pensament sistèmic.

L'aprenentatge cognitiu de l'estudiantat augmenta, a mida que s'aplica una pedagogia més orientada a la comunitat i més constructiva. Així, l'aprenentatge cognitiu de la sostenibilitat també millora a través d'una l''educació activa, experiencial i multimetodològica. A més a més, en l'aprenentatge de la sostenibilitat, el paper del professorat és molt important pel que fa a l'aprenentatge implícit de valors, principis i pensament crític associats a la sostenibilitat

Les universitats tecnològiques actualment implementen l'educació en sostenibilitat a través de quatre estratègies principals: un curs específic, una especialització en sostenibilitat, un màster en sostenibilitat o en tecnologies sostenibles, i la integració del desenvolupament sostenible en tots els cursos. No obstant això, la principal barrera per a la integració de la sostenibilitat en tots els cursos és la manca de comprensió del terme per part del professorat. L'"enfocament individual" (Peet et al., 2004) ha demostrat ser un bon sistema per superar aquesta barrera.

Hi ha una necessitat clara de lideratge per part de l'equip de govern de les universitats en el procés de canvi cap a una educació en sostenibilitat. Aquest lideratge ha de promoure l'enfocament de baix a dalt. Els processos d'educació en sostenibilitat es reforcen quan aquests no només integren l'educació, sinó també totes les altres àrees clau d'activitat de la universitat: recerca, gestió i relació amb la societat.

En breu, l'estructura d'aquesta tesi és la següent. El **capítol 1** introdueix el plantejament de la recerca. El **capítol 2** revisa l'estat de l'art i la literatura en relació a les competències que els enginyers han de tenir quan es graduen, A continuació, el **capítol 3** descriu les estratègies pedagògiques per al desenvolupament sostenible i les analitza des d'un punt de vista teòric i metodològic presentant els avantatges i desavantatges de les més utilitzades en l'ensenyament d'enginyeria El **capítol 4** presenta les estructures curriculars que han de catalitzar el procés d'aprenentatge en sostenibilitat. El **capítol 5** desenvolupa el marc conceptual de la recerca, les propostes metodològiques de la investigació i els casos d'estudi analitzats. El **capítol 6** avalua comparativament les competències en sostenibilitat definides en tres universitats tecnològiques que són líders europeus en sostenibilitat. El **Capítol 7** introdueix el marc metodològic per a l'avaluació de l'aprenentatge cognitiu en sostenibilitat del estudiantat. Aquesta metodologia s'aplica en el **capítol 8** als 10 cursos de sostenibilitat impartits en 5 universitats tecnològiques europees, que conformen els casos d'estudi d'aquesta recerca. A partir de les 45 entrevistes realitzades a experts en sostenibilitat provinents de 17 universitats tecnològiques europees, el **capítol 9** estudia les millors pràctiques en pedagogia per a l'aprenentatge de la sostenibilitat i el **capítol 10** examina l'estructura curricular que més facilita l'aprenentatge en sostenibilitat a les universitats tecnològiques. En el **Capítol 11** es comparen els resultats obtinguts en els diferents casos d'estudi i s'avaluen les propostes plantejades en el capítol 1. Finalment, el **capítol 12** planteja les conclusions de la recerca i algunes recomanacions per a les institucions d'educació superior tecnològiques.

Resumen

En el actual contexto social global, en el que un número considerable de señales irrefutables ponen de manifiesto que nuestra sociedad está contribuyendo al colapso del planeta, "es necesario un nuevo tipo de ingeniero, un ingeniero que sea plenamente consciente de lo que le está sucediendo a la sociedad y que tenga la habilidades necesarias para afrontar los aspectos sociales de las tecnologías"(De Graaff et al., 2001).

La educación superior es un instrumento esencial para superar con éxito los retos del mundo actual y para formar ciudadanos capaces de construir una sociedad más justa y abierta (Álvarez, 2000). Por tanto, las instituciones de educación superior tienen la responsabilidad de educar los futuros titulados con la finalidad de que adquieran una visión moral y ética y adquieran los conocimientos técnicos necesarios para asegurar la calidad de vida de las generaciones futuras (Corcoran et al, 2002).

Con el objetivo de asegurar que los futuros titulados sean ingenieros sostenibles, tres cuestiones fundamentales han guiado esta investigación:

4. ¿Qué competencias en sostenibilidad tiene que adquirir un ingeniero en la universidad?
5. ¿Cómo poden adquirirse estas competencias de una forma eficiente?
6. ¿Qué estructura educacional es más eficaz para facilitar los procesos de aprendizaje necesarios?

La primera pregunta se refiere a "¿Qué?", es decir, a qué competencias relacionadas con la sostenibilidad (conocimientos, habilidades y actitudes) tiene que tener un ingeniero que se gradúe en el siglo 21. La segunda cuestión se refiere a "¿Cómo?" y se centra en como los procesos educativos pueden hacer posible el aprendizaje de las competencias en sostenibilidad a través de las estrategias pedagógicas más adecuadas. La última pregunta se refiere a "¿Dónde?" desde la perspectiva de qué plan de estudios y qué estructura organizativa son necesarios para poder aplicar la didáctica más óptima para graduar ingenieros con competencias en sostenibilidad.

Esta investigación se ha enfocado des de una vertiente teórico-práctica en que tanto las estrategias pedagógicas como las competencias en sostenibilidad se han estudiando en paralelo. Con esta orientación se ha diseñado una herramienta de evaluación que mide estos dos aspectos y su relación, herramienta que se ha aplicado a 10 casos de estudio formados por cursos de sostenibilidad de 5 universidades tecnológicas europeas, en los cuales han participado más de 500 estudiantes. Para completar el estudio, se ha analizado la introducción de la sostenibilidad en los planes de estudio de 17 universidades tecnológicas, y se han entrevistado a 45 expertos en educación de sostenibilidad en la ingeniería.

En relación a las preguntes clave, los resultados de la investigación han sido los siguientes:

En el momento de titularse, los estudiantes de ingeniería tendrían que haber adquirido las siguientes competencias: pensamiento crítico, pensamiento sistémico, ser capaces de trabajar en un entorno transdisciplinar, y tener valores en consonancia con el paradigma de la sostenibilidad. Por otro lado, de acuerdo con los requisitos del EEES, también hace falta establecer un marco común para definir, describir y evaluar las competencias en sostenibilidad a nivel europeo.

Después de haber realizado un curso en sostenibilidad, la mayoría del estudiantado sigue priorizando el rol tecnológico de la sostenibilidad, viendo la tecnología como la solución a los problemas ambientales, y sin apenas considerar los aspectos sociales. Por tanto, los cursos sobre sostenibilidad tienen que enfatizar más la parte social y institucional de la sostenibilidad.

Existe una relación directa entre el aprendizaje de la transdisciplinariedad y el pensamiento sistémico.

El aprendizaje cognitivo del estudiantado aumenta, a medida que se aplica una pedagogía más orientada a la comunidad y más constructiva. Así, el aprendizaje cognitivo de la sostenibilidad también mejora a través de una educación activa, experiencial i multimetodológica. Además, en el aprendizaje de la sostenibilidad, el papel del profesorado es muy importante en cuanto al aprendizaje implícito de valores, principios y pensamiento crítico asociados a la sostenibilidad

Les universidades tecnológicas actualmente implementan la educación en sostenibilidad a través de cuatro estrategias principales: un curso específico, una especialización en sostenibilidad, un master en sostenibilidad o en tecnologías sostenibles, y la integración del desarrollo sostenible en todos los cursos. No obstante, la principal barrera para la integración de la sostenibilidad en todos los cursos es la falta de comprensión del término por parte del profesorado. El "enfoque individual" (Peet et al., 2004) ha demostrado ser un buen sistema para superar esta barrera.

Hay una necesidad clara de lideraje por parte del equipo de gobierno de les universidades en el proceso de cambio hacía una educación en sostenibilidad. Este lideraje tiene que promover el enfoque de abajo hacia arriba. Los procesos de educación en sostenibilidad se refuerzan cuando estos no solo integran la educación, sino también todas las otras áreas clave de actividad de la universidad: investigación, gestión y relación con la sociedad.

Brevemente, la estructura de la tesis es la siguiente. El **capítulo 1** introduce el planteamiento de la investigación. El **capítulo 2** revisa el estado del arte y la literatura en relación a las competencias que los ingenieros han de tener cuando se gradúan. A continuación, el **capítulo 3** describe las estrategias pedagógicas para el desarrollo sostenible y las analiza desde un punto de vista teórico y metodológico presentando las ventajas e inconvenientes de las más utilizadas en la enseñanza de la ingeniería. El **capítulo 4** presenta las estructuras curriculares que han de catalizar el proceso de aprendizaje en sostenibilidad. El **capítulo 5** desarrolla el marco conceptual de la investigación, las propuestas metodológicas de la misma y los casos de estudio analizados. El **capítulo 6** evalúa comparativamente les competencias en sostenibilidad definidas en tres universidades tecnológicas que son líderes europeas en sostenibilidad. El **Capítulo 7** introduce el marco metodológico para la evaluación del aprendizaje cognitivo en sostenibilidad del estudiantado. Esta metodología se aplica en el **capítulo 8** a los 10 cursos de sostenibilidad impartidos en 5 universidades tecnológicas europeas, que conforman los casos de estudio de esta investigación. A partir de las 45 entrevistes realizadas a expertos en sostenibilidad provenientes de 17 universidades tecnológicas europeas, el **capítulo 9** estudia las mejores prácticas en pedagogía para el aprendizaje de la sostenibilidad y el **capítulo 10** examina la estructura curricular que mejor facilita el aprendizaje en sostenibilidad en les universidades tecnológicas. En el **Capítulo 11** se comparan los resultados obtenidos en los diferentes casos de estudio y se evalúan las propuestas planteadas en el capítulo 1. Finalmente, el **capítulo 12** plantea las conclusiones de la investigación y algunas recomendaciones para las instituciones de educación superior tecnológicas.

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Contents

1 Introduction

This chapter introduces the role of education for sustainable development in the engineering curriculum and the need for such an education due to the key role of the engineering profession in building up the path to a more sustainable future. This chapter also puts forward different research questions to determine the learning processes which can help train the engineers that society needs. Finally, the chapter outlines the research methodology carried out in this work and the thesis structure.

1.1 Sustainable Development in Higher Education

Nowadays there are a considerable number of contrasting signs which highlight that our society is contributing to the planet's collapse: a growing environmental burden, tremendous wealth imbalances, an ecological footprint that is exceeding the earth's carrying capacity, people who can not cover their basic needs, etc. increase year after year (PNUD: Human development reports[1], World Watch Institute reports[2]). For the first time in history, humans are pervasive and dominant forces in the health and well-being of the earth and its inhabitants. We are the first generation capable of destroying the habitability of the planet for humans and other species. Engineers have played a key role in the unsustainabilities in our society.

Sustainable Development (SD) is recognised as the path to amend unsustainabilities. It consists of a development process:

- that leads to a society in which all present and future humans are healthy and have their basic needs met and in which everyone has fair and equitable access to the earth's resources, a decent quality of life, and celebrates cultural diversity,
- where all current and future generations are able to pursue meaningful work and have the opportunity to realize their full human potential both personally and socially,
- where communities are strong because they celebrate cultural diversity, encourage collaboration and participation in governance and emphasize the quality of life over material consumption,
- where globalization is humanized by solidarity to support democracy, human rights, and economic opportunity for everyone.

This society needs scientists, engineers, and business people who design technological and economic activities that sustain rather than degrade the natural environment; activities that enhance human health and well-being. It needs a kind of technology inspired by the biological models operating on renewable energy, where the concept of waste is eliminated because every waste product is a raw material or nutrient for another species or activity or returned into the cycles of nature, and in which management of human activities restores and increases the biological diversity and complexity of the ecosystems on which we all depend. A society in which humans could live off nature's interest, not its capital, for generations to come. In this context, "*a new kind of engineer is needed, an engineer who is fully aware of what is going on in society and who has the skills to deal with societal aspects of technologies*" (De Graaff et al., 2001).

To follow a sustainable development path, a fundamental, transformative shift in thinking, values and action by all society's leaders, professionals and the general population is needed. To quote Albert Einstein (1954): "*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 who have achieved an ethical moral vision and the necessary technical knowledge to assure the quality of life for future generations. This implies that sustainable development will be the framework in which higher education has to focus its mission (Corcoran et al, 2002). Moreover, Alvarez (2000) states that education in general, and higher education particularly, are essential instruments to overcome the current world challenges and to train citizens able to build a more fare and open society. Society based in solidarity, respect to human rights and all societies.

In relation to SD, so far there is no direct relation between educated societies with the highest rate of "educated" citizens and the highest sustainability[3]. Sustainability demands a specific kind of learning; quoting E.F. Schumacher (1973): "*The volume of education… continues to increase, yet so do pollution, exhaustion of resources, and the dangers of ecological catastrophe. If still more education is to save us, it would have to be education of a different kind: an education that takes us into the depth of things*". In addition some authors call for a deep change in society to achieve a more SD (Whatever it is). *SD is not just a matter or acquiring some extra knowledge. Attitude is also important. Moreover, it is often necessary to change social structures* (Mulder, 2006).

Stephen Sterling maintains that the nature of sustainability requires a fundamental change of epistemology, and therefore, of education. He writes:

Sustainability is not just another issue to be added to an overcrowded curriculum, but a gateway to a different view of curriculum, of pedagogy, of organizational change, of policy and particularly of ethos. At the same time, the effect of patterns of unsustainability on our current and future prospects is so pressing that the response of higher education should not be predicated only on the 'integration of sustainability' into higher education , because this invites a limited, adaptive, response…. We need to see the relationship the other way around—that is, the necessary transformation of higher education towards the integrative and more whole state implied by a systemic view of sustainability in education and society (Sterling, 2005)

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. See table 1.1.

The mobilization of universities started in the nineties (Table 1.1). Two declarations and two international organizations can be considered the initial promoters of the international coordination of universities in the area of education for sustainable development. On the one hand, the "Talloires Declaration" (1991) from which the "University Leaders for Sustainable Future" (USLF) was created. This association acts as secretariat for more than 300 universities in more than 40 countries who have signed the Talloires Declaration and promotes the education for sustainability with regard to the Earth Charter. On the other hand, the COPERNICUS University Charter for Sustainable Development signed by more than 320 rectors of 38 European countries in 1993 as a response to the Earth Summit in Rio de Janeiro marked a breakthrough in raising awareness within the European universities about the necessity of working together to preserve the future,.

In the year 2000, the Global Higher Education for Sustainability Partnership (GHESP) was formed by the two organizations mentioned above, the International Association for Universities (IAU), an international centre of cooperation between 800 institutions of higher education and universities who developed and adopted the Kyoto Higher Education declaration, UNESCO, who is responsible for implementing the Chapter 36 of the Agenda 21 "Education, Awareness and Training", and the UN Commission for Sustainable Development education programme.

1972:	The Stockholm declaration[4], adopted in the United Nations Conference on the Human Environment. Stockholm, Sweden.
1977:	The Tbilisi Declaration[5] constitutes the framework, principles, and guidelines for environmental education at all levels- local, national, regional, and international- and for all ages both inside and outside schools
1990:	The Talloires Declaration[6] approved at the Tufts University European Centre, Talloires, France.
1991:	The Halifax Declaration[7], Follow-up to the Halifax Conference on University Action for Sustainable Development. Halifax, Canada.
1992:	The Declaration of Rio on Environment and Development[8], United Nations Conference on Environment and Development (UNCED), Chapter 36 (rtf, 68 kb): Promoting Education, Public Awareness and training of AGENDA 21. Rio de Janeiro, Brazil.
1993:	The Swansea declaration[9], Declaration released at the conclusion of the Association of Commonwealth Universities' fifteenth Quinquennial Conference, Swansea, Wales.
1993:	The Kyoto Declaration[10]. IAU Declaration adopted by 90 universities leaders that embodies the language and substance of both the Halifax Declaration and the Swansea Declaration. Kyoto, Japan.
1994:	CRE-Copernicus Charter[11]. Charter written by the CO-operation Programme in Europe for Research on Nature and Industry through Coordinated University Studies whose aim is to bring together universities and other concerned sectors of society from all parts of Europe to promote a better understanding of the interaction between man and the environment and to collaborate on common environmental issues.
1994:	Declaration of Barbados[12]. Declaration adopted by the States participating in the Global Conference on the Sustainable Development of Small Island Developing States, Bridgetown, Barbados.
1997:	The Earth Charter of the Earth (first version). Revised and presented during the Forum Rio+5.
1997:	Thessaloniki Declaration[13]. Declaration presented and unanimously adopted by the 83 countries present at the International Conference on Environment and Society Education and Public Awareness for Sustainability, organised in Thessaloniki by UNESCO and the Government of Greece.
2000:	Earth Charter[14]. Shared values, principles and aspirations on sustainable development compiled by The Earth Charter Initiative. The Earth Charter (final document).
2001:	Lüneburg Declaration on Higher Education for Sustainable Development[15]. The Lüneburg Declaration was adopted by the GHESP partners (IAU, ULSF, Copernicus Campus and UNESCO), on 10 October 2001 in Lüneburg, Germany, on the occasion of the International COPERNICUS Conference, "Higher Education for Sustainability Towards the World Summit on Sustainable Development (Rio+10)" held at the University of Lüneburg.
2002:	The Declaration UBUNTU[16] in Education, Science and Technology for the Sustainable Development.
2002:	United Nations Decade of Education for Sustainable Development[17] (2005-2014) (DESD). The overall goal of the Decade is to integrate the values inherent in sustainable development into all aspects of learning. The aim: to encourage changes in behaviour that allow for a more sustainable and just society for all.
2004:	The Barcelona Declaration[18] was settled at the 2nd International Conference on EESD. The Declaration underlines the importance of Sustainable Development in all technological education, and to stimulate Higher Education Institutions in the engineering field to progressively implement their Education in Sustainable Development (ESD) objectives into concrete actions.
2004:	Graz Declaration[19]. The Graz Declaration addresses in particular the forthcoming Ministerial conference in Bergen to the Bologna-Process and asks Ministers to take appropriate action to incorporate the principle of sustainable development in the establishment of the European Higher Education Area.
2004:	1st ASIAN-EU Rectors' Conference "Higher education and Sustainable Development". Lumpur.
2005:	Start of UNE Decade of ESD
2005:	International Implementation Scheme for UN DESD.
2006:	Research agenda for UN DESD (UNU-UNESCO)
2006:	UNESCO Action Plan for DESD

Table 1.1 Milestones about Sustainability in Higher Education

The GHESP represents over 1000 universities which have the commitment of putting sustainability at the central goal of their education and operation. In 2001 the members of GHESP signed the Lüneburg Declaration committing themselves to carrying out the following actions:

- Promoting the subscription and implementation of the Kyoto, Talloires and Copernicus declarations.
- Creating a tool of performance addressed to universities, business agents, administrators, teachers and students, designed to go from commitment to action.
- Improving the development and networking of regional centres of excellence in developed and developing countries.

The existence of these types of institutions brings to light the interest in the university community towards education for sustainable development (ESD). This interest has led to the celebration of numerous conferences like Engineering Education in Sustainable Development (EESD), European Networks Conference on Sustainability in Practice (ENCOS), International Symposium IGIP/IEEE/ASEE Local Identity, Global Awareness, Engineering Education Today, Environmental Management for Sustainable Universities (EMSU), Congreso Iberoamericano de Educación Ambiental, etc. Moreover this interest has promoted the publication of books and scientific articles, and the establishment of units in the sinus of the universities that watch over Sustainability in higher education.

1.2 Engineers qualified for Sustainable Development

"Why is the sun important for life?" This was the answer given by Mr Van der Veer, Chief executive of Royal Dutch Shell to the question "Why is engineering important for sustainable development?" (Van der Veer, 2006). Such an answer shows the important position that company managers give to the role that engineers play in the path to a more sustainable development. Moreover quoting the Barcelona Declaration (2004) "*It is undeniable that the world and its cultures need a different kind of engineer, one who has a long-term, systemic approach to decision-making, one who is guided by ethics, justice, equality and solidarity, and has a holistic understanding that goes beyond his or her own field of specialisation"*.

To play this role some questions arise. What is a "sustainable" engineer? What implications will this have for engineering education institutions? In other words: Which competences in relation to SD should a graduated engineer have? How should these competences be acquired at engineering Higher Education Institutions (HEI)?

The SD competences that engineers should obtain have been proposed by several stakeholders like Accreditation Agencies, declarations, governments, engineering associations and HEIs. The following paragraphs show examples of each of them.

The Accreditation Board for Engineering and Technology USA (ABET) in the 2007-2008 Criteria for Accrediting Engineering Programs states that to be accredited an Engineering program must demonstrate that their students attain (ABET, 2007):

- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an understanding of professional and ethical responsibility
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

The Barcelona Declaration(EESD, 2004) approved during the EESD conference in 2004 declares that today's engineers must be able to:

- Understand how their work interacts with society and the environment, locally and globally, in order to identify potential challenges, risks and impacts.
- Understand the contribution of their work in different cultural, social and political contexts and take those differences into account.
- Work in multidisciplinary teams, in order to adapt current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention and waste management.

- Apply a holistic and systemic approach to solving problems and the ability to move beyond the tradition of breaking reality down into disconnected parts.
- Participate actively in the discussion and definition of economic, social and technological policies, to help redirect society towards more sustainable development.
- Apply professional knowledge according to deontological principles and universal values and ethics.
- Listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures.

The United Kingdom Engineering Council in the "UK Standard for Professional Engineering Competence" (ECUK, 2005) declares that Chartered Engineers must be competent throughout their working life, by virtue of their education, training and experience, to undertake engineering activities in a way that contributes to sustainable development. This could include the ability to:

- Operate and act responsibly, taking account of the need to progress environmental, social and economic outcomes simultaneously
- Use imagination, creativity and innovation to provide products and services which maintain and enhance the quality of the environment and community, and meet financial objectives
- Understand and encourage stakeholder involvement.

Finally as an example of HEI, the Technical University of Catalonia (UPC) in its "UPC Sostenible 2015" [20] Plan (UPC, 2006) declares that: "All UPC graduates will apply sustainability criteria to their professional activity and to their area of influence"

In relation to how these competences should be acquired, many approaches in technological universities have been developed, which follow a similar pattern (Segalas et al. 2006):

- To offer a basic compulsory/elective course for all (or most) students,
- To embed SD in 'ordinary' courses
- To offer the possibility of specializing in SD – Bachelor's or Master's degree.

Most approaches focus on the curriculum content and syllabus, but not much attention has been given to the pedagogical strategies which can facilitate the acquisition of the attitudes, values and ethics needed to switch to a SD engineer.

These competence aspects are analysed in depth in chapter 2 and 5 of this work.

1.3 Research questions and relevance

Since Education for Sustainable Development has been on the agenda of many engineering faculties since the late nineties, many approaches have been developed to graduate well-trained engineers with the knowledge, abilities, values and attitudes needed to switch to SD. In this work they will be referred to as "sustainable engineers".

Related to these approaches to graduate sustainable engineers, three main questions have guided this research:

1. The What: Which SD competences must an engineer learn at university?
2. The How: How can these competences be acquired efficiently? The role of pedagogy.
3. The Where: Which education structure is more effective for the required pedagogy and also to embed SD in the curriculum?

The first main question is a "*What*" question, which focuses on what competences: knowledge/understanding, skills/abilities and attitudes an engineer graduating in the 21st century should have in relation to SD. The second main question is a "*How*" question and focuses on how the education processes through the proper pedagogical strategies can make this learning achievable. The last main question is a "*Where*" question from the perspective of the curriculum and the organizational structure needed to apply the optimal didactics to achieve the goal of graduating sustainable engineers.

These three main questions have been further developed into a set of more specific research questions:

1- What competences in relation to SD should an engineer learn at university and how should they be defined?

2- If they are, how are these competences trained nowadays in HEIs?

3- Which are the pros and cons of different pedagogical strategies when learning SD?

4- How can the level of SD learning be measured?

5- What do students learn in specific SD courses?

6- Which pedagogical strategies are more effective to acquire SD competences?

7- Which kind of curriculum structure is the most favourable to allow the necessary pedagogical strategies?

8- What recommendations can be given to university/school/department managers and teachers to improve in a systemic manner the Engineering Education regarding sustainability?

In short, research questions 1-3 refer to literature research, theorising and conceptualising; research questions 4-5 refer to the empirical part of this research; questions 6-8 focus on reflections and recommendations.

Relevance

This work is developed under the framework of EESD research. Nowadays there are an increasing number of specific introductory SD courses in most engineering faculties. This work is the first to evaluate, in a set of these courses within a European scope, the learning and understanding of students. It also analyses and compares the competences of three reference SD European universities.

It is also important to highlight its European scope: the research covers case studies from 5 European technological universities from 4 different countries with a sample of around 500 students, and also interviews to more than 40 experts from 18 European technological universities.

The results of this research aim to enhance the important role of action-oriented-learning-processes in order to acquire SD competences. The study may reveal the different approaches of SD training applied in different technological HEIs. It may also validate the use of conceptual maps as an appropriate evaluation tool of competences on SD. Finally, this study is expected to help SD teachers, educational managers and university boards to train and graduate the engineers needed for the 21st century.

Additionally, given the new higher education framework in Europe after the Bologna Declaration (1999) and the changes it implies, it is also interesting to see this work as a contribution to the current educational framework and a window of opportunity for introducing SD in new curricula., Under this new European Higher Education Area[21] (EHEA) framework, SD competences definition has still not been deeply analysed in the literature. The thesis studies how these competences are formulated nowadays and the need for a common framework to define them in order to facilitate their comprehension, assessment and dissemination in HEI.

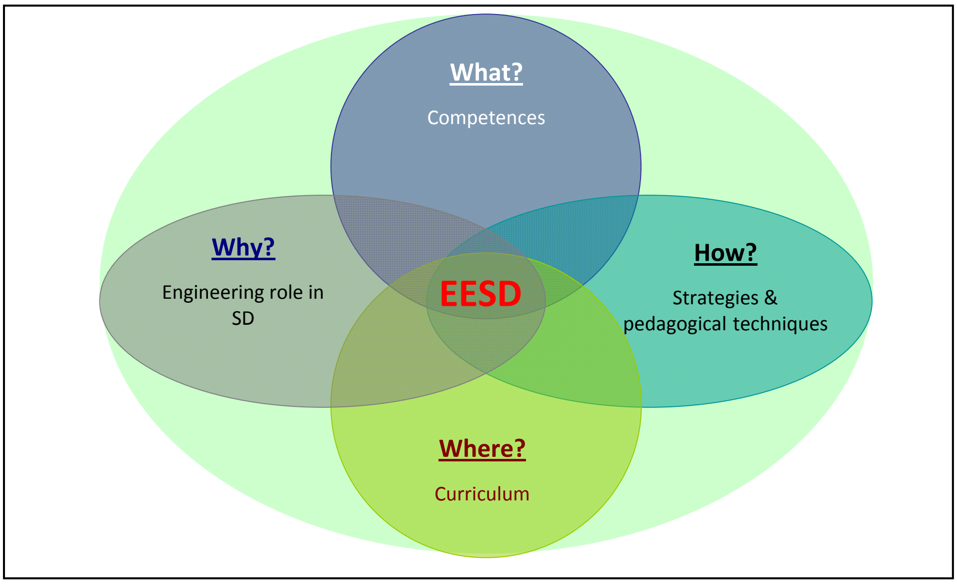

Figure 1.1 Diagram of thesis aims. (EESD= Engineering Education in Sustainable Development)

1.4 Scope and limitations of this work

This work evaluates sustainability education in Engineering. The work is focused on European technological universities. Universities from Spain, Sweden, The Netherlands, Belgium, Ukraine, Scotland and England are studied. The universities have been selected for being the technological universities that are most engaged in ESD in their own countries.

In the competences study, the work focuses on the transversal SD competences that engineers should have when graduating from 1st cycle (Bachelor) degrees. A further study that remains out of the scope of this work could be to analyse the competences requirements for 2nd cycle (Master) engineering studies, both for specific SD Masters and for non SD ones.

The learning measurement is focused on specific SD courses. The learning achieved during an entire degree is not measured. Further steps of research could be to evaluate the complete curriculum or even the professional application of SD learning that has taken place at university.

The wide scope of this work does not allow us to analyse the effect of all possible independent variables, specially taking into account the variety of courses, countries and universities that participated in the samples. In this sense, the purpose of this work is to initiate a research path in the EESD field at a European level, applying different assessment tools, from which new research may be developed.

1.5 Research methodology outline

The focus of this research is to evaluate the most effective pedagogical strategies to convey SD competences to the engineering students. This requires a theoretical research approach in which both pedagogical strategies and SD competences are studied. An assessment tool that measures the relation between both topics is developed and case studies are run in 10 SD courses at 5 European technological universities, in which about 500 students have participated. Moreover, the different approaches to introduce SD in the curriculum of 17 technological universities are analyzed, and 45 experts on teaching SD to engineering students have been interviewed.

This research has been organised as follows (See table 1.2, Figures 1.2 and 1.3). First, an exploration of the engineering competences in SD literature and related approaches has been conducted. Next, literature has been studied to analyse the pedagogical strategies and the educational research conceptual framework. Based on this preliminary work, methodological assessments for both pedagogical strategies and competences are proposed. Afterwards, two types of studies have been carried out by using mixed (qualitative and quantitative) research approach; data are collected through semi-structured interviews and conceptual maps. Further on, the studies are compared and the propositions evaluated. Finally conclusions are drawn and discussed, followed by recommendations.

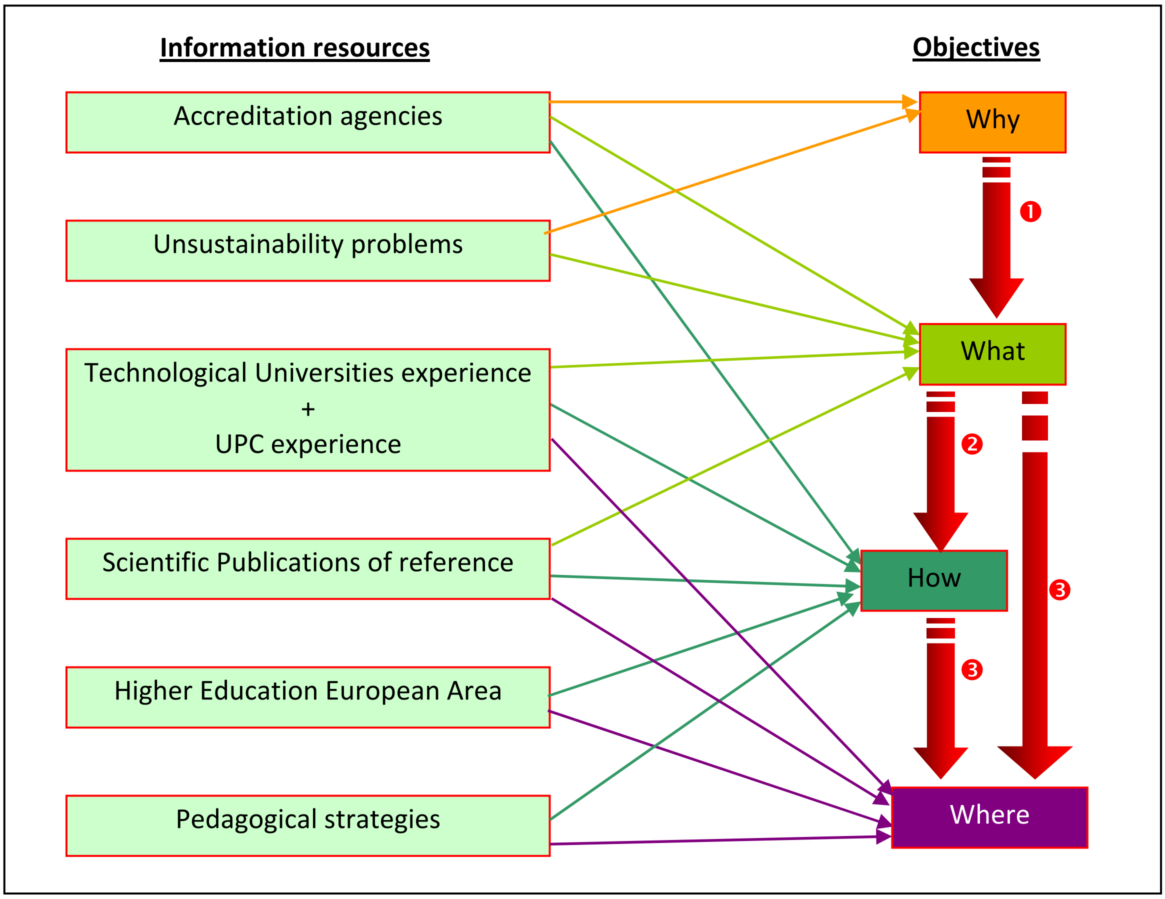

Figure 1.2 Information resources used in the theoretical exploration and its relation to the research questions

	Activities	Chapter
Introduction	Defining research topic and proposing research approach	Chapter 1 (Introduction)
Literature review & state of the art	Theoretical exploration of SD competences that engineers should have when graduating	Chapter 2 (research question 1)
	Theoretical and methodological exploration of pedagogical strategies: pros & cons and learning outcomes	Chapter 3 (research question 2 -3)
	Theoretical exploration of curriculum strategies to ESD	Chapter 4 (research question 7)
Research methodologies	Research methodologies and case studies definition	Chapter 5 (research question 4)
Competences	Benchmarking evaluation of SD competences	Chapter 6 (research question 1)
Pedagogy	Methodological evaluation of SD competences acquired by engineering students when participating in a SD training process.	Chapter 7 (research question 4)
	Results of SD understanding acquired by engineering students when participating in a SD training process (case studies)	Chapter 8 (research question 5)
	Pedagogical strategies: Interview analysis	Chapter 9 (research question 5)
Curriculum structure	Curriculum structures to learn SD on engineering universities: Interview analysis	Chapter 10 (research question 7)
Conclusion	Testing propositions and comparing cases	Chapter 11 (research question 6-7)
	Drawing conclusions and providing recommendations	Chapter 12 (research question 8)

Table 1.2 Overview of research steps and content of this thesis

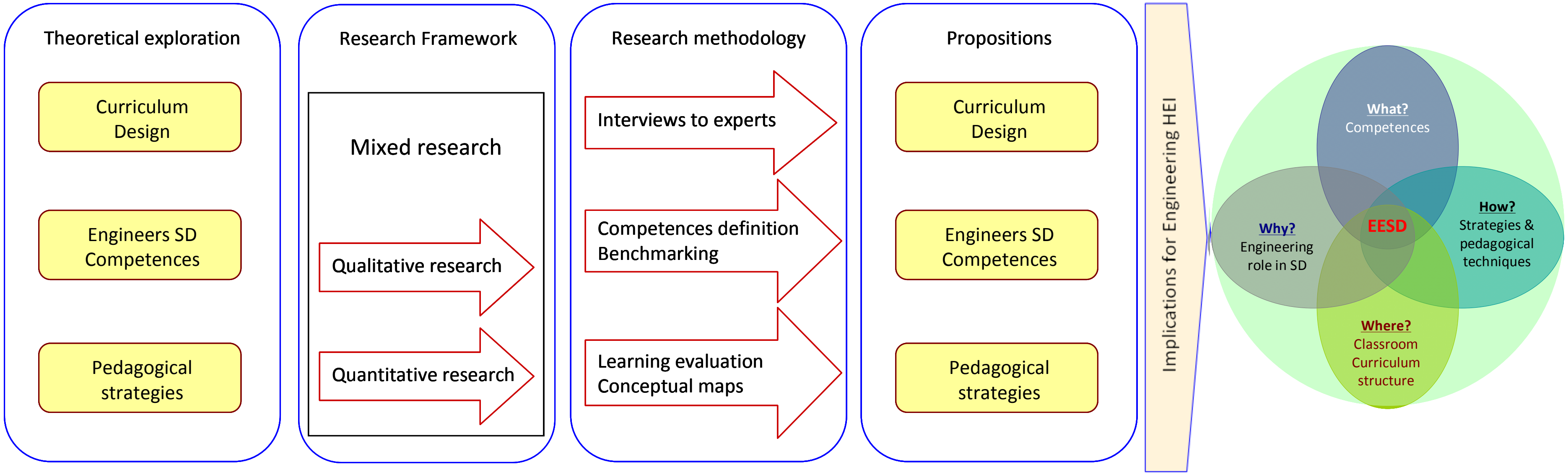

Figure 1.3 Diagram thesis methodology

1.6 Outline of this thesis

This thesis is organised as follows (see also table 1.1). The introduction in **chapter 1** is followed by the state of the art and literature review in competences that engineers should have when graduating in **chapter 2**. **Chapter 3** introduces the pedagogical strategies for SD and develops a theoretical and methodological exploration of these strategies, which presents the pros & cons and learning outcomes of the most common pedagogical strategies in engineering. **Chapter 4** describes the curriculum structures that catalyse the process of sustainable education. **Chapter 5** presents the development of the conceptual research framework, propositions and case studies research methodologies. A comparative SD competence analysis of three European leading SD technological universities is presented in **chapter 6**. **Chapter 7** introduces the methodology framework to evaluate the knowledge on SD acquired by students; this methodology is later applied in **chapter 8** to 10 case studies related to SD courses taught in 5 European technological universities. From the results of the interviews with 45 experts from 17 European technological universities, **chapter 9** analyses the best pedagogical practices for SD learning and **chapter 10** analyses the curriculum structure that most facilitates the introduction of SD learning in technological universities. **Chapter 11** compares the different cases analyzed and evaluates the propositions developed in chapter 1. Finally, in **chapter 12** conclusions are drawn and recommendations for technological higher education institutions are provided.

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Notes *(all the on-line documents have been checked in March 2009)*

[1] <http://hdr.undp.org/>

[2] <http://www.worldwatch.org/>

[3] Even some indicators of environmental Sustainability as Ecological footprint show a direct correlation between the most "developed" countries and their ecological impact.

[4] <http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=97&ArticleID=1503 >

[5] <http://www.gdrc.org/uem/ee/tbilisi.html>

[6] <http://www.ulsf.org/programs_talloires_td.html>

[7] <http://www.iisd.org/educate/declarat/halifax.htm>

[8] <http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm>

[9] <http://www.iisd.org/educate/declarat/swansea.htm>

[10] <http://www.unesco.org/iau/sd/sd_dkyoto.html>

[11] <http://www.bologna-bergen2005.no/Docs/03-Pos_pap-05/041008_Copernicus-Campus_GHESP_WWF.pdf>

[12] <http://islands.unep.ch/dbardecl.htm>

[13] <www.unesco.org/iau/sd/rtf/sd_dthessaloniki.rtf>

[14] <http://www.earthcharterinaction.org/content/>

[15] <http://www.unesco.org/iau/sd/rtf/sd_dluneburg.rtf>

[16] <http://www.unesco.org/iau/sd/rtf/sd_dubuntu.rtf>

[17] <http://portal.unesco.org/education/en/ev.php-URL_ID=27234&URL_DO=DO_TOPIC&URL_SECTION=201.html>

[18] <https://www.upc.edu/eesd-observatory/who/declaration-of-barcelona/BCN%20Declaration%20EESD_english.pdf>

[19] <http://www.uni-graz.at/sustainability/Graz_Declaration.pdf>

[20] h<ttp://www.upc.edu/mediambient/Pla%20UPC%20Sostenible%202015.pdf>

[21] <http://www.ond.vlaanderen.be/hogeronderwijs/bologna/>

2 Learning outcomes and competences on SD for engineering graduates

This chapter analyses the generic competences that engineering graduates may have when graduating. First of all the concepts of learning outcomes and competences are introduced, their role in the European Higher Education Area under the qualifications framework is presented, introducing the "Dublin descriptors" competences. Then three cases studies in the introduction of sustainable development generic competences from Chalmers University of Technology (Sweden), Delft University of Technology (The Netherlands) and Technical University of Catalonia (Spain) are illustrated. Finally the commonalities of SD competences between the three universities are analysed, an analysis that shows the need for a common framework in the definition of competences at international level.

2.1 Introduction

Today's society places challenging sustainability demands on individuals and professionals, who are confronted with complexity in many aspects of their lives. In relation to engineering education, a question arises: **what competences do engineers need to be able to fulfil society's demands?** Defining such competences can improve assessments of how well prepared engineers are for SD challenges, as well as identifying overarching goals for education systems.

The Organisation for Economic Co-operation and Development's (OECD) Education minister stated that "*Sustainable Development and social cohesion depend critically on the competences of all of our population – with competences understood to cover knowledge, skills, attitudes and values*" (Stevens, 2008). Therefore the definition of SD competences is a key subject in education in general and in engineering education in particular if the important role that engineers have as change agents to sustainability is considered.

2.2 Learning outcomes and competences in Higher Education

First of all it should be distinguished among learning outcomes and competences. The Tuning Project[1] (2007a) defines them as:

Learning outcomes are statements of what a learner is expected to know, understand and/or be able to demonstrate after completion of learning. They can refer to a single course unit or module or else to a period of studies, for example, a first or a second cycle[2] programme. Learning outcomes specify the requirements for award of credit.

According to Tuning (2007b), learning outcomes are expressed in terms of the level of competence to be obtained by the learner.

Competences represent a dynamic combination of cognitive and meta-cognitive skills, knowledge and understanding, interpersonal, intellectual and practical skills, and ethical values. Fostering competences is the object of educational programmes. Competences will be formed in various course units and assessed at different stages.

There are different competence taxonomies (González and Wagenaar, 2003; Joint Quality Initiative, 2004; Bologna working group, 2004; Sterling, 2004). In this work the description of competences embraces three strands:

- *Knowledge and understanding*: Theoretical knowledge of an academic field, the capacity to know and understand.
- *Skills and abilities*: practical and operational application of knowledge to certain situations.
- *Attitudes*: Values as an integral element of the way of perceiving and living with others and in a social context.

In this context, a competence means that a person puts into play a certain capacity or skill and performs a task, where he/she is able to demonstrate that he/she can do so in a way that allows evaluation of a level of achievement. Competences can be assessed and developed. This means that, normally, persons do not either possess or lack a competence in absolute terms, but command it to a varying degree, so that competences can be placed on a continuum and can be developed through exercise and education.

Although some authors define four kinds of competences[3], in this study it will be differentiate among two kinds of competences as do others:

Generic competences

Generic competences represent a dynamic combination of knowledge, understanding, skills and abilities. Three types of generic competences can be distinguished (González and Wagenaar, 2005):

- Systemic competences: abilities and skills concerning whole systems, a combination of understanding, sensibility and knowledge; prior acquisition of instrumental and interpersonal competences required. (*Knowledge and understanding*).
- Instrumental competences: cognitive abilities, methodological abilities, technological abilities and linguistic abilities; (*Skills and abilities*).
- Interpersonal competences: individual abilities like social skills, social interaction and co-operation; (*Attitudes*).

As an example of generic competences the DeSeCo[4] project (DESECO, 2003) classified the key competences needed for a successful life and well-functioning society in three broad categories: First, individuals need to be able to use a wide range of tools for interacting effectively with the environment: both physical ones such as information technology and socio-cultural ones such as the use of language. They need to understand such tools well enough to adapt them to their own purposes – to use tools interactively. Second, in an increasingly interdependent world, individuals need to be able to engage with others, and since they will encounter people from a range of backgrounds, it is important that they are able to interact in heterogeneous groups. Third, individuals need to be able to take responsibility for managing their own lives, situate their lives in the broader social context and act autonomously. These competences include:

1. *Using tools interactively:*
    a. *Use language, symbols and text interactively.*
    b. *Use knowledge and information interactively.*
    c. *Use technology interactively.*
2. *Interacting in Heterogeneous Groups.*
    a. *Relate well to others.*
    b. *Co-operate, work in teams.*
    c. *Manage and resolve conflicts.*
3. *Acting autonomously:*
    a. *Understand and consider the wider context of their actions and decisions*
    b. *Formulate and conduct life plans and personal projects.*
    c. *Defend and assert rights, interests, limits and needs.*

Subject-specific competences

In addition to the generic competences described above, each learning programme will certainly seek to foster more specific subject competences. The subject related skills are the relevant methods and techniques pertaining to the various discipline areas according to the subject area.

The ABET criteria (ABET, 2007) for accrediting engineering programs defines specific competences for each specific engineering program. For example, for geological engineering programs, the specific competences are:

- *the ability to apply mathematics including differential equations, calculus-based physics, and chemistry, to geological engineering problems;*
- *proficiency in geological science topics that emphasize geological processes and the identification of minerals and rocks;*
- *the ability to visualize and solve geological problems in three and four dimensions;*
- *proficiency in the engineering sciences including statics, properties/strength of materials, and geo-mechanics;*
- *the ability to apply principles of geology, elements of geophysics, geological and engineering field methods; and*
- *engineering knowledge to design solutions to geological engineering problems, which will include one or more of the following considerations: the distribution of physical and chemical properties of earth materials, including surface water, ground water (hydrogeology), and fluid hydrocarbons; the effects of surface and near-surface natural processes; the impacts of construction projects; the impacts of exploration, development, and extraction of natural resources, and consequent remediation; disposal of waste; and other activities in society place on these materials and processes, as appropriate to the program objectives.*

To summarise, learning outcomes are revealed by sets of competences, expressing what the student will know, understand or be able to do after completion of a process of learning. They may refer to a period of studies or to a single course unit or module. Competences can be classified into generic (the ones that all graduates should have at a certain level of education) and subject-specific competences (related to a specific field of knowledge or profession).

2.3 Competences within the EHEA framework

The European Higher Education Area (EHEA) also known as “The Bologna Process” has among its goals to provide tools to connect and compare different educational systems to facilitate exchange (of e.g. students) between the systems. In that respect the creation of an effective EHEA asks for the adoption of a system of easily readable and comparable degrees which requires outcomes-focussed qualification frameworks that share common and clear methodological descriptors. One of the most important features of the Bologna process is the comparable three cycle degree system:

- first cycle (Bachelor level, 180 – 240 ECTS[5]);
- second cycle (Master level, 90 – 120 ECTS credits beyond the first cycle, with a minimum of 60 credits at the level of the second cycle);
- third cycle (PhD level).

Traditional models and methods of expressing qualifications structures are now, in *The Bologna* P*rocess*, giving way to systems based on explicit reference points using learning outcomes and competences, levels and level indicators, subject benchmarks and qualification descriptors (Bologna Working Group on Qualifications Frameworks, 2005). These tools provide more precision and accuracy and facilitate transparency and comparison. Without these common approaches, full recognition, real transparency and thus the creation of an effective EHEA, would be more difficult to achieve. Reinforcing the adoption of these reference points in September 2003 European Education Ministers refer to an overarching framework of qualifications for the EHEA (JQI, 2004): *Ministers encourage the member States to elaborate a framework of comparable and compatible qualifications for their higher education systems, which should* *seek to describe qualifications in terms of workload, level, learning outcomes, competences and profile. They also undertake to elaborate an overarching framework of qualifications for the European Higher Education Area.* The purpose of recognition is to make it possible for learners to use their qualifications in another education system or country without losing the full value of those qualifications.

The JQI Dublin descriptors for Bachelors and Masters were first proposed in March 2002[6]. The JQI meeting in Dublin on 23 March 2004 proposed that for a better understanding of the 'Dublin descriptors' in the context of the Berlin communiqué and their possible future usage, headings by cycles may be more appropriate. The JQI meeting on 23 March also proposed a set of shared descriptors for third cycle qualifications. Table 2.1 illustrates the competences that students may acquire in the first and second higher education cycles.

	Qualifications are awarded to students who
First Cycle - Bachelor (180-240 ECTS)	- *have demonstrated knowledge and understanding in a field of study that builds upon their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study* - *can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of study* - *have the ability to gather and interpret relevant data (usually within their field of study) to inform judgements that include reflection on relevant social, scientific or ethical issues* - *can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences* - *have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy*
Second Cycle - Master (60-120 ECTS)	- *have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with a Bachelor's level, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context* - *can apply their knowledge and understanding, and problem solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study* - *have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgements* - *can communicate their conclusions, and the knowledge and rational underpinning these, to specialist and non-specialist audiences clearly and unambiguously* - *have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous*

Table 2.1 *Dublin descriptors* for first and second cycle under the EHEA framework

These Dublin descriptors were adopted by European Ministers of Education in May 2005[7] and are a reference in Europe when defining the new EHEA Bachelor and Masters degrees. For example Criteria for Academic Bachelor's and Master's Curricula (Meijers et al., 2005) for Dutch technological universities are developed under the Dublin descriptors scheme.

2.4 Learning outcomes and competences for SD in engineering education

There have been many approaches to define the SD learning outcomes and/or competences that engineering students should have when graduating. In this section it will be first presented some of these approaches and finally their commonalities will be discussed.

2.4.1 Barcelona Declaration

An important milestone in the definition of learning outcomes and competences for engineering education is the Barcelona Declaration (2004), which was the result of the work of the EESD 2004 conference scientific committee. The declaration gathers the orientations to be taken to integrate sustainable development in engineering education. In relation to competences it states that today's engineers must be able to:

- *Understand how their work interacts with society and the environment, locally and globally, in order to identify potential challenges, risks and impacts.*
- *Understand the contribution of their work in different cultural, social and political contexts and take those differences into account.*
- *Work in multidisciplinary teams, in order to adapt current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention and waste management.*
- *Apply a holistic and systemic approach to solving problems and the ability to move beyond the tradition of breaking reality down into disconnected parts.*
- *Participate actively in the discussion and definition of economic, social and technological policies, to help redirect society towards more sustainable development.*
- *Apply professional knowledge according to deontological principles and universal values and ethics.*
- *Listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures.*

2.4.2 National Level

At a national level there have been some approaches to defining SD competences and/or learning outcomes. For example in United Kingdom the Engineering Council defined the UK Standard for Professional Engineering Competence which describes the requirements that have to be achieved for becoming recognised both as a professional Engineering Technician and a Chartered Engineer. In relation to SD, table 2.2 and table 2.3 show the competences required from both sets of engineering graduates.

	The Standard
Chattered engineer	***Demonstrate a personal commitment to professional standards, recognising obligations to society, the profession and the environment.*** ***Comply with relevant codes of conduct.*** *This could include an ability to:* - *Comply with the rules of professional conduct of own professional body* - *Work constructively within all relevant legislation and regulatory frameworks, including social and employment legislation.* ***Manage and apply safe systems of work.*** *This could include an ability to:* - *Identify and take responsibility for their own obligations for health, safety and welfare issues* - *Ensure that systems satisfy health, safety and welfare requirements* - *Develop and implement appropriate hazard identification and risk management systems* - *Manage, evaluate and improve these systems.* ***Undertake engineering activities in a way that contributes to sustainable development.*** *This could include an ability to:* - *Operate and act responsibly, taking account of the need to progress environmental, social and economic outcomes simultaneously* - *Use imagination, creativity and innovation to provide products and services which maintain and enhance the quality of the environment and community, and meet financial objectives* - *Understand and encourage stakeholder involvement.*

Table 2.2 UK Standard for Chattered Engineering Competence in relation to SD. (Adapted from ECUK, 2005a)

	The Standard
Professional Engineering Technician	***Make a personal commitment to an appropriate code of professional conduct, recognising obligations to society, the profession and the environment.*** *In order to satisfy this commitment, they must:* - *Comply with the Codes and Rules of Conduct of their Licensed Institution or Professional Affiliate;* - *Manage and apply safe systems of work;* - *Undertake their engineering work making and utilising risk assessments, and observing good practice with regard to the environment;*

Table 2.3 UK Standard for Professional Engineering Competence in relation to SD. (Adapted from ECUK, 2005b)

Another example of competences for SD can be found in the Criteria for accrediting engineering programs from the Accreditation Board for Engineering and Technology (ABET, 2007). In the ABET[8] criteria for the 08-09 accreditation cycle in relation to SD one can find:

Engineering programs must demonstrate that their students attain:

- *an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*
- *an understanding of professional and ethical responsibility*
- *the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*
- *a knowledge of contemporary issues*

In the Netherlands the three technological universities (Delft University of Technology, Eindhoven University of Technology and the University of Twente) developed the Criteria for Academic Bachelor's and Master's Curricula (Meijers et al, 2005). These criteria distinguish seven areas of competence that characterise a university graduate. They concern the domain of the university graduate – understood here as the fields of study involved, the academic method of thinking and doing and the context of practising science. Figure 2.1 gives a graphical representation of the areas of competence.

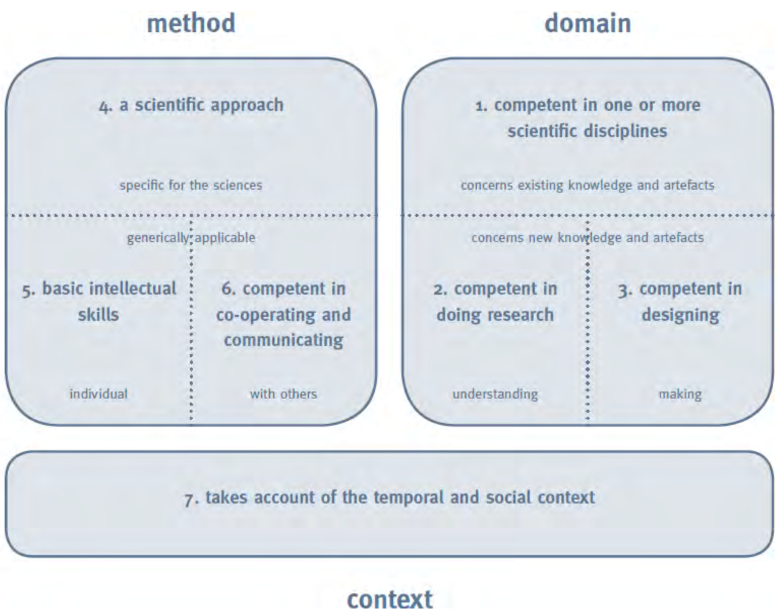

Figure 2.1 Areas of competence of a university graduate (Meijers et al., 2005)

The Criteria for Academic Bachelor's and Master's Curricula doesn't make explicit the need of SD in engineering education; nevertheless several competences implicitly related to SD in it can be found. See table 2.4.

Area	Bachelor	Master
Doing research	- *Understands, where necessary, the importance of other disciplines (interdisciplinarity).*	- *Is able, and has the attitude to, where necessary, draw upon other disciplines in his or her own research.*
Basic intellectual skills	- *Is able (with supervision) to critically reflect on his or her own thinking, decision making, and acting and to adjust these on the basis of this reflection.*	- *Idem, independently.*
	- *Is able to reason logically within the field and beyond; both 'why' and 'what-if' reasoning.*	- *Is able to recognise fallacies.*
takes account of the temporal and social context	- *Is able to analyse and to discuss the social consequences (economic, social, cultural) of new developments in relevant fields with colleagues and non-colleagues.*	- *Integrates these consequences in scientific work.*
	- *Is able to analyse the consequences of scientific thinking and acting on the environment and* ***sustainable development.***	- *Integrates these consequences in scientific Work.*
	- *Is able to analyse and to discuss the ethical and the normative aspects of the consequences and assumptions of scientific thinking and acting with colleagues and non-colleagues (both in research and in designing).*	- *Integrates these ethical and normative aspects in scientific work.*
	- *Has an eye for the different roles of professionals in society.*	- *Chooses a place as a professional in society.*

Table 2.4 Competences for first and second cycle in The Netherlands

2.4.3 International Level

At an international level an additional scheme is the CDIO™ INITIATIVE[9], an innovative educational framework of curricular planning and outcome–based assessment for engineering universities and schools. CDIO formed *focus groups*[10] of industry representatives, engineering faculty and other academics, university review committees, and alumni in order to compile a list of the abilities needed by engineers. The outcome of these groups is the CDIO Syllabus, whose objectives are to create a clear, complete, and consistent set of goals for undergraduate engineering education, in sufficient detail that they could be understood and implemented by engineering faculty. The CDIO Syllabus is structured in four high level expectations: a mature individual interested in technical endeavours possesses a set of *Personal and Professional Skills*, which are central to the practice. In order to develop complex value-added engineering systems, students must have mastered the fundamentals of the appropriate *Technical Knowledge and Reasoning*. In order to work in a modern team-based environment, students must have developed the *Interpersonal Skills of Teamwork and Communications*. Finally, in order to actually be able to create and operate products and systems, a student must understand something of *Conceiving, Designing, Implementing, and Operating* Systems in the Enterprise and Societal Context (Crawley, 2001). Table 2.4 illustrates the competences implicitly related to SD in the CDIO Syllabus.

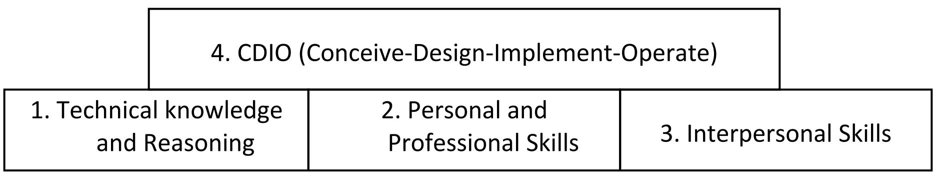

Figure 2.2 Building blocks of knowledge, skills, and attitudes necessary to Conceive, Design, Implement, and Operate Systems in the Enterprise and Societal Context

Category	Subcategory	Program outcomes
Personal and professional skills	Systems thinking	- *Trans-disciplinary approaches that ensure the system is understood from all relevant perspectives* - *The societal, enterprise and technical context of the system* - *The interactions external to the system, and the behavioural impact of the system*
	Professional skills and attitudes	- *One's ethical standards and principles* - *The possibility of conflict between professionally ethical imperatives* - *An understanding that it is acceptable to make mistakes, but that one must be accountable for them* - *A commitment to service* - *The potential impact of new scientific discoveries* - *The social and technical impact of new technologies and innovations*
CDIO	External and societal context	- *Roles and Responsibility of Engineers* - *The goals and roles of the engineering profession* - *The responsibilities of engineers to society* - *The Impact of Engineering on Society* - *The impact of engineering on the environment, social, knowledge and economic systems in modern culture* - *Society's Regulation of Engineering* - *The role of society and its agents to regulate engineering* - *The diverse nature and history of human societies as well as their literary, philosophical, and artistic traditions* - *The discourse and analysis appropriate to the discussion of language, thought and values* - *The important contemporary political, social, legal and environmental issues and values* - *The process by which contemporary values are set, and one's role in these processes* - *The internationalization of human activity* - *The similarities and differences in the political, social, economic, business and technical norms of various cultures*
	Design	- *Aesthetics and human factors* - *Implementation, verification, test and* ***environmental sustainability***
	Operate	- *The end of useful life* - *Disposal options* - *Residual value at life-end* - *Environmental considerations for disposal*

Table 2.5 Program outcomes related to ESD from the CDIO Initiative (summarised from Crawley, 2001)

2.4.4 Synthesis

Analysing these examples of SD competences in engineering education it can be concluded that the communalities are very high and most competences are related:

- *Critical thinking* is regularly mentioned explicitly (…is able to critically reflect...; .. "why" and "what if" reasoning…) and implicitly (…understand how their work interacts with society and the environment…) in sets of competences. The idea of mental processes of discernment, analysis and evaluation in an open-minded point of view is often highlighted.
- Systemic thinking is expressed as the idea that everything interacts with the things around it and that the world therefore consists of complex relationships. The need for having the competence to move beyond the tradition of breaking reality down into disconnected parts.
- Inter-trans-disciplinarity is also stated as important for SD taking into account both, the participation of different professionals to solve problems and stakeholder participation in technological processes.
- Values and ethics are at the core of the meta-cognitive sets of competences, they are shown as the main force to change attitudes to act personally and professionally for SD.

These commonalities match the works done by Svanström et al. (2008) when analysing the learning outcomes for SD in higher education in general.

2.5 Conclusions

This chapter firstly studied the concepts of learning outcomes and competences; both concepts are used indistinctly in engineering programs, nevertheless there are slight differences in its significance: *Learning outcomes* are statements of what a learner is expected to know, understand and/or be able to demonstrate after completion of learning. Learning outcomes are revealed by sets of *competences*, expressing what the student will know, understand or be able to do after completion of a process of learning. They can refer to a period of studies or to a single course unit or module. Competences can be classified into generic (the ones that all graduates should have in a certain level of education) and subject-specific competences (related to a specific field of knowledge or profession). Competences are usually clustered in three cognitive domains: (a) knowledge and understanding, (b) skills and abilities and (c) attitudes.

Secondly the role of competences in the EHEA is analysed. The EHEA asks for a framework of comparable and compatible qualifications for their higher education systems, which should seek to describe qualifications in terms of workload, level, learning outcomes, competences and profile.

In relation to competences the Dublin descriptors are a reference in Europe when defining the new EHEA first and second cycle levels.

Finally SD competences in engineering education are studied both at national and international level. The commonalities of these SD competences frameworks in relation to SD are highlighted, and they are related to *critical thinking,* systemic thinking, inter-trans-disciplinarity and values and ethics. Quoting Alvarez (2000) HEIs have to ensure that education is pertinent, thus take into account the close socio-cultural and professional context.

Nevertheless, there is no common framework of definition of SD competences at a European level. In order to try to find this common framework, chapter 6 presents the analysis of three case studies for engineering first cycle graduates in three Technological Universities using the EHEA descriptors.

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[1] The project "Tuning Educational Structures in Europe" aims to contribute to the elaboration of a framework of comparable and compatible qualifications in each of the signatory countries of the *Bologna Process*. These qualifications should be described in terms of workload, level, learning outcomes, competences and profile. Available at: <http://tuning.unideusto.org/tuningeu/>.

[2] In the European Higher Education Area (EHEA) also known as "Bologna Process" the higher education is divided into three cycles. The first cycle corresponds to the Bachelor's, the second cycle corresponds to the Masters and finally the third cycle corresponds to PhD. In this thesis it is going to be used the "Bologna" nomenclature of 1st, 2nd and 3rd cycle.

[3] Joan Mateu (2006) defines the following competences: **Key competences** (they are needed to achieve other competences easily), **generic competences** (they are present in many disciplines without being exclusive to any), **specific competences** (the ones linked to a particular discipline) and **basic competences** (those needed in a social context and that have to be guaranteed by the education system).

[4] In late 1997, the OECD initiated the DeSeCo Project with the aim of providing a sound conceptual framework to inform the identification of key competencies and strengthen international surveys measuring the competence level of young people and adults. Available at: <http://www.deseco.admin.ch/bfs/deseco/en/index.html>.

[5] ECTS (European Credit Transfer System) is the unit for the students' work load (1 ECTS ≈ 25÷30 hours of student work) and 60 ECTS normally corresponds to one year of fulltime studies ≈1500 hours of student work.

[6] See: <www.jointquality.org>.

[7] See: The framework of qualifications for the European Higher Education Area <http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/QF-EHEA-May2005.pdf>.

[8] ABET defines Program Outcomes – Program outcomes are narrower statements that describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviours that students acquire in their matriculation through the program.

[9] CDIO stands for Conceive — Design — Implement — Operate. See: <www.cdio.org>.

[10] A focus group is a form of qualitative research in which a group of people is asked about their attitude towards a product, service, concept, advertisement, idea, or packaging. Questions are asked in an interactive group setting where participants are free to talk with other group members.

3 Pedagogical strategies for learning sustainability in engineering education

This chapter first, conceptualizes learning and education for sustainable development, second it analyses the shift and transformation in the pedagogy used in Engineering Education Institutions needed to train change agent engineers for sustainability. Learning strategies, techniques and activities are described and their role to facilitate the shift to Education for Sustainable Development in Higher Education Institutions is analyzed. Next, pedagogical approaches that are being implemented successfully in engineering universities are also analysed. Finally some suggestions to achieve the transformation on Engineering Universities in relation to pedagogical strategies and structure of education are described.

3.1 Introduction

Pedagogical strategy is the way learning processes are arranged in order to achieve certain learning outcomes, which confer competences to the learner. Before evaluating the pedagogical strategies which are more suitable to Education for Sustainable Development (ESD) some introductory definitions are needed.

***Learning** can be defined as the result of the process of continuous interaction of an individual or a group with its physical and social environment. Learning is partly an individual and partly a group process. In learning social interaction is important because an individual learns by comparing his/her mental models to those of others, a multidisciplinary learning environment therefore can be a richer learning environment. In context-embedded learning interaction between different disciplines and individuals would get a more prominent place in the design of learning* (Van Dam-Mieras, 2006).

Education can be described as an institutionalized process aimed at realizing defined learning objectives for defined target groups. *The learning objectives comprise disciplinary, social, cultural, and economic items. The target groups can be divided according to age and the level of prior education or development. The educational system tries to provide contexts that support the learning of individuals* (Van Dam-Mieras, 2006).

In relation to sustainable development (SD), so far, there is no direct relation between educated societies with highest rate of "educated" citizens and highest sustainability[1]. Quoting E.F. Schumacher: "*The volume of education… continues to increase, yet so do pollution, exhaustion of resources, and the dangers of ecological catastrophe. If still more education is to save us, it would have to be education of a different kind: an education that takes us into the depth of things*". (Schumacher, 1973). Sustainability demands a specific kind of learning. Some authors call for a deep change in society to achieve a more SD (Whatever it is). "*Sustainable Development is not just a matter or acquiring some extra knowledge. Attitude is also important. Moreover, it is often necessary to change social structures"* (Mulder, 2006).

In this study the debate on the definition of SD will not be discussed. Some authors, even, request that it should not be defined as it is an evolutionary concept (Holmberg & Samuelsson, 2006). On the other hand defining ESD could be constructive when analysing pedagogical strategies.

There are many definitions of Education for Sustainable Development[2] (ESD) which do focus on three main aspects: competences, curriculum design and pedagogy.

In the **competences** framework UNESCO[3] describes Education for sustainable development as about learning to:

- respect, value and preserve the achievements of the past;
- appreciate the wonders and the peoples of the Earth;
- live in a world where all people have sufficient food for a healthy and productive life;
- assess, care for and restore the state of our Planet;
- create and enjoy a better, safer, more just world;
- be caring citizens who exercise their rights and responsibilities locally, nationally and globally.

Learning for sustainable development could be described as *learning to deal with dilemma's in a complex societal context in which ecological, economic and socio-cultural aspects are at stake and in which links between the local and the global level are made. It also means taking into account the interaction between different levels of scale from local (the scale of human daily life) to global (the scale of economy, climate systems and world ecosystems).* (Van Dam-Mieras, 2005; 2006).

These competence aspects of the ESD definitions, fully match analysis of the literature review and case studies on competences described in chapter 2.

In the **curriculum design** aspect Sterling points out that: *If engineers are to contribute truly to sustainable development, then sustainability must become part of their everyday thinking. This, on the other hand, can only be achieved if sustainable development becomes an integral part of engineering education programmes, not a mere 'add on' to the 'core' parts of the curriculum* (Sterling, 2004a).

Finally on the **pedagogy** side there are also some definitions to be considered: Education for sustainability, above all, *means the creation of space for transformative social learning. Such space includes: space for alternative paths of development; space for new ways of thinking, valuing and doing; space for participation minimally distorted by power relations; space for pluralism, diversity and minority perspectives; space for deep consensus, but also for respectful disagreement and differences; space for autonomous and deviant thinking; space for self-determination, and; finally, space for contextual differences* (Wals & Corcoran, 2005). *What is needed is an **integrated approach to teaching sustainable development** which should provide students with an understanding of all the issues involved as well as raise their awareness of how to work and act sustainably* (Perdan et al., 2000). John Fien (2006) besides of highlighting the importance of pedagogy - ***Issues of pedagogy are vital in reorienting education towards sustainability***- claims that the teacher role is as important as the pedagogy used - *the teacher's beliefs and attitudes, together with the teaching strategies chosen, will significantly affect the nature of students' learning experiences and the objectives achieved. Such choices and attitudes determine whether or not curriculum plans reproduce the existing social and cultural mores, or contribute to empowering people for participation in civil society.*

All definitions mainly ask for an education where there is space for critical thinking. Social and cultural complexity is at stake. Values and ethics are important and trans-disciplinary and trans-cultural approaches are inherent to the learning process.

But what is needed to achieve an effective ESD in higher education (HE) and specifically in engineering education? What pedagogy is especially good for SD?

3.2 Pedagogical shift to Education for Sustainable Development

A reorientation on pedagogy and learning processes is a must to achieve an effective education for sustainable development. Quoting the Barcelona declaration (Barcelona declaration, 2004) "*teaching strategies in the classroom and teaching and learning techniques must be reviewed*". In that direction, recently, experts are suggesting different schemes and actions to facilitate and promote this needed pedagogy transformation in higher education institutions and in engineering education specifically.

Examples of the required pedagogical revision are found in (Fenner et al., 2004) where is stated that "***changes need to be made in the way engineering education is conceived and delivered****, so that graduating engineers can become proponents for the implementation of sustainable practices in their organisations. What is required is the stimulation of self-reflective learning, in which students are exposed to a range of differing views, and continually encouraged to challenge their own assumptions"*. Wals and Jickling (2002) also declare that "*teaching about sustainability requires the transformation of mental models. Teaching about sustainability presupposes that those who teach consider themselves learners as well and that students and other concerned groups of interest are considered as repositories of knowledge and feelings too. Teaching about sustainability includes deep debate about normative, ethical and spiritual convictions and directly relates to questions about the destination of humankind and human responsibility.* ***Sustainability in programming demands serious didactical re-orientation***".

Nathalie Lourdel (2004), as well, emphasizes the **need of a directed innovative pedagogic reflection** for an education that aims at an integration of sustainable development. And more recently Kagawa (2007) asked for a change in pedagogy too: "*There is no universal formula for ESD. In order to make student' learning more relevant to a specific contest,* ***it is indeed vital to create a curriculum change process within which students' needs, aspirations, and concerns for sustainability are addressed***".

Some authors (Sterling, 2004a; Canadell, 2006) point out that most learning/education is functional or informational learning, which is oriented towards socialization and vocational goals that take no account of the challenge of sustainability. This has been reinforced by the introduction on managerial and instrumental view of education in Western educational systems, which derives from a fundamentally mechanistic and reductionist social and cultural paradigm. *This mechanistic education model blocks the holistic vision of reality which is needed to solve the problems* (Canadell, 2006).

Wals and Corcoran (2005) propose eight principles that can serve as anchor processes to integrate sustainability in higher education:

Principle	Description	Examples
1. Total immersion	Fostering a direct experience with a real-world phenomenon	Observing and monitoring sustainability impacts Managing a specific site
2. Diversity in learning styles	Being sensitive to the variety of learning styles and preferences that can be fount in a single group	Offering a variety of didactic approaches Reflecting on the learning process with the learner
3. Active participation	Developing discourse and ownership by utilising the learners' knowledge and ideas	Soliciting the learners' own ideas, conceptions and feelings Consulting learners on the content of the learning process
4. The value of valuing	Exposing the learner to alternative ways of knowing and valuing through self-confrontation	Giving learners opportunities to express their own values Creating a safe and open learning environment
5. Balancing the far and near	Developing empowerment by showing that remote issues have local expressions which one can influence	Relating issues of biodiversity or sustainability to last night's dinner Showing examples of groups of people successfully impacting the local and global environment
6. A case-study approach	Digging for meaning by studying an issue in-depth and looking for transferability to other areas	Assigning different people to explore different angles of a particular theme and bringing the different angles together
7. Social dimensions of learning	Mirroring the learners' ideas, experiences and feelings with those of others through social interaction	Taking time for discussion and exchange Addressing controversy Stimulating flexibility and open-mindedness
8. Learning for action	Making the development of action and action competence an integral part of the learning process	Allowing learners to develop their own course of actions and to follow through with it Studying examples of action-taking elsewhere.

Table 3.1 Principles to integrate sustainability in higher education (Wals & Corcoran, 2005)

When referring to learning and pedagogy, Sterling (2004a) highlights the need to shift from mechanistic to ecological thinking in three dimensions and proposes the change needed in learning and pedagogy in four areas (see table 3.2):

- **Perceptual**: the need to widen and deepen our boundaries of concern, and recognize broader contexts in time and space.
- **Conceptual**: the disposition and ability to recognize and understand links and patterns of influence between often seemingly disparate factors in all areas of life, to recognize systemic consequences of actions and to value different insights and ways of knowing.
- **Practical**: A purposeful disposition and capability to seed healthy relationships recognizing that the whole is often greater than the sum of the parts; to seek positive synergies and anticipate the systemic consequence of actions.

	Mechanistic/traditional view of education	Ecological/Alternative view of education
Teaching and Learning	Transmission	Transformation
	Product oriented	Process, development and action oriented
	Emphasis on teaching	Integrative view: teachers also learners, learners also teachers
	Functional competence	Functional, critical and creative competencies valued
View of Learner	As a cognitive being	As a whole person with full range of needs and capacities
	Deficiency model	Existing knowledge, beliefs and feelings valued
	Learners largely undifferentiated	Differentiated needs recognized
	Valuing intellect	Intellect, intuition, and capability valued
	Logical and linguistic intelligence	Multiple intelligences
	Teachers as technicians	Teachers as reflective practitioners and change agents
	Learners as individuals	Groups, organizations and communities also learn
Teaching and Learning Styles	Cognitive experience	Also affective, spiritual, manual and physical experience
	Passive instruction	Active learning styles
	Non-critical inquiry	Critical and creative inquiry
	Analytical and individual inquiry	Appreciative and cooperative inquiry
	Restricted range of methods	Wide range of methods and tools
View of Learning	Simple learning (first order)	Also critical and epistemic (second/third order)
	Non-reflexive, causal	Reflective, iterative
	Meaning is given	Meaning is constructed and negotiated
	Needs to be effective	Needs to be meaningful first
	No sense of emergence in the learning environment/system	Strong sense of emergence in the learning environment/system.

Table 3.2 Shift needed in ESD: from mechanistic to ecologic view (Sterling, 2004a)

Natalie Lourdel (2004) also defines eight pedagogical objectives to reach ESD:

- consciousness of the evolutionary dimension of the concept
- notion of uncertainty
- divergences of acceptance
- systemic thinking mode
- ethical reflection
- responsibility
- the change of paradigm
- To transform a theoretical notion to a pragmatic action.

Wagner and Dobrowolski (2000) pointed out the following requirements, for a didactical re-orientation to integrate SD in HE:

- focus on competencies and higher thinking skills
- foundational appreciation of holistic principles, critical system understandings, and practical systemic competencies
- an early start, i.e. well before students enrol in universities
- critical reflection on one's own teaching
- self-commitment and taking responsibility
- empowerment of learners by enabling them to work on the resolution of real issues that they themselves have identified
- appreciation and respect for differences
- courage (``dare to be different'')
- creativity, as there are no recipes.

Integrating aspects of sustainability cannot be realized without thinking very critically about the re-structuring of didactical arrangements. This re-orientation requires ample opportunity for staff members and students to embark on new ways of teaching and learning. For this to happen they have to be given the opportunity to re-learn their way of teaching and learning and to re-think and to re-shape their mutual relationships. These new didactical arrangements pre-suppose a problem orientation, experiential learning and lifelong learning. The following shifts in educational orientation appear to make sense in this regard (Wals & Jickling, 2002):

- from consumptive learning to discovery learning and creative problem solving;
- from teacher-centered to learner-centered arrangements;
- from individual learning to collaborative learning;
- from theory dominated learning to praxis-oriented learning;
- from sheer knowledge accumulation to problematic issue orientation;
- from content-oriented learning to self-regulative learning;
- from institutional staff-based learning to learning with and from outsiders;
- from low level cognitive learning to higher level cognitive learning;
- from emphasizing only cognitive objectives to also emphasizing affective and skill-related objectives.

The Sustainable Development Education Panel (UK) suggests firstly that SD education is best integrated into specialist courses through learning activities which are firmly set in the context of the specialism, and secondly that different learning activities and learning materials will be needed to deliver the sustainability learning agenda to students from the different branches of engineering. (SDE Panel, 1999)

Harpet (2006) highlights that the mixed characteristics of the public to be trained or whose awareness is to be raised on sustainable development and ethics, requires a pedagogic method that would enable a constructive dialogue between different cultures, languages, courses, and visions so as to achieve a common vision for a collective future/destiny. This new pedagogy sees itself as:

- global and holistic
- as systemic
- as analogous and broad
- by exploring notions of complexity and uncertainty
- by betting upon the democratic value of constructive scientific controversies
- of participation-based pedagogic activities

- by use of illustrations and schemata

Seven pedagogic principles which follow the same lines as those introduced by sustainable development should be retained in order to renew the concept of knowledge transfers:

1. a systemic approach of knowledge
2. a local-global approach
3. a transversal approach
4. a trans-disciplinary approach
5. discussions and debates around currently admitted postulates and concepts confronted with those new global challenges and stakes
6. heuristic learning as well as learning through intellectual projections onto levels of individual and collective responsibility
7. new responsibilities concerning the uses and potential uses of this information in the new technology systems

New pedagogical methods that take into consideration the new complex and multi-cultural scenarios are required in engineering studies. For that, new methodologies must include a process of evaluation to develop information into new valid knowledge. In this sense, a pedagogy that allows the students to better evaluate the information and to develop complex and interconnected knowledge, that understands the linkage and interactions between the technology and their environmental, cultural, social and economic aspects, is needed. Education and knowledge are then understood as a process of inquiry consisting in acts of cognition and not transfers of information, in which dialogical relations are indispensable. In order to do this the following methodological aspects are essential (Lobera et al., 2006):

- Dialogical learning: Dialogical learning is based on an egalitarian dialogue among all agents involved in the learning process (all students and educators). On one hand, this means that previous personal knowledge is taken into account, and each individual provides information based in daily life experience. On the other hand, the educators´ role in this process will be facilitating a learning process in which all these personal perceptions are set in a theoretical context by means of dialogue among all the group members and the introduction of new information. Dialogic learning is thus proposed as a shared systematic process of deep analysis on the causes and results of those topics students feel more affected by. Knowledge is constructed in a collective way in which participation and personal involvement are essential.
- Joint construction of knowledge: This is achieved by means of group learning techniques in which dialogue is established among participants in an egalitarian way so that each student learns and teaches. This allows a deeper reflection on the present technological development, its risks and opportunities, its links with daily life, and on the local use they could make out of it.
- Interconnectivity: This is possible by means of:
  - interconnectivity of technology issues with everyday life;
  - a progressively autonomous learning. Techniques must favour greater levels of autonomy in learning, take into account personal interests and awake a research desire;
  - discussing and exchanging previous knowledge and meanings. This allows the developing of new meanings in technology related to previous ones.
- Progressive autonomous learning: Learning improves when students gain progressive levels of autonomy. This way, proposed techniques should allow increasing discussion and decision taking possibilities as participants develop the ability to identify new interests. Learning must be as significant and profound as possible and motivation always needs to be intrinsic. The educator will then transform its traditional conducting role into a facilitating one. And mechanical learning is replaced by comprehensive learning, with which it is possible to ascribe signification to its contents.

The previous literature review can be synthesised in four dimensions (orientations) of ESD: Adapted from (Martin et al., 2005).

- **Educators as role models and learners:** This approach places an emphasis on how the tutor can act as a role model to develop a deeper understanding of the sustainability agenda. It also encompasses the mutual learning that can take place between tutors and students through personal actions. Supporters of this approach argue that if tutors do not change themselves and their lifestyles to be role models for students and their communities, similar to the function of elders in indigenous (traditional) societies, then there will be no transformation to a more sustainable society.
- **Experiential Learning: reconnecting to reality.** This approach focuses on real and practical life issues and actual experiences as learning situations to avoid the kind of 'reductionist solutions' which have prevailed since the Industrial Revolution. Experiential learning is based on a messy reality, with all its paradox and untidiness, its ever-changing pattern, its refusal to conform to our expectations.
- **Systemic learning:** This approach emphasises the need to move from a 'reductionist' path towards making interdisciplinary and trans-disciplinary connections. Sterling (2004a) argues that sustainability education requires a deeper or Transformative learning approach, in which the learner is helped to see things within a whole system and to deal adequately with messy or complex situations.
- **Critical thinking,** which is an important meta-skill because students need to be able to think critically about the nature of knowledge and the ways in which knowledge is produced and validated. This ability is crucial because students will not be able to retreat onto the familiar and safe territory of their prime discipline, instead they must have the ability and confidence to assess processes and solutions which take their elements from many different disciplines. Successful ESD learning should also lead to individual behavioural and hence social change. Such social change cannot be prescribed by an ESD teaching program that should develop the capacity to managing, facilitating and enacting change, rather than imposing a particular type of change on the students.

The following section evaluates how the learning techniques and strategies applied in engineering education can help to shift the Engineering Education to Engineering Education for SD.

3.3 Learning and teaching methods

Didactic strategy can be described as the set of procedures, supported by educational techniques, which have the goal to carry the didactic action to a good end, that is, attain the goals of the learning. (DIDE, 2004a).

Likewise, a didactic technique is a procedure that helps to carry out a part of the learning of the strategy. It is also a logical procedure with psychological foundations with the purpose of orienting the student learning. The technique hits in a specific sector or in a phase of the course or subject that is run, as the presentation at the beginning of the course, the analysis of contents, the synthesis or the criticism of itself. The didactic technique is the particular resource that the teacher uses for attaining the purposes brought up from the strategy.

In the process of applying a technique, different activities may be necessary to achieve the desired learning goals. These activities are still more partial and specific than the technique itself and can vary according to the type of technique or the type of group which is participating. The activities can be isolated and described in consonance to the learning of the group.

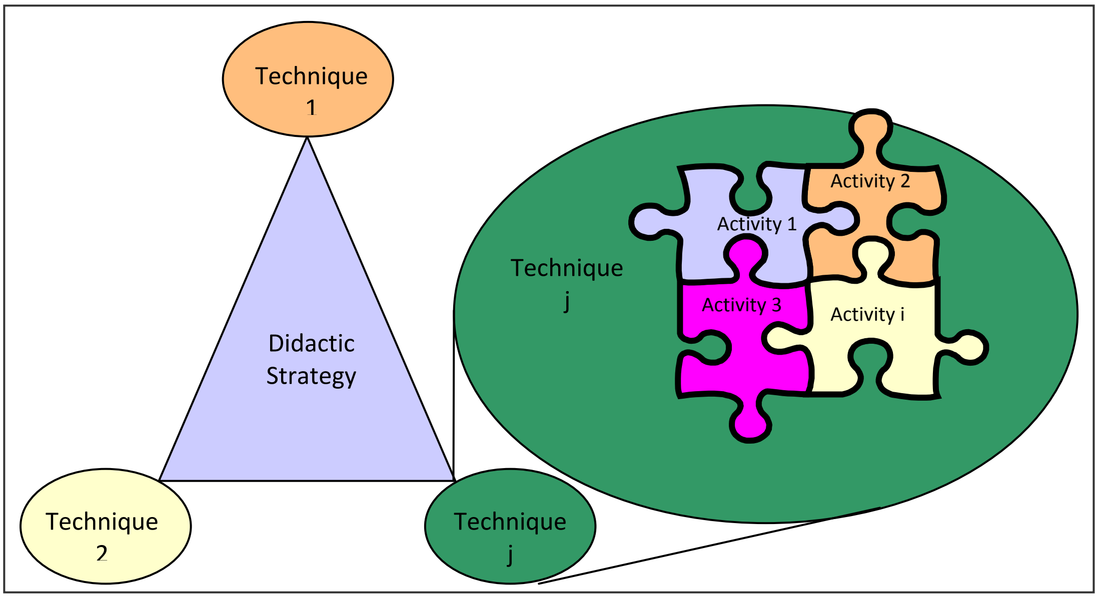

Figure 3.1 Relation between didactic strategy- technique - activity

Students learn in many ways— by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of his or her learning style and the instructor's teaching style. (Felder et al., 1998; 2000). People tend to learn in different ways. Most of us have preferred learning styles that influence how successfully learners interact with different forms of the learning experience. A widely used inventory of learning styles, developed by Honey and Mumford (Honey & Mumford, 1992), suggests that there are four broad learner types: activists, reflectors, theorists and pragmatists.

Richard M. Felder (Felder et al., 1988; 2000) defined four dimensions of learning styles and the teaching styles that adapt to them.

Learning		Teaching	
Sensory Intuitive	Perception	Concrete Abstract	Content
Visual Verbal	Input	Visual Verbal	Presentation
Active Reflective	Processing	Active Passive	Student participation
Sequential Global	Understanding	Sequential Global	Perspective

Table 3.3 Dimensions of learning and teaching styles

To increase students' success in engineering education, one must understand students' individual learning style and provide pedagogical methods and environments accordingly. (Carver et al., 1999). Nevertheless the conventional teaching approach used in engineering education emphasizes lectures over active engagement (favouring reflective and verbal learners over active and visual learners), focuses more on theoretical abstractions and mathematical models than on experimentation and engineering practice (favouring intuitive learners over sensing learners), and presents courses in a relatively self-contained manner without stressing connections to material from other courses or to the students' personal experience (favouring sequential learners over global learners) (Felder et al., 1988, 1996). Table 3.3 shows that there are 16 (2^4) learning styles. Most instructors would be intimidated by the prospect of trying to accommodate 16 diverse styles in a given course. As mentioned before, the usual methods of engineering education adequately address four categories (intuitive/verbal/reflective/sequential) and effective teaching techniques substantially overlap the remaining categories. The addition of a relatively small number of teaching techniques to an instructor's repertoire should therefore suffice to accommodate the learning styles of every student in the course. Adapted from (Felder et al., 2000).

3.4 The learning paradigm and the pedagogical strategies and techniques

Quoting Erik de Graaff (2004), "*the goal in engineering education is not fill the engineering students' heads full of knowledge, but to provide a well-adapted learning environment, which allows them to "learn-to-learn", and enables them to acquire the combination of knowledge, skills and attitudes needed to obtain professional engineering competences"*. Moreover, the distinct and unique aspect of Sustainable Development imposes new educative approaches. In relation to educate engineers for Sustainability what is required is the stimulation of self-reflective learning, in which students are exposed to a range of differing views, and continually encouraged to challenge their own assumptions (Fenner et al., 2004).

Sustainable Development is not just a matter of acquiring some extra knowledge. Attitude is also important. It is not very effective to teach this only by lectures (Mulder, 2006). Therefore a wide range of pedagogical strategies and techniques should be applied to ensure, that the learning style of every student is accommodated in the courses, shift from mechanistic to ecological view of education.

The strategies and didactic techniques can be classified according to two different parameters: according to the degree of participation (number of people involved in the process of learning, which can go from self-instruction to cooperative learning) or according to their reach (the time involved in the didactic process is estimated, from a single subject until a real course or whole curriculum).

Participation	Examples of strategies and techniques
Self-directed-learning 	▪ Individual study ▪ Search and analysis of information ▪ Elaboration of reports ▪ Individual tasks ▪ Projects ▪ Research ▪ Etc.
Active learning 	▪ Lecture exposition from the teacher ▪ Speech of an expert ▪ Interviews ▪ Visits ▪ Panels ▪ Debates ▪ Seminaries ▪ Etc.
Cooperative learning 	▪ Case study ▪ Project based learning ▪ Problem based learning ▪ Analysis and discussion in groups ▪ Discussions and debates ▪ Etc.

Table 3.4 Classification of didactic strategies and techniques according to the participation

Reach	Examples of strategies and techniques
Techniques (Short periods and specific issues) 	▪ Method of consensus. ▪ Play roles ▪ Debates ▪ Seminar ▪ Symposium ▪ Simulations
Strategies (Long periods: a semester or a degree) 	▪ Case study ▪ Project Based Learning ▪ Personalized learning system

Table 3.5 Classification of didactic strategies and techniques according to their reach

Self-learning: In its broadest meaning, "self-directed-learning" describes a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes (Straka, 1997).

Interactive learning: defined as opportunities for students to make sense of the subject matter for themselves and often contrasted with 'passive learning' that characterizes the conventional student experience of lectures (Macmillan & Mclean, 2005). These concepts are derived from constructivist views of learning which emphasise that:

- Knowledge is actively constructed by the learner, not passively received from the environment.
- Coming to know is a process of adaptation based on, and constantly modified by, a learner's experience of the world.

Cooperative learning: Cooperative learning in HE is instruction that involves students working in teams to accomplish a common goal, under conditions that include the following elements: Positive interdependence, individual accountability, face-to-face promotive interaction, appropriate use of collaborative skills and group processing (Felder & Brend, 2007). Research studies on team-based learning in HE show that both individual and group performance is superior when cooperative methods are used as compared with competitive or individualistic methods (Johnson et al., 2000). It has positive effects on a variety of cognitive and affective outcomes (Terenzini et al., 2001; Springer et al., 1997).

The following sections describe the general characteristics of pedagogical strategies and techniques and how they can contribute to ESD.

3.4.1 Lecturing Technique

Introduction

Lecturing is probably the method of education most used at universities, but also the one more criticized during the last years when referring to obsolete or ineffective educational practices (DIDE, 2004a).

Indeed, in order to prepare students to assume the challenges and roles of a changing world, nowadays teachers need to face the requirement of reducing the use of lecturing and to generate a more interactive working environment where the student participates in cooperative activities with his/her colleagues.

Certainly, when this method is applied correctly, with the contents suitable to the available time and integrated to other didactic techniques, it can contribute significantly to the learning process in an effective way.

Lecturing as a didactic technique

Lecturing consists of the presentation of a subject in a structured way, where the main resource is the oral language, even though it can also be a written text that is read.

In the last years the need to alternate the use of lecturing with other didactic techniques, even in the same session of class, has been highlighted. Pauses are made in logical points of the lecture, where the teacher requests that the pupils carry out some activity for keeping them involved in the subject. Like this the lecture is more dynamic and allows student to have time for processing and understanding the contents of the lecture. Moreover the teachers can notice the concepts that are not clear.

Lecturing is associated normally with an activity carried out by the teacher. It is necessary to also take into account, however, that it can be used by the students when they are asked to "lecture" to their classmates. (Adapted from DIDE, 2004b).

Lecture learning outcomes

Lecturing allows learning concepts and procedures, as well as skills, attitudes and values (DIDE, 2004b). Regarding ESD lecturing is a good method to introduce students to sustainability concepts. (Azapagic et al., 2005).

Frequently the lecture is used in directed activities for the acquisition of concepts by students, even though traditionally it has been considered that conceptual learning supposes the domain of experimental aspects of knowledge inherently. However, it is not always like this. To facilitate the acquisition of procedures it is necessary that the teacher experiments the procedure to be learned using experimental pedagogical methodologies.

Analogously to the area of the acquisition of concepts it is important to ensure that the learning of procedures is inserted in a more extend range of meanings, in the students' cognitive structure.

The fact that students lecture to their colleagues and to the teacher hits directly upon the development of their oral communication skills.

The direction of teacher lecturing can also make possible the development of the skill of oral communication of the students, in the measure in which the teacher promotes this skill. Besides, it allows the development of critical thinking when the presentation of a subject leads the student to judging and valuing the information that he or she presents. To succeed, the student has to apply a set of superior and complex cognitive processes like analyzing, synthesizing, evaluating, solving problems, taking decisions, etc. This is possible when the lecture is complemented with the use of other didactic techniques.

Difficulties and barriers when lecturing

Using lecturing requires a lot of preparation of the subject and personal capacity to express and to pick up the attention of students.

There are some inconveniences that the teacher has to be confronted with when using this technique:

- The teacher is the only actor, and as such has to try hard to control all the elements that hit or affect his or her task.
- The fixation of the learning is more difficult when the message is only oral, for which it is always convenient to use other means that help the students to process the data of the message transmitted.
- The motivation is in general more difficult when the message and actions are limited only to one person.
- The verbal expression and the use of visual supports require of suitable conditions of space.

3.4.2 Project Based Learning

Introduction

Project Based Learning (PBL[4]) is a clear example of cooperative and active learning (Felder & Brend 2007; De Graaff & Ravesteijn 2001; De Graaff & kolmos, 2007). The PBL appears from a vision of the education in which the students have more responsibility in their own learning and where they apply, to real projects, the skills and knowledge acquired in the classroom.

This method propitiates the confrontation of the students to situations that lead them to rescuing, understanding and applying what they learn like a tool to solve problems or to propose improvements in the communities where they develop.

When the PBL method is used as a strategy, the students stimulate their stronger skills and develop some new ones. The value of the learning, the feeling of responsibility and effort, is reinforced as also is the impression of the important role that they have in their communities.

The students look for solutions to non trivial problems when:

- Making questions
- Discussing ideas
- Making predictions.
- Designing plans and/or experiments.
- Picking up and analyzing data.
- Establishing conclusions.
- Making new questions.
- Creating artefacts.

PBL can be described like a set of experiences of learning that involve students in complex projects and of the real world through which they develop and apply skills and knowledge (DIDE, 2004a). A project is a complex effort that necessitates an analysis of the target (problem analysis) and must be planned and managed, because of desired changes that are to be carried out in people's surroundings, organization, knowledge, and attitude to live; it involves a new, not previously solved task or problem; it requires resources across traditional organizations and knowledge; it must be completed at a point in time determined in advance (Algreen-Ussing & Fuensgaard, 1990).

This learning requires that the students use many information sources and disciplines that are necessary to solve problems or to answer questions. These experiences make students learn to control and to use resources as time and materials. Besides they develop and finish off academic skills, both social and personal through the project work. The skills are placed in a context that makes them significant for the students.

PBL supposes a way to understand the sense of the education based on learning for the understanding, which implies that the students participate in a process of research, that has meaning for them using different strategies of study; students can participate in the process of learning planning, and it helps them to be flexible and to understand their own personal and cultural environment. This attitude favours the interpretation of the reality and the anti-dogmatism. These projects point out towards another way to represent knowledge based on the reality interpretation, orientated towards the establishment of relationships between the students' life and the teacher. All this promotes the development of strategies of search, interpretation and presentation of the applied process on studying a subject or a problem. Because of its complexity, it supports the self-recognition of students and teachers themselves and of the world in which they live (Hernandez, 1998).

In the organization of PBL, when putting the student in front of a real problematic situation, a learning which is more linked to the reality is favoured. This allows the student to acquire the knowledge in a non isolated way, and knowledge has more credibility and sense of "being useful".

There are some characteristics that facilitate the management of PBL (Blumenfeld, 1991):

- A project based on a "real life" problem and that involves different areas of knowledge.
- Opportunities so that the students carry out research that allows them to learn new concepts, to apply the information and to represent their knowledge in several ways.
- Collaboration among the students, teachers and other involved persons, with the purpose that the knowledge is shared and distributed among the members of the "learning community".
- The use of cognitive tools and a learning environment that motivate the student to represent his or her ideas. These can be: rooms of computers, hypermedia, graphic applications and telecommunications.

The "Buck Institute for Education[5]" mentions some characteristic elements of PBL:

- The managed contents are significant and relevant for the student, since they represent real problems and situations.
- The activities allow the students to look for information to solve problems, as well as to construct their own knowledge favouring the retention and transfer of this knowledge.
- The conditions in which the projects take place allow that the student develops skills of collaboration instead of competition, since the interdependence and the collaboration are crucial to achieve that the project works.
- The work with projects allows the students to develop skills of productive work, as well as skills of autonomous learning and of continuous improvement.

Project Based Learning strategy learning outcomes

PBL is related with an extensive range of learning techniques, like case studies, debates, problem based learning, etc.

Using one or more of these techniques together with PBL creates to all participants an appropriate environment for the acquisition and development of knowledge, skills and attitudes.

Besides the knowledge typical for each subject or discipline, the students acquire and develop a series of skills and attitudes shown in table 3.6.

Skills	Attitudes
Solution of problems	Desire to learn
Understanding of the role in their communities	Responsibility
Learning ideas and complex skills in realistic stages	Initiative
Learn to learn	Persistence
Social skills related with the work in group and the negotiation	Autonomy
Professional skills and strategies typical of the discipline	
Skills and strategies associated with planning, driving, managing and evaluating of a variety of intellectual research	
Meta-cognitive skills (example: self-direction, self-evaluation)	
Integrating concepts across areas of different subjects and concepts	
Relating cognitive milestones, social, emotional and personal with the real life	

Table 3.6 Skill and attitudes acquired by students trained with PBL

Difficulties and barriers when using the PBL technique

PBL presents some difficulties. An objection is that the projects can require great amounts of time from instruction, reducing the opportunities for other learning. Moreover in a unit of PBL can be difficult to establish if the students have attained the established learning goals, therefore PBL requires specific tools of learning assessment.

The projects are vulnerable to the criticism that the students pass major part of their time carrying out activities that can not be directly related with the subject or represent new learning.

The problems observed by the researchers can be summarized in:

- Time. Research and Discussions often take more time that then that of the foreseen one. Also the deep exploration of ideas takes away more time than the superficial and known sources of concepts.
- Knowledge of the lines that guide the syllabus. Teachers need to select accurately the guiding questions, so that the students can learn the contents stipulated in the syllabus.

- Administration of the classroom. Students need sufficient freedom for speaking about their research, but the teachers have to sustain the order so that the students can work productively.
- Control. Teachers often hear the need to control the lessons for checking that the students are obtaining the correct information.
- Support to the students learning. Teachers frequently give the students too much independence without giving them the suitable conceptual models, structure of the situation or feedback.
- Use of the technology. Teachers who have not used technology like a cognitive tool have difficulties in incorporating it into the classroom.
- Assessment. Teachers have difficulties to design an assessment system that the majority of the students can understand. The questions asked to the students not always require that they synthesize information or generate new conceptual representations.

Special attention requires interdisciplinary and multicultural projects regarding ESD, as Karel Mulder (2006) stresses: "*Sustainability is a complex theme that needs to be approached with an open mind and a wide scope. Working in interdisciplinary teams is a method to work on complex societal themes, in an integral and creative way*". Multidisciplinary projects allow the integration of sustainability thinking into the overall curriculum from the fundamentals to the design projects (Azapagic et al., 2005).

In that direction other authors underline the role of multidisciplinary and multicultural approaches for ESD:

Influence of national culture is important when evaluating and integrating sustainability and environmental issues (Eagan et al. 2002). Interdisciplinary courses incorporate theories from more than one discipline, may have multiple instructors from different departments, and often utilize broad-based moral and political perspectives in order to present given subject matter (Abell-Walker 1999). Davis and Newell (1981) identify several advantages for students who participate in interdisciplinary courses, including: "*an appreciation for perspectives other than one's own; an ability to evaluate the testimony of experts; tolerance of ambiguity; increased sensitivity to ethical issues; an ability to synthesize or integrate; enlarged perspectives or horizons; more creative, original, or unconventional thinking; increased humility or listening skills; and sensitivity to disciplinary, political, or religious bias*''. Perhaps most often highlighted as an advantage of interdisciplinary training is an ability to understand better the complexity of real-world problems.

Interdisciplinary training and approaches are seen as ``hallmark'' traits of environmental education. Educators and administrators hope that interdisciplinary approaches to environmental studies will teach students critical thinking skills, problem-solving skills, and the ability to understand complicated issues, all skills seen as necessary to work toward more effective solutions to environmental problems. (Eagan et al., 2002)

The modules and materials for teaching sustainability to engineering students must include not only technological analysis and economic evaluation, but also environmental and social consideration. A multidisciplinary approach is essential (Perdan et al., 2000).

PBL specially organised as interdisciplinary projects, could contribute to adapt engineering curricula to enhance mutual understanding of science and technology with social sciences (Adapted from Mulder, 2006).

3.4.3 Case study methodology

Case studies have been used for teaching and research in many disciplines for many decades. In the educational process, the representation of a real situation as a basis for the reflection and learning has been used manifold. The approach of a case is always an opportunity of significant and transcendental learning in the measure in which those who participate in its analysis can be involved and engaged in the discussion of the case as well as in the group process for its reflection.

Introduction

The technique of the case study consists in providing a series of cases that represent diverse problematic situations of the real life so that they can be studied and analyzed. The purpose is to train students in problem solving.

This technique is indicated especially to diagnose and to decide in the field of problems, where the human relationships play an important role. With this technique people can:

- Analyze a problem.
- Gauge a method of analysis.
- Acquire agility to gauge alternatives or actions.
- Take decisions.

In this technique three models can be highlight according to the methodological purposes to be courted:

- **Model centred on the analysis of cases** (cases already studied and solved by teams of experts). This model emphasises the understanding of the diagnosis and intervention processes carried out, as well as of the resources used, the used techniques and the results obtained through the programs of intervention proposed. Through this model, basically it is intended that students know, analyze and appraise the processes of intervention elaborated by the experts in the resolution of concrete cases. Besides, alternative solutions can be studied to the proposed in the studied case.
- **Models that teach how to apply principles and legal rules to cases,** so that the students practice in the selection and application the principles suitable for each situation. The goal is to develop an inferential thinking, through the preferential attention to the rule, to the objective references and by finding the correct answer to the situation brought up. This model is used mainly in the field of law and medicine.
- **Model of training in the resolution of situations.** They are cases that, besides the consideration of a theoretical frame and the application of practical prescriptions to the resolution of determinate problems, they require that attention is paid to the singularity and complexity of specific contexts. It is important to respect the personal subjectivity and to pay attention to the interactions that are produced in the stage that is being studied. There is not a correct answer and the teacher has to be open to diverse solutions.

The technique of the study of cases has the advantage that it adapts perfectly to several levels and areas of knowledge.

Table 3.7 illustrates different types of case studies case studies depending on the dimension taking into account.

Dimension	Classification
Design	Holistic or embedded Single case or multiple case
Motivation	Intrinsic or instrumental
Epistemological status	Exploratory, descriptive or explanatory
Purpose	Research, teaching or action/application
Data	Quantitative or qualitative
Format	Highly structured, short vignettes Unstructured or groundbreaking
Synthesis	Informal, emphatic or intuitive Formative or method given

Table 3.7 Dimensions and Classifications of case studies (Scholz & Tietje, 2002)

<u>Case study technique learning outcomes</u>

This technique is very interesting in the areas that require training on theoretical and practical competences. Through the technique of case study the students can develop (Lopez, 1997):

- Cognitive skills like critical thinking, analysis, synthesis and assessment.

- Learning of concepts and application of those learned previously, both in a systematic way and from the own experience.
- Skills to work in group and the interaction with other students, as well as the attitude of cooperation, exchange and flexibility which constitutes an effective preparation for the human relationships.
- Approach to reality, the understanding of phenomena and social facts, to familiarize with the needs of the environment and to be sensitized for the diversity of contexts and personal differences, the improvement in the attitudes to face human problems.
- Unblock insecure attitudes.
- Development of the feeling "us".
- Dynamic training of self-expression, communication, acceptance, reflection and integration.
- Motivation for learning, since the students in general find the work of case study more interesting than attending to lecturing lessons and reading of textbooks.
- The processes of decision making.

In exploring value frameworks and how judgement and expert opinion can be considered, shared experiential learning is important, in which participants can take a position drawn from their own background. The use of case studies is a helpful tool. These are usually of a qualitative and descriptive nature and can be used to explore specific issues such as different stakeholder perspectives, examples of actual practice, and demonstrations of where progress towards sustainability is, and can, be made in the real world. These case studies can be linked to role-playing exercises where students engage with different stakeholder views (Fenner et al., 2004).

For the teaching of subjects as sustainability or quality of life, case studies provide a useful way of illustrating the subject matter (Yuan, 2001).

Difficulties and barriers when using the case study technique

Many teachers consider this technique complicated, however, even though it requires a specific preparation from the teacher, it can be said that it is a very effective system of education.

The difficulties that the implantation of the method of cases brings up can be summarized in the following points:

- Working with cases of open end and the non-existence of concrete answers can be difficult to accept for some students.
- If there are many groups of students the control of the group can be lost.
- It is difficult to design a correct system of evaluation.
- It is difficult to fit the strategies of assessment with the goals of learning.
- Time of discussion of the case has to be administered suitably, otherwise can be lost.
- The case has to treat a subject matter that includes the main part of the students group; otherwise some students can lose interest to participate in the case.
- Students can perceive little relation between the case and the contents of learning of the course.

3.4.4 Problem based Learning

In the learning based on problems the process of the conventional learning is inverted, from deductive to inductive learning. In problem based learning the information is exposed and in the resolution of a problem its application is looked afterwards. In this, first the problem is brought up, next the needs of learning are identified, then the necessary information is looked up and the problem is finally solved.

The learning based on problems is used in many universities like a curricular strategy in different areas of professional training.

Introduction

Problem based learning had been introduced in the late 1960s by Donald Woods of McMaster University in Ontario, Canada, as an innovative educational approach to undergraduate Engineering students (Woods, 1985).

The problem based learning is a learning strategy in which the acquisition of knowledge is as important as the development of skills and attitudes.

In the problem based learning a small group of students meets, with the support of a tutor, to analyze and to solve a problem designed to attain certain goals of learning. During the process of students interaction to understand and to solve the problem, is achieved that the students can elaborate a diagnostic of their own needs of learning, understand the importance to collaborate in the work, develop skills of analysis and synthesis of information, and also the commitment with theirs process of learning.

According to the constructivist theory with the problem based learning three basic principles are followed:

- The understanding of a situation of the reality appears from the interactions with the surroundings.
- The cognitive conflict in facing each new situation stimulates learning.
- The knowledge develops through the recognition and acceptance of social processes and of the evaluation of the different individual interpretations of the same phenomenon.

The steps that the problem based learning follows can be summarized in figure 3.2.

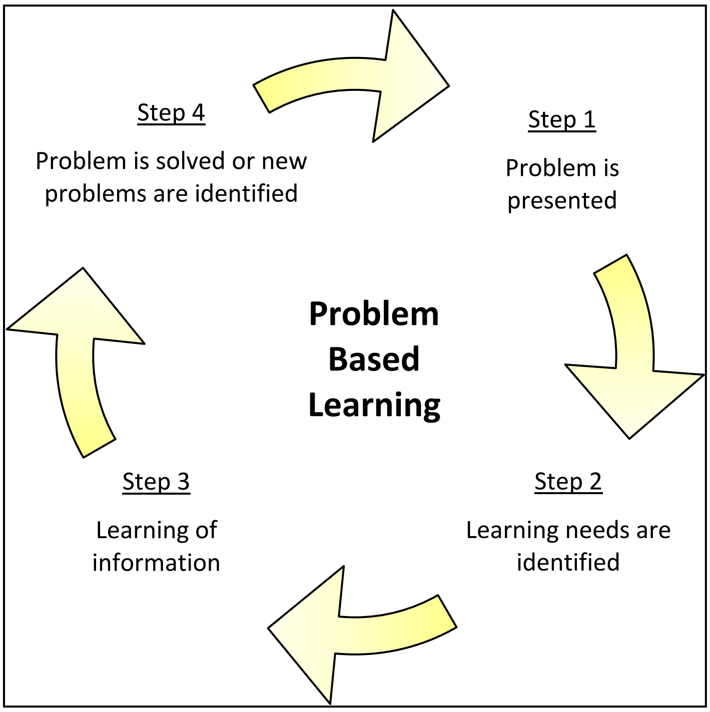

Figure 3.2 Steps of the Project Based learning process

Problem based learning technique learning outcomes

From its own dynamics of work learning based on problems generates a favourable environment so that very diverse learning is achieved. The learning of knowledge of the course as well as the integration of skills, attitudes and values are stimulated to the students by the challenge of the resolution of a problem working in a cooperative way.

Learning that is fostered to students when participating in this didactic technique are (DIDE, 2004b):

Skills	Attitudes
Cognitive skills, like critical thinking, analysis, synthesis and evaluation	Cooperative attitude and predisposed to exchange.
Learning of concepts and contents related to the field of study	Participating in processes of decision making
To identify, analyze and solve problems	A culture directed to work
To detect the learning needs	Confidence and autonomy in their actions
Using different information sources efficiently	Questioning their own scale of values (honesty, responsibility, commitment)
Understanding the phenomena that are a part of their environment, of their speciality as well as contextual (politician, social, economical, ideological, etc) one	An attitude positive and predisposed towards learning and the contents of the subject
Arguing and discussing ideas using solid foundations	The feeling of belonging to the group is developed
Listening and communicating in an effective way	

Table 3.8 Skills and attitudes acquired by students trained with Problem Based Learning

Problem solving prepares students to be responsable. The characteristics of problem based learning provide a unique opportunity for students to learn about themselves. As a part o the problem-solving process students must consider their own educational goal, which is likely to require introspection about students' values, ethics and beliefs (Knowlton, 2003).

Problems can serve as vehicle for promoting thoughtfulness among students, stimuli for activity and to promote higher-order thinking (Weiss, 2003).

Difficulties and barriers when using the problem based learning technique

Some difficulties that may occur when applying the method of learning based on problems are:

- It is a difficult transition. To pioneer the work with this technique it is necessary that teachers and students change their vision of learning. They have to assume responsibilities and to carry out actions that are not usual in an environment of conventional learning.
- Curricular modification. When working the contents of learning with regard to problems they can be approached from a different form, from many perspectives, with more depth, and for many more disciplines, therefore it is necessary to make an analysis of the relations of the contents of different courses that shape a degree.
- More time is required. When using learning based on problems it is not possible to transfer information in such a fast way as with the conventional methods. Students need more time to attain the learning. The teachers also have to dedicate more time to prepare the problems and to supervise students across consultancies and feedback.
- The teachers lack as assistants. Most of the teachers do not have the necessary training to work with students groups, since the inertia of being the centre of the class and of setting forth information is very great. The most handicapped area for the teachers is a deficient knowledge of the technique of group interaction (cohesion, communication, competition, etc).

Because Problem Based Learning is a relatively new and innovative learning strategy, it application has created tension for professors who plan to design and implement Problem based learning activities (Hung et al., 2003):

- Depth versus Breadth curriculum.
- Higher-order thinking versus factual knowledge acquisition.
- Long-term effects versus immediate learning outcomes.

- Students' initial discomfort versus their positive attitudes.
- Traditional role of professors versus the roles of Problem based learning tutors.

3.4.5 Backcasting

Backcasting is the creation of a future vision, bearing in mind what is necessary to achieve in the future and then working towards that goal from this day forward. Backcasting means literally looking back from the future. In backcasting the desirable future is envisaged first, before analysing how it could be achieved by looking back from this future and identifying what steps need to be taken to bring about that future. In addition, it is also possible to look back from an undesirable future and to determine what to do to avoid this (Quist, 2007).

Backcasting as a didactic technique

Backcasting is mainly used for R&D purposes, but it also has been used for teaching purposes as, in its very nature, it implies a collective learning experiment.

Quist (2007) analyses four backcasting approaches from literature (See figure 3.9):

- The backcasting approach as proposed by Robinson (1990);
- The Natural Step backcasting approach (Holmberg, 1998; Nattrass and Altomare, 1999; Holmberg & Robert, 2000);
- The Sustainable Technology Development (STD) backcasting as described by Weaver et al. (2000);
- The backcasting approach as applied in the SusHouse project, based on Vergragt (2000), Quist et al. (2001), and Green & Vergragt (2002).

Learning is important in all of them (Quist, 2007).

Bakcasting learning outcomes

Backcasting is particularly interesting in the case of complex and persistent problems, where there is need for major change, dominant trends are part of the problem, when there are externalities that cannot be satisfactorily solved in markets, and in case of sufficiently long time horizons alternatives are allowed that need long development times (Dreborg, 1996). Due to its normative and problem-solving character, backcasting approaches a much better suited (in reference to forecasting) to address long-term problems and sustainability solutions (Quist, 2007).

Dreborg (1996) states that backcasting is particularly useful when applied to complex and persistent problems, when dominant trends are part of the problem, when externalities are at play, when there is a need for major change and when time horizon and scope allow development of radical alternative options. Sustainability problems obviously combine all these characteristics.

3.4.6 Role plays, simulation games, structured controversies

The role play, simulation games and structured controversies are all pedagogical techniques and actions, where interaction and communication is promoted and allow significant learning.

The role play

Role play can be defined as a learning process in which participants act out the roles of other individuals in order to develop particular skills and to meet particular learning objectives.

Amongst the active pedagogies, role playing seems to be particularly relevant. Training based on this type of activity tends to be very enriching. Role play allows learners to be presented with complex, dynamic and changing situations. Participants must engage critically with the material, develop their communication skills, be organised, and work as part of a group and practice negotiation. It also allows them to express their point of view and to compare it with that of others, within what is known as a 'zone of proximal development' (Lourdel et al., 2006).

The role play is an approach which combines at the same time complexity, the setting in situation, work in group, autonomy and action of the student is particularly relevant for ESD. Adapted from Lourdel (2004b). Lourdel also underlines the learning outcomes in relation to ESD facilitated by the role play:

	Robinson's	Natural Step	Sustainable Technology Development	SusHouse
Key assumptions	- Criteria for social and environmental desirability are set externally to the analysis - Goal-oriented - Policy-oriented - Design-oriented - System oriented	- Decreasing resource usage - Diminishing emissions - Safeguarding biodiversity and ecosystems - Fair and efficient usage of resources in line with the equity principle.	- Sustainable future need fulfilment - Factor 20 - Time horizon of 40-50 years - Co-evolution of technology & society - Stakeholder participation Focus on realising follow-up	- Stakeholder participation - Factor 20 - Sustainable households in 2040 - Social and technological changes are needed - Achieving follow-up is relevant
Methodology	o Determine objectives o Specify goals, constraints and targets & describe present system and specify exogenous variables o Describe present system and its material flows o Specify exogenous variables and inputs o Undertake scenario construction o Undertake impact analysis	1.Define a framework and criteria for sustainability 2.Describe the current situation in relation to that framework 3.Envisage a future sustainable situation 4.Find strategies for sustainability	1.Strategic problem orientation 2.Develop sustainable future vision 3.Backcasting- set out alternative solutions 4.Explore options and identify bottlenecks 5.Select among options & set up an action plan 6.Set up cooperation agreements 7.Implement research agenda	1. Problem orientation and function definition 2. Stakeholder analysis and involvement 3. Stakeholder creativity workshop 4. Scenario construction 5. Scenario assessments 6. Stakeholder bakcasting and strategy workshop 7. Realisation follow-up and inplementantion
Examples off methods	- Social impact analysis - Economic impact analysis - Environmental analysis - Scenario construction methodologies - System analysis & modelling - Material flow analysis and modelling	- Creativity techniques - Strategy development - Employee involvement - Employee training	- Stakeholder analysis - Stakeholder workshops - Problem analysis - External communication - Technology analysis - Construction of future visions - System design & analysis	- Stakeholder analysis - Function & system analysis - Backcasting analysis - Stakeholder workshops - Scenario construction - Scenario evaluation

Table 3.9 Backcasting approaches. From Quist (2007).

To apply the notion of evolutionary concept. The role plays fit in this current of thought which puts forth the assumption that to learn how to learn is more important than the accumulation of knowledge to face a world characterized by an acceleration of the changes and an explosion of knowledge. The role play built from a structured scenario will evolve according to the participants and their interventions. Thus it makes possible to students to acquire relational know-how, a better knowledge and a control of difficult situations. From its evolutionary and non-predictive sides the role play can make possible to the students to better apprehend unpredictable situations and variable concepts.

To apply the concept of uncertainties. The role play supposes interactions and exchanges between the students. The debates make possible to develop a critical spirit, the argumentation research, and the use of approaches very different from a strategic point of view. The argumentation and the discussions between the students can support the acquisition of knowledge, attitudes and competences. Indeed, to be able to structure their argumentations the students will have to analyze documents, to seek information, and thus to show skills of synthesis. During the discussions, the participants will be confronted with divergent information, situations or information not available. The role plays can thus be used in order to place the students in situation where they must face uncertainties and with the asymmetry of information.

To take into account of the divergences of acceptance The settings in situation inherent in the role play are organized around a problem and lead the participants to be perceived compared to it and to understand the position, the feelings and the attitudes of the others. Indeed, the play supposes a circulation of information and interactions between the players. The students could be confronted with points of view coming from different disciplines and different cultures. They can thus share their way of understanding a situation. This activity sensitizes students, while making them empathic, it allows certain broadmindedness.

To acquire a systemic way of thinking. The role plays constitute a teaching structure which makes possible to apprehend complex problems. Indeed, in a play of simulation, the players are brought to take individual or collective initiatives to control evolutionary or unforeseen situations. In these exercises, the knowledge is not acquired in a linear way but is the subject of a complex approach. The plays of simulation encourage thinking in term of systems, relations, dynamic processes rather than in term of isolated events. The systemic approach is favoured.

To apply the concepts of ethics. The role play can also stimulate the expression of the individual by calling upon his values and its personal ideas. The role plays are often seen like excellent tools to study the problems of human relations and communication from the point of view of search for solutions. The student is confronted with standpoint, with questionings on his values, it must invest, deliver his opinion. The reflexions on the concept of ethics on the positioning of value compared to a role to be played can be caused by a collective debriefing at the end of the play.

To apply the concept of responsibility. They enable to students to develop aptitudes to make decisions and to solve problems. Indeed, in the plays of simulation, the participants must make decisions and face the consequences of their decisions. It is one of the first stages to confront the students with issues of responsibility, cooperation and trust. Thanks to the role play the “student-passive-spectator” transforms into a fascinating “student-active-participant-actor” being responsible of his/her learning.

To facilitate the change of paradigm. The role play allows learning by action and observation. The role plays give the opportunity to the students of discovering new approaches of new visions where multiple dimensions interfere. This approach can contribute to fundamental changes from the point of view of the students; it can enable them to change paradigms and to change their prospects in relation to SD.

Simulation games

In simulation games, students learn from the experience of action contents and at the same time from solving simulated situations. It promotes interaction and communication allowing significant learning (DIDE, 2004b).

It is a good technique for contents that require the experience to make them significant, to develop specific skills for facing and solving simulated situations and to stimulate the students’ interest in a specific subject when participating in the game.

A simulation game at *Ecole des Mines de Saint-Etienne* was applied with multiple sustainability educational objectives (Lourdel et al., 2004a):

- To give students a more concrete vision of the stakes that are associated to Sustainable Development on a real case.
- To make them think about the possibilities of integration of the concept in an industrial context.
- To make them apprehend the notions of competitive versus collaborative negotiation and consultation with the various stakeholders.
- To make the students apprehend the complexity of a real case by identifying the interrelations between the various stakes.

Also, it is important to notice that social simulations give students insights in the difficulties to affect social change (Mulder, 2006).

Structured controversy

A structured controversy is a mode of teaching where the students are involved in role-playing and assume the identity of stakeholders brought together to debate an issue. By definition, the issue is controversial and is structured in such a way that the lecturer not only facilitates the exercise, but also manages it towards a certain teaching goal (Johnson & Johnson, 1988; Watters, 1996).

A classic structured controversy involves a proposed development in an environmentally sensitive region that puts developers against nature advocates. The general approach is to divide the students into two or more groups and provide them with common 'facts and figures' as to the reasons for the proposed development. In addition, each group is provided with extra information particular to the stakeholder whose identity the group is assuming. Each group should use the first 20–30 minutes of the workshop to marshal arguments that their stakeholder will put forward at a public meeting. It is not necessary that individuals within a group hold personally that viewpoint – they must just assume that role and try to argue from that stakeholder's perspective (Wareham et al., 2006).

The proposed development can be any contentious issue; however, one with a local flavour gives students the opportunity to bring their own experience and knowledge to the issue. As part of the common information provided to all stakeholders, the area to be developed should have a wealth of natural resources. In addition, the local community proposing the development should have fallen on difficult times due to either resource depletion or a shift in market forces away from the export of existing resources.

The case study use to have four stake holders:

- The Developer
- The nature advocate
- The consulting engineer
- The regional council officer

From the case, three ethical connections appear (Wareham et al., 2006):

- The teleological viewpoint: This perspective is characterized by a focus on the endpoint with less emphasis on the means to achieve those ends. In common parlance, it is known as 'the end justifies the means'. Framework adopted by both the developer and the nature advocate
- The deontological viewpoint: This viewpoint therefore focuses on the rule and not the consequence of the action. This platform is associated with the regional council member.
- The utilitarian viewpoint: this ethical stance is epitomized by the phrase 'the greatest good for the greatest number'. In this case, translated as bringing the greatest good to the largest number of stakeholders involved in the process. The consulting engineer holds this viewpoint.

In this kind of controversy sustainable development flows in the dialogue. And then the facilitator can expand on it.

3.4.7 Graphical learning tools

In the last few years, the development of graphic knowledge representation skills is the centre of attention to many investigators, who consider them a powerful tool to achieve significative learning. This section analyses the suitability to ESD of some of the graphical tools used in education.

Conceptual maps

Concept maps are graphical tools for organizing and representing knowledge, and were first developed in 1972 by Novak and his collaborators at Cornell University (Novak, 1990a; 1997; Moreira, 1997). They are directly related to Ausubel's original constructivist learning theory and have been proven useful in facilitating meaningful learning (Novak, 1990a; 1991; Moreira, 1997).

Concept maps 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. Concept is defined as a perceived regularity in events or objects, or records of events or objects, designated by a label. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement. Sometimes these are called semantic units, or units of meaning. Figure 3.3 shows an example of a concept map that describes the structure of concept maps and illustrates the above characteristics.

The fact that two concepts are linked is important since it shows that, for the person creating the map, there is a relation between these two concepts. What is important is for the map to become an instrument that clearly shows the meanings attributed to the various concepts and how these concepts relate to each other within the context of a given body of knowledge. Concepts, and the words linking them, create an assertion that projects the meaning of the conceptual connection (Ojeda et al., 2007).

The importance of the concept map role in Science Teaching has been demonstrated since the publication, in 1990, of a special edition of the Journal of Research in Science Teaching about this subject that includes an article by Al-Kunifed & Wandersee (1990) citing around one hundred references related to the use of the maps. Since then, considerable research has validated the usefulness of concept maps in meaningful learning.

Concept mapping is a technique that exposes the concepts and assertions hidden within the cognitive structure of each student and it is of great importance since it shows the changes occurring in this cognitive structure, clarifies misconceptions and superficial interpretation in the teaching/learning process, and allows the teacher and student to exchange points of view on the validity or absence of a link between two concepts. In addition, the process of creating concept maps may also contribute to the development of a cooperation between the student and teacher in the sharing of meaning, where "making and remaking concept maps, and sharing it with others may be considered a team effort in the sport of thinking" (Novak, 1990a).

Cognitive maps are also a useful tool for representing changes in knowledge structure of learners over time, and they allow students to visualise the way in which they organize their knowledge (Novak, 1990).

The use of Cmaps in ESD has been applied by some authors, among them it is important the work developed by Åhlberg (2004) at the University of Helsinki and Lourdel (2004b) at the Université Jean Monnet de Saint-Etienne.

Using cognitive maps as pedagogical tool is pertinent to the process of metacognition because it allows students and teachers to check the outcomes of their learning activities. By allowing students to compare the differences between earlier and later cognitive maps, they can evaluate the evolution of their ideas, knowledge, values and motivations with respect to SD. To see their progress from different perspectives could allow learners the opportunity to more thoroughly examine the vast and dynamic subject of SD. (Adapted from Lourdel et al., 2005).

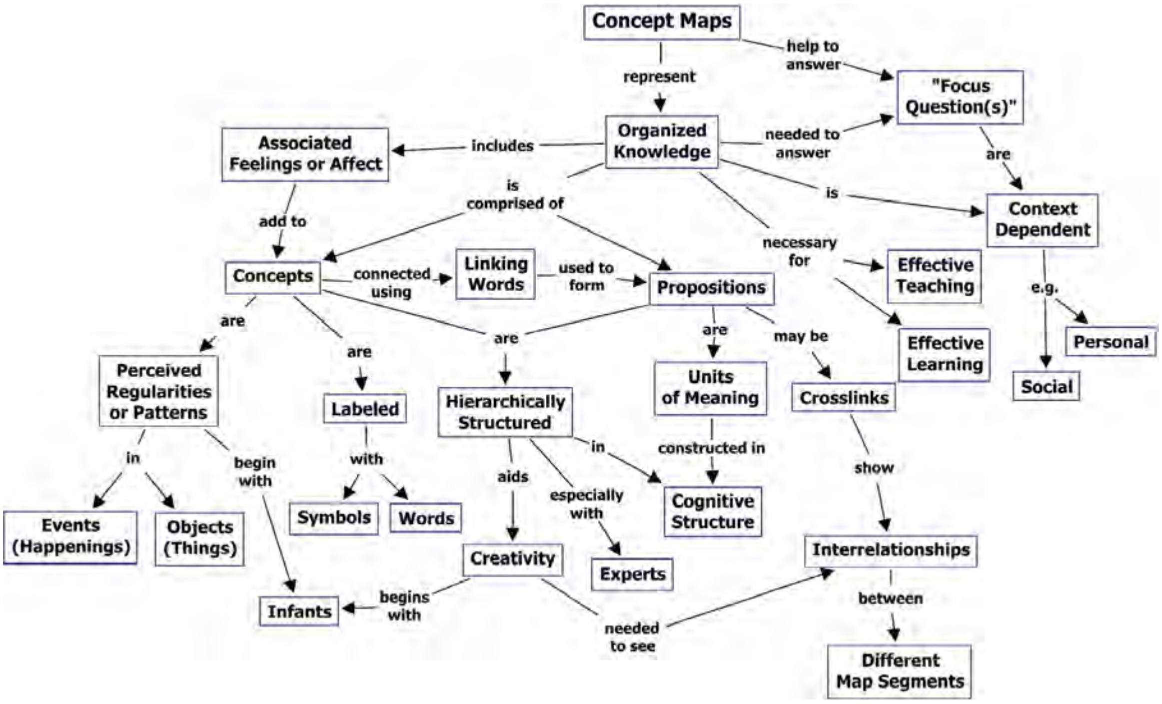

Figure 3.3 Concept map showing the key features of concept maps (Novak & Cañadas, 2008).

Photolangage

Photolangage was originally created to help adolescents to express themselves and communicate with others; however, very quickly, it proved itself to be a very resourceful tool in adult education. Photolangage is a brand name under this name, its creators, Baptiste and Belisle (1991), propose a method to facilitate group work as well as thematic photo-documents which can be used to support various types of communication and educational activities.

Since its creation, Photolangage can be defined by two distinct criteria:

1. Photolangage is a collection of thematic photo-documents implying a specific approach of photography which can be used for groupwork
2. Photolangage focuses at the same time on work within a group, on the recognition, by the participant, of his personal concepts and in oral participation

The technique of Photolangage® has been applied to sustainable development training as follows. Photographs are selected representing a range of subjects, such as oil pollution, malnutrition in Africa, wind turbines, the relationship between humans and the natural world or wild landscapes. The photographs are selected because of their strong power of suggestion, their capacity to represent concepts broader that the simple content of the picture, their aesthetic quality and their symbolic value, thus allowing the viewer to consider the reality that they represent. Looking at one of these photographs, the viewer is encouraged to consider their own world view and by discussing this as part of a group, perspectives are widened and a more critical analysis is encouraged.

For sustainable development training, a three hour session is required. Each participant selects a photograph that they feel is linked to sustainable development and explains their choice. They then describe and comment on the picture to the group as a whole; this is followed by comments from the rest of the group and hence a varied discussion. All the information is synthesised, thus forming the basis for a debate to address all the topics raised.

There are a number of objectives:

- Increasing participants’ awareness of the issues associated with sustainable development
- Broadening participants understanding of sustainable development
- Allowing participants to review their own ideas as a result of hearing others’ opinions
- Demonstrating diversity – showing that interpretation and perspective varies

- Valuing listening and open-mindedness

Knowledge can be viewed as a social construct and that is precisely the approach in this type of activity. By then engaging in a discussion, all participants horizons are likely to be expanded, and more global issues addressed. This process of negotiation allows questioning of perspectives without any implication of right and wrong. Learners can thus gradually modify their outlook as they assimilate input form other learners.

By incorporating both visual and emotional aspects into the activity, as well as verbal communication, social interaction and the application of previous knowledge, a range of intelligences are addressed, thus encouraging all learners to engage fully with the process. It is acknowledged that, just as learners all have different perspectives, opinions and a different knowledge base; they also express their intelligence in different ways. Some learners may have poor interpersonal skills, and this type of activity can thus be a challenge, but by making it inclusive and by valuing the ideas of all participants it should be possible for everyone to participate and, in addition, to develop both listening and verbal communication skills. (Lourdel et al., 2006)

3.5 Selection criteria of didactic strategies and techniques

Given the extended range of strategies and didactic techniques, it is necessary to describe some criteria when selecting them.

First of all considering the different learning approaches from students (see table 3.2) it is a must to assure that all ways of learning are addressed in order to reach all the students of the group. In that sense, Richard Felder (Felder et al., 1988; 2000) suggests that whatever the pedagogical technique is used, teachers should:

- Motivate learning. As much as possible, relate the material being presented to what has come before and what is still to come in the same course, to material in other courses, and particularly to the students' personal experience (inductive/global).
- Provide a balance of concrete information (facts, data, real or hypothetical experiments and their results) (sensing) and abstract concepts (principles, theories, mathematical models) (intuitive).
- Balance material that emphasizes practical problem-solving methods (sensing/active) with material that emphasizes fundamental understanding (intuitive/reflective).
- Provide explicit illustrations of intuitive patterns (logical inference, pattern recognition, generalization) and sensing patterns (observation of surroundings, empirical experimentation, attention to detail), and encourage all students to exercise both patterns (sensing/intuitive). Do not expect either group to be able to exercise the other group's processes immediately.
- Follow the scientific method in presenting theoretical material. Provide concrete examples of the phenomena the theory describes or predicts (sensing/ inductive); then develop the theory or formulate the mod (intuitive/inductive/ sequential); show how the theory can be validated and deduce its consequences (deductive/sequential); and present applications (sensing/deductive/sequential).
- Use pictures, schematics, graphs, and simple sketches liberally before, during, and after the presentation of verbal material (sensing/visual). Show films (sensing/visual.) Provide demonstrations (sensing/visual), hands-on, if possible (active).
- Use computer-assisted instruction—sensors respond very well to it (sensing/active).
- Do not fill every minute of class time lecturing and writing on the board. Provide intervals—however brief—for students to think about what they have been told (reflective).
- Provide opportunities for students to do something active besides transcribing notes. Small-group brainstorming activities that take no more than five minutes are extremely effective for this purpose (active).
- Assign some drill exercises to provide practice in the basic methods being taught (sensing/active/sequential) but do not overdo them (intuitive/reflective/ global). Also provide some open-ended problems and exercises that call for analysis and synthesis (intuitive/reflective/global).

- Give students the option of cooperating on homework assignments to the greatest possible extent (active). Active learners generally learn best when they interact with others; if they are denied the opportunity to do so they are being deprived of their most effective learning tool.
- Applaud creative solutions, even incorrect ones (intuitive/global).
- Talk to students about learning styles, both in advising and in classes. Students are reassured to find their academic difficulties may not all be due to personal inadequacies. Explaining to struggling sensors or active or global learners how they learn most efficiently may be an important step in helping them reshape their learning experiences so that they can be successful (all types).
- Formulate and publish clear instructional objectives.
- Establish relevance of course material and teach inductively.
- Balance concrete and Abstract information in every course.
- Promote active learning in the classroom.
- Use cooperative learning.
- Give challenging but fair test.
- Convey a sense of concern about the students' learning.

Some authors (Martín, 1998; Zabalza, 1991) propose among other the following criteria to take into account:

- Validity. It refers to the congruence with respect to the goals, to the relation between activity and wished behaviour. An activity is valid in so far as it makes possible a change of behaviour or personal improvement of the student in the direction of a learning goal.
- Comprehensibility. It refers to the fact that the activity works all learning goals out in all their amplitude. It is necessary to supply the students of the types of experiences and development areas that are aimed to promote.
- Variety. It is necessary because there are several types of learning.
- Adequacy. It refers to the adaptation of the several phases of development and levels of maturity of the student. For example, the teacher has to have the following conditions minimally identified: number of students, the courses that these have made before, semester in which the course is placed, relation of the course with the other ones that are carried out simultaneously, etc. This may be difficult taking into account that higher education increases choices for students.
- Significance or signification. It is related with the possibility of transferability and utility for the actual and future life.
- Clarity in the intention. The goal has to be clearly defined when deciding to include some type of strategy or didactic technique in a course.
- Knowing and dominating the procedures. When selecting a technique a full knowledge of the procedures that have to be followed to carry out the activities is needed.
- Suitable insertion of the strategy in the planning. Identifying the moments along the course in which it is wished to work certain contents, and selecting the strategy or technique that will be used from the designing of the course.

It is also important to highlight that the average retention of learning varies from one pedagogical methodology to another, been the most effective the active learning ones (see figure 3.4).

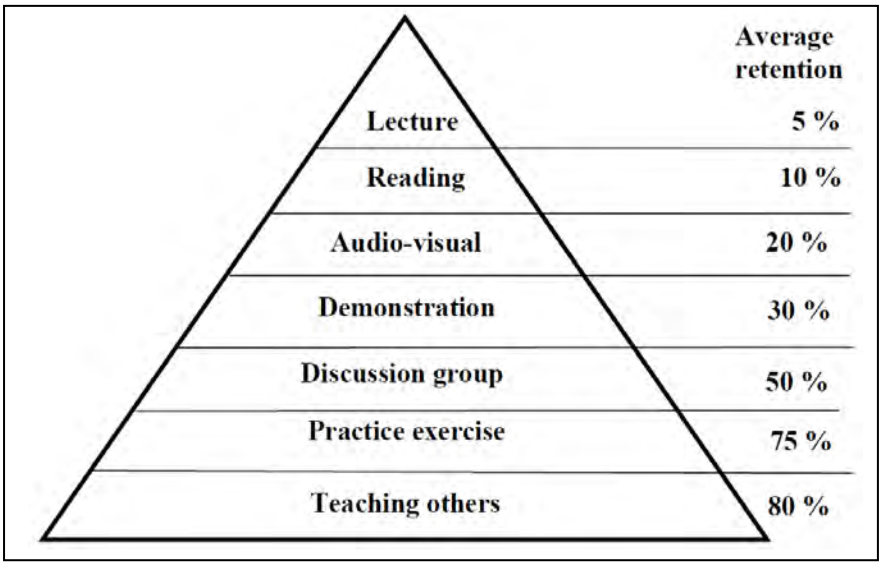

Figure 3.4 Bales pyramid of learning average retention (Bales, 1996)

In relation to ESD most authors do not opt for one specific learning technique, but for using a wide range of pedagogical tools and strategies, as Fien (2006) highlights: "*Important aspects of pedagogy in Education for Sustainable Development include encouraging students to explore questions, issues and problems of sustainability, especially in contexts relevant to them and their communities; this involves student-centred and interactive enquiry-based approaches to teaching and learning. Such approaches do not preclude the use of more teacher-centred methods such as explanation, narration and demonstration where appropriate. However, they do emphasise using the environment and community as a resource for learning and student-centred activities such as debating controversial issues, role play, simulation games, values clarification and analysis, as well as a range of creative and experiential activities*".

Learning must prepare individuals for functioning in professional and societal settings in which they will be confronted with complex problems and will have to work together with experts from different disciplinary domains and societal stakeholders. Most probably acquiring knowledge will remain an important objective, but the ability to actively apply knowledge within a practical context becomes more and more important as well. For the design of learning environments this means more emphasis on an active, individualised learning process in a rich, contextualized and open learning environment. In comparison with traditional education, mainly focussed on the acquisition of knowledge, competences oriented education gives much more attention to role-playing, tasks and problem solving (Van Dam-Mieras, 2005).

Julie Klein suggests that there are innovative approaches that promote dialogue and community, higher-order critical thinking and problem-solving, and proposes some strategies to facilitate integrative teaching and learning (Klein, 2006):

- Team-teaching and team planning.
- Collaborative learning and learning communities.
- Clustered and linked courses.
- Core seminars at introductory and capstone levels.
- Theme or problem focus in courses.
- Proactive attention to integration and synthesis.
- Models of interdisciplinary and integrative process.
- Theories and methods from interdisciplinary fields.
- Projects and case studies.
- Dyads, triads, and small groups for discussion.
- Game and role playing.
- Inquiry- and discovery-based learning.

- Learning portfolios.
- Experiential- and service-learning, internships, and fieldwork.
- Residential living-learning experiences.

In addition Dawe (2005) points out that respecting a variety of different approaches towards ESD may be the best way forward, and may lead to emancipation for tutors, rather than inhibition under yet another —as it might be perceived— set of rules or regulations. Rather than be too formulaic or 'legislative' about approaches to be adopted, respecting often divergent, even 'imperfect' approaches, and exploring their apparent contradictions, will encourage tutors to find their own space in which to express ESD. Indeed, this very diversity of approaches can be said to be at the philosophical heart of sustainability.

Azapagic (2005) proposes the three-tier approach to teaching sustainability. This approach was developed at the University of Surrey.

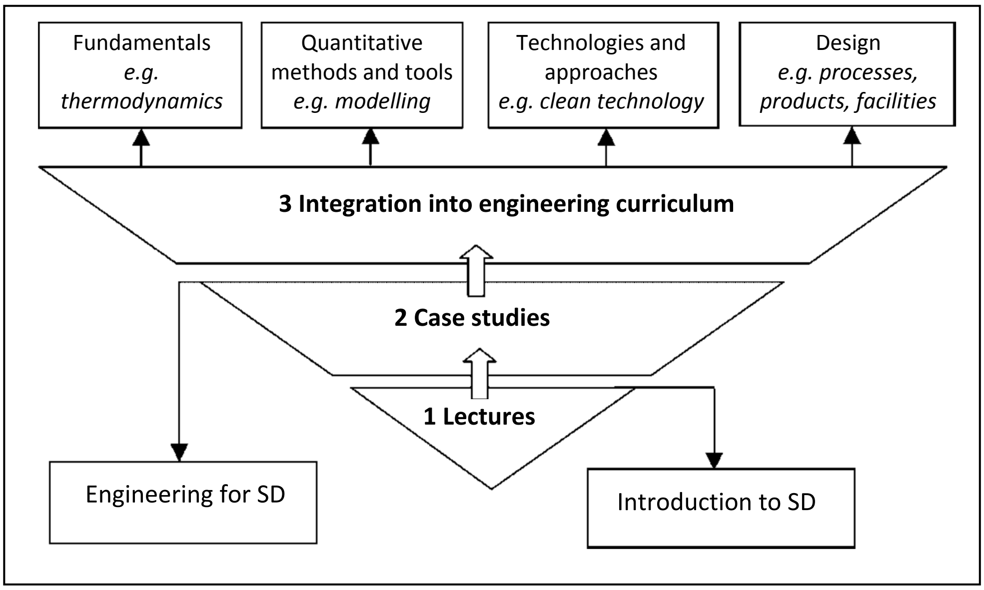

Figure 3.5 The "three-tier" approach to teaching Sustainability. (Azapagic et al., 2005)

As illustrated in figure 3.5, the "three-tier" approach comprises the following elements:

(1) dedicated lectures and tutorials on sustainable development;

(2) specific case studies;

(3) integration of sustainability into the overall curriculum.

The first tier introduces students to sustainability concepts as one of the key learning areas through a series of lectures and tutorials. In the second tier, students are exposed to specific, practical case studies, to enable them to apply the sustainability concepts and identify sustainable solutions. Taking a life cycle approach to address economic, environmental and social issues, a series of practical case studies have been developed from a range of industrial sectors including water, energy, waste, chemicals, glass and mining and minerals (Azapagic et al., 2004; Perdan and Azapagic, 2003). The third and final tier is integration of sustainability thinking into the overall curriculum, from the fundamentals (e.g. thermodynamics) through quantitative methods and tools (e.g. mathematical modelling) to the design projects (e.g. processing plants, facilities and products). This is probably the most challenging task, which is best facilitated through further, more complex case studies and multidisciplinary design projects. Furthermore, students could learn how to integrate different sustainability criteria into the conventional design approaches by using, for example, life cycle thinking, industrial ecology approaches and appropriate ethical principles.

Such an integrated approach enables a systematic introduction of sustainability criteria into the curriculum, starting with a lower level of complexity and progressing towards more complex considerations at the higher levels of study. It promotes learning outcomes that enable graduates to establish a clear connection between engineering and sustainable development and helps them in practising sustainable engineering (Azapagic et al., 2005).

From the literature analysis table 3.9 describes the general characteristics of pedagogical strategies and techniques and how they can contribute to ESD.

Strategy	Description	Contribution to ESD
Lecturing	Lecturing consists of the presentation of a subject in a structured way, where the main resource is the oral language, even though it can also be a written text.	Regarding ESD, lecturing is a good method to introduce students to sustainability concepts (Azapagic et al., 2005).
PBL	PBL can be described like a set of experiences of learning that involve students in complex projects and of the real world through which they develop and apply skills and knowledge [10].	PBL, especially PBL that is organised as interdisciplinary projects, could contribute to adapt engineering curricula to enhance mutual understanding of science and technology with social sciences (Mulder, 2006).
Case study	Case study consists in providing a series of cases that represent diverse problematic situations of the real life so that they can be studied and analyzed.	Case studies are usually of a qualitative and descriptive nature and can be used to explore specific issues such as different stakeholder perspectives, examples of actual practice, and demonstrations of where progress towards sustainability is, and can, be made in the real world (Fenner et al., 2004).
Problem based learning	In the problem based learning a small group of students meets, with the support of a tutor, to analyze and to solve a problem designed to attain certain goals of learning.	Problem solving prepares students to be "persons". The characteristics of problem based learning provide a unique opportunity for students to learn about themselves. As a part o the problem-solving process students must consider their own educational goal, which is likely to require introspection about students' values, ethics and beliefs (knowlton, 2003; Sterling, 2004b, Huntzinger et al., 2007; McKay and Raffo, 2007).
Backcasting	Backcasting is the creation of a future vision, bearing in mind what is necessary to achieve in the future and then working towards that goal from this day forward.	Due to its normative and problem-solving character, backcasting approaches are much better suited (in reference to forecasting) to address long-term problems and sustainability solutions (Quist, 2007).
Role play	Role play can be defined as a learning process in which participants act the roles of other individuals in order to develop particular skills and to meet particular learning objectives.	The role play is an approach which combines at the same time complexity, the setting in situation, work in group, autonomy and action of the student is particularly relevant for ESD (Lourdel, 2004b; McLaughlan, 2007; Maier et al., 2007; Dieleman and Huisingh, 2006).

Table 3.10 Contribution to ESD from different pedagogical strategies

3.6 Conclusions

This chapter showed the characteristics of some pedagogical strategies and their role in ESD.

The literature review in this chapter showed that learning is an important condition but not a guarantee for change. Thus, learning about SD does not guarantee realisation of actions and activities supporting changes necessary for Sustainability (Quist, 2006). Sustainability learning for change needs a deep knowledge of the basics of sustainability, but furthermore it has to capacitate students with the appropriate competences in relation to their future profession.

Studies on learning reveal that students learn in different ways; therefore a multi-pedagogical active methodology approach is needed in order to reach all of them. The literature supporting the notion that active, student-centred learning is superior to passive, teacher-centred instruction is encyclopaedic.

Several theories substantiate that sustainability needs systemic thinking; a lot of pictures are still in a mechanistic mode, understanding divided in boxes, etc. To create a pedagogical approach that optimizes the understanding of flows of relationships between concepts of all kind is needed. Sustainability is a clear multidisciplinary "potpourri" (Environmental, social, economic, values, future, culture, diversity, etc…) and thus, transdisciplinary teaching/learning processes are necessary. Moreover, these must be active and cooperative learning processes under the constructivism paradigm (Alvarez, 2000), not forgetting that the process of teaching is as important as the contents "the teacher role".

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[1] Even some indicators of environmental Sustainability as Ecological footprint show a direct correlation between the most "educated" countries and their ecological impact.

[2] Some authors used the term Education for Sustainability, Learning for Sustainability or Learning for Sustainable development. In this work I used the expression education for sustainable development (ESD) as it is more widely used.

[3] DESD (Decade of Education for Sustainable Development). [Online]. Available at: <http://portal.unesco.org/education/en/ev.php-URL_ID=38477&URL_DO=DO_TOPIC&URL_SECTION=201.html>.

[4] Some authors (De Graaff and Kolmos, 2007) use the acronym PBL also for Problem Based Learning. In this work PBL accounts for Project Based Learning.

[5] The Buck Institute for Education (BIE) is a non profit research and development organization working to make schools and classrooms more effective through the use of problem and project based learning. <http://www.bie.org/index.php/site/>

4 Engineering Curriculum and Education for Sustainable Development

This chapter analyses the curriculum change needed at universities in order to facilitate the integration of SD in the engineering curriculum. A SWOT analysis is presented with Drivers and Barriers identified in the literature. Finally the most common approaches to achieving the embedding of sustainability in technological universities are introduced.

4.1 Introduction

Chapter 3 highlighted the need to change from a Mechanistic/Traditional view of education to an Ecological/Alternative one. Nevertheless Higher Engineering Education is a field with strong traditions. Therefore the transition from Mechanistic/Traditional approaches to innovative curricula based on active/cooperative learning represents a major challenge (adapted from De Graaff and Kolmos, 2007). Moreover there are also other barriers and drivers when trying to embed a sustainability culture in higher education institutions. The following section analyses the challenges that universities face when changing to ESD.

4.2 Curriculum Change for SD in HEI

In December 2005 the author of this thesis and the two supervisors participated in a UNESCO workshop held in Gothenburg on "Drivers and barriers for implementing SD in Higher Education" (Holmberg & Samuelson, 2006). From this workshop some relevant outcomes in relation to the HE curriculum were:

- "*Sustainable development brings many challenges to universities. Universities, with their core values of scepticism, curiosity and freedom of speech, have a profound role to play in developing students' qualities to cope with uncertainty, poorly defined situations, diverging norms, values, interests and reality constructions. Wals & Blaze Corcoran (2006) further state that sustainability is about systemic change within our institutions that allow for transformative learning to take place. This means looking at sustainability issues from a range of disciplinary angles, cultural perspectives (see Lotz-Sisitka & Lupele, 2006), different time perspectives and a range of spatial perspectives. Universities cannot in an instrumental fashion teach now for sustainable development in the future (Scott & Gough, 2006). Lundholm (2006) shows that dealing with attitudes and values (which are largely hidden) are as important a challenge for university as achieving knowledge and understanding.*
- *It must be hard to find something more multi- and transdisciplinary than sustainable development. It is also quite clear that the traditional discipline-based structuring of knowledge and research are here to stay. This combination constitutes a major challenge for universities when implementing learning for sustainable development in higher education (Van Dam-Mieras, 2006; Van Dam-Mieras & Jansen, 2006; Mulder & Jansen, 2006).*
- *Separate courses and programs and an integrated perspective throughout the whole curriculum are needed for SD. A separate course is needed to give the basic understanding of the challenges associated with sustainable development; to deliver tools and conceptual models for dealing with*

dynamic and complex systems; and to attain a feeling of how things are interconnected. The separated basic courses on sustainable development delivered at universities today often have an environmental focus. This needs to be balanced with more integration of social and economic aspects of sustainability. There is also a need for education for professional sustainability management competences outside university (Rydén 2006)."

Ferrer-Balas et al. (2008) recently carried out a comparative analysis of ESD in seven technological universities. In their study they identified a set of barriers and drivers to change towards ESD in universities.

Drivers:

- Visionary Leadership in institutions where, to be effective, leaders must have appropriate assignments and responsibilities.
- Sustainability Innovators (Lozano, 2006) at their universities can be important agents for change.
- Existing internal networks of people such as interdisciplinary research groups that reach across the university to include a critical mass of campus actors.
- Small size may also act as a driver. Large universities of more than 10,000 – 12,000 students often find that the complexity of the organization reduces the possibility of rapid transformation.
- The existence of a coordination unit or project for the sustainability transformation may also be important, as it keeps the process of change alive and helps distribute responsibility for the different activities.
- There is an increase of active learning pedagogy being used in HEI, which should facilitate the introduction of Sustainability competences in the curriculum
- Benchmarking from peer institutions or top-tier universities can serve as examples to promote change.
- Sources of funding and employment availability. Corporations or government bodies willing to pay for sustainability-focused research may drive a university-wide transformation, as may employers who demand university graduates with particular strengths in sustainability.
- Pressure from accreditation bodies. For example ABET (2007) in the USA, the Engineering Council in the UK (2005a; 2005b), the Institution of Engineers of Ireland (2007), the Canadian Council of Professional Engineers (2008) and the Engineering Council of South Africa (2004).
- The adaption to the European Higher European Area (EHEA) framework. In Europe all universities are changing their curriculum degree to fulfil the EHEA requirements, which in many cases redefines the curriculum structure. This curriculum change should be an opportunity to introduce SD in education.
- The existence of networks of universities on ESD, both at a national level such as for example the DHO (Dutch network of HEI on SD) and the EDUSOST (Catalan network for research on education for SD in HEI), and at an international level like for example the GHESP (Global Higher Education for Sustainability Partnership), the USLF (University Leaders for Sustainable Future), the AGS (Alliance for Global Sustainability), IR3S (Integrated Research System for Sustainability Science), and the AASHE (Association for the Advancement of Sustainability in Higher Education).

Barriers:

- The freedom of individual faculty members. Most universities are bottom-up institutions where individual faculty members make decisions on how best to achieve research and education goals. As such, it is difficult for an administrator to propose changes and achieve consensus among groups of faculty at any level. Nevertheless this freedom could also be seen as a driver for motivated faculty.
- The incentive structure of universities (salaries, promotions, and granting of tenure) that does not recognize faculty contributions to sustainable development. (Lidgren et al., 2006)
- Lack of desire to change. Building quality of educational and research facilities requires a great amount of time and investment, and once established, these activities may stay the same for years as long as the university is attracting good students, and faculty members are conducting successful research. In such institutions, it may be especially difficult to gain support for a major transformation.

- Pressure from society. Unless society demands major changes in the desired characteristics of graduates and research, a university may find little reason to make transformations and may continue with the status quo.
- There is a great lack of a comprehensive SD perspective and interdisciplinary skills among university staff.

This set of drivers and barriers is clustered and summarised in a Strengths, Weaknesses, Opportunities, and Threats (SWOT) frame. See figure 4.1.

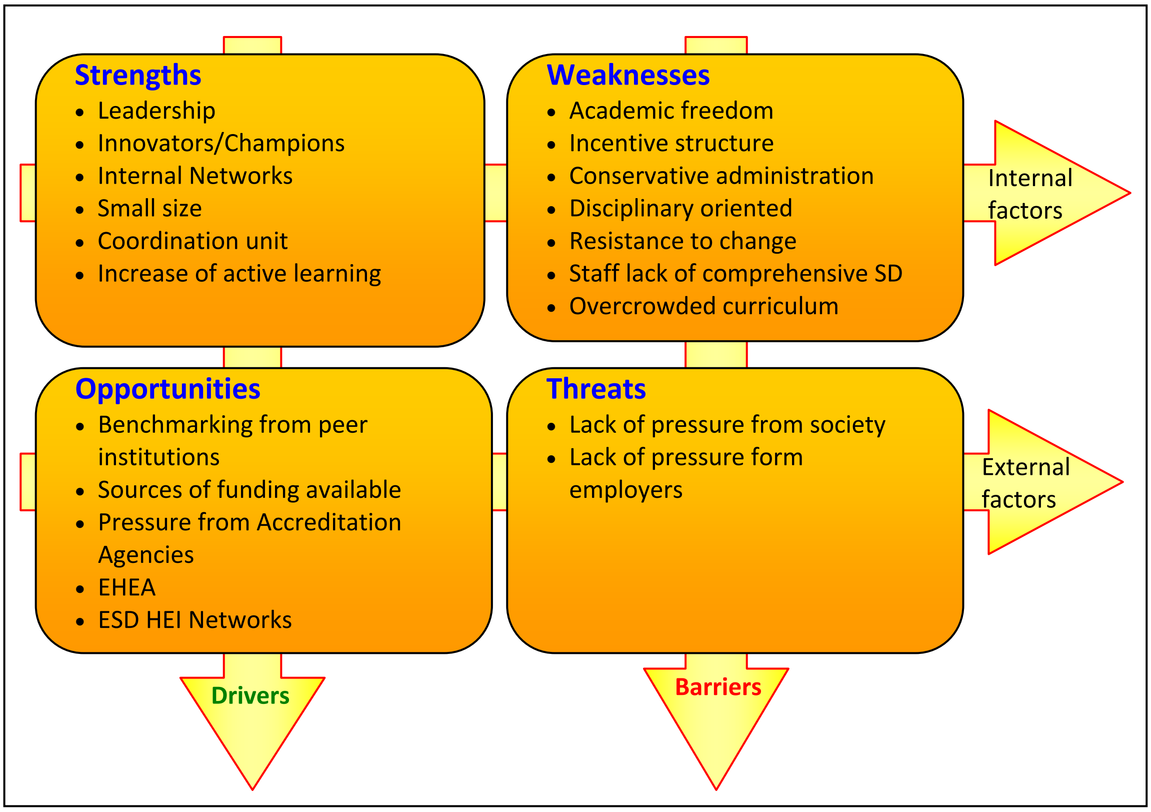

Figure 4.1 SWOT analysis of Curriculum change for EESD

4.3 Strategies to embed SD in Engineering Curriculum

Despite the barriers to introducing ESD in HEI, there are some successful approaches in the literature. These approaches include different strategies:

- In most cases Technological universities offer a specific course on Sustainability or Sustainable Technology in the 1st cycle (Bachelor's) and/or 2nd cycle (Masters) students. Examples of these courses can be found at UPC (Segalàs et al., 2004b; Segalàs et al., 2008), Chalmers University of Technology (Svanström, 2008), Eindhoven University of Technology (Kirkels et al., 2002), University of Surrey (Perdan et al., 2000), Delft University of Technology (Peet and Mulder, 2004; Mulder, 2006); Carnegie Mellon University (Davidson et al., 2007), Ball State University (Vann et al., 2006), Monterrey Institute of Technology (Lozano et al., 2006). These specific courses are offered as either compulsory or elective.
- Some universities offer a Minor/Track speciality: To get the minor, students usually should take some elective courses which relate sustainability to their engineering speciality and focus their final thesis on a sustainability topic (these minors are offered both at 1st and 2nd cycle). Examples of this minor can be found at UPC (Segalàs et al., 2004), EUT (Kirkels et al., 2002), DUT (Mulder, 2006), etc.
- Masters degrees devoted to sustainability or Sustainable Technologies. At European level, a joint venture among the Royal Institute of Technology (KTH), Technical University of Catalonia and Delft University of Technology (DUT) under the Erasmus Mundus Action IV framework was created. In this

SDPROMO1 project an online database2 is developed where all Sustainability and engineering related Masters programmes that are offered in Europe can be found.

- Embedding of Sustainability contents in the entire curriculum (CSF, 2008). There have been many approaches in many universities. Some examples took place at Delft University of Technology, (Boks & Diehl, 2006,), Lund University (Lidgren et al., 2006), Chalmers University of Technology (CUT) (Svanström et al., 2008), UPC (Esteban et al., 2008), Cambridge University (Fenner et al., 2004), Rowan University (Jahan & Mehta, 2007), etc.

In order to achieve the embedding of SD many approaches have been carried out with more or less success:

- Training lecturers (Bras-Klapwijk et al., 1999), although this approach has shown not to be very effective in some cases (Peet et al., 2004). The main reason is the incentive structure in universities which prioritises research over education so lecturers have little time to be trained in SD. Moreover teachers usually do not like to be taught. Typically the lecturers who attend these training courses are the ones that are interested in SD. Therefore most of the faculty is not influenced by organising training courses for them.
- Design and implementation of Curriculum Greening plans for Schools and Departments at UPC (Segalàs, 2004a).
- Facilitate learning tools and sources of information on ESD (Segalàs et al., 2002).
- The individual interaction method (Peet et al., 2004) builds on the idea that lecturers must be approached as sources of knowledge rather than as subjects of teaching efforts. This method has proven to be quite successful in finding links between a scientific discipline and SD and achieving integration of SD in the curriculum at CUT, DUT and UPC (Holmberg et al., 2008).

4.4 Conclusions

Embedding sustainability within the curriculum does not only mean including new contents (Holmberg et al., 2008). If engineers are to contribute truly to SD, sustainability must become part of their paradigm and affect everyday thinking. This, on the other hand, can only be achieved if SD becomes an integral part of engineering education programmes, not a mere ‘add-on’ to the ‘core’ parts of the curriculum (Sterling 2001).

There are many drivers and barriers identified (see figure 4.1) when trying to embed sustainability within the curriculum, and many attempts have been carried out at technological universities in order to achieve this goal. There are mainly four strategies applied: First a compulsory course for all graduates at 1st Cycle (Bachelor) level. Second, a minor or track on SD in both 1st Cycle and 2nd Cycle studies. Assuring the introduction of SD in the final thesis project of graduation and finally, and most challenging, intertwining sustainability in all the subjects/courses of the curriculum.

Up to the present embedding SD in the entire curriculum has shown to be the most difficult strategy to be achieved. The approaches applied so far (facilitate learning tools, develop learning materials, training lecturers, etc.) have shown to be necessary but not enough. Nevertheless, the individual interaction, a new avenue applied at DUT seems to open new horizons in order to increase the embedding of SD in the whole curriculum

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[1] <http://www.sdpromo.info/web/page.aspx>

[2] <http://www.sdpromo.info/web/page.aspx?pageid=41399>

5 Research methodologies and case studies definition

This chapter describes the research framework of the educational research methodologies applied in the thesis. Firstly both quantitative and qualitative education research designs are analysed. Then mixed research is introduced and the mixed strategies studied. Next conceptual maps, Horvath topography and semi-structured interviews as research assessment tools are introduced. Finally, the case studies of both quantitative and qualitative assessment tools are presented.

5.1 Educational research

Research on education as a discipline appeared at the end of the XIX century when experimental methodology was adopted in pedagogy. Educational research can be described as the application of concepts as scientific knowledge, science, scientific method and scientific research to the education field (Albert, 2007). It can be defined as "a systematic and sustained inquiry, planned and self-criticism, which is subject to public criticism and the empirical findings where these are appropriate" (Stenhouse, 1984). Elliot (1978) defines it as "a diagnostic reflexion about the actual practice".

Educational research's most relevant characteristics can be described as (adapted from Latorre et al., 1996; Albert, 2007):

- *The educative reality itself*. The educative reality consists of dynamic and interactive phenomenon, with some of them as complex as beliefs, morals, values, and ethics which make educational reality distinct from the natural-physical one. This makes solving problems difficult due to their qualitative character, introducing therefore a risk of subjectivity and vagueness in the results.
- *The greatest epistemological difficulty of educational phenomena*. This difficulty is evident for three reasons:
    - the fact that the phenomenon of education in most cases can not be repeated,
    - the difficulty acheiving the same precision and accuracy as in the natural sciences
    - and, finally, the difficulty of control of all the variables involved in the educational phenomenon.
- *The pluri-paradigmatic character*. Educational research is guided by different perspectives and methods that are difficult to reconcile giving it a multifaceted character.
- The peculiar relationship between researcher and researched object. In educational research, the researcher is part of the social phenomenon that is investigated, their beliefs, values, ideas, and so on. He/she is not fully independent or neutral about the phenomena studied.
- *The pluri-methodological character*. The phenomena of education requires the use of different methodologies, both experimental and non-experimental with the aim of studying the educational reality from a comprehensive and holistic position.
- *Difficulty of achieving the goals of science*. One of the aims of science is the establishment of regularities and generalization. In education, this generalization is difficult because these phenomena

have a great variability both in space and in time, that variability makes it difficult to generalize. These circumstances force the researcher to take positions more carefully than in other sciences.

Quantitative qualitative and mixed methodologies can be applied in educational research. The following paragraphs highlight their characteristics, constraints and capabilities.

5.1.1 Quantitative research methodology in Education

Quantitative research methods were originally developed in the natural sciences to study natural phenomena. The quantitative approach is based on logical positivism, on measurement control, objectivism, regardless of the data, aimed at checking, reductionist, inferential, hypothetical-deductive, result-oriented, reliable, repeatable, standardisable and atomistic. It includes the true experiments and the less rigorous experiments called quasi-experiments and correlational studies (Campbell & Stanley, 1963), and specific single-subject experiments (Cooper et al., 1987). Quantitative research uses the correlation and analysis of data in order to answer research questions and hypothesis testing. It relies on numeric measuring and frequently in the use of statistics establishing patterns of behaviour in a population.

Education research from the quantitative perspective aims at the study of relations and regularities in order to discover the universal laws which explain and govern the educative reality. The quantitative methodology refers to the group of methods whose justification's logic is supported by objectivity principles, emphasizing the empiric evidence and the quantification. Nevertheless many authors (Latorre et al., 1996; Albert, 2007) consider the quantitative methodology insufficient to explain the complexity of educational reality.

The general process of quantitative research methodology can be described using the scheme in Figure 5.1. Adapted from Albert (2007).

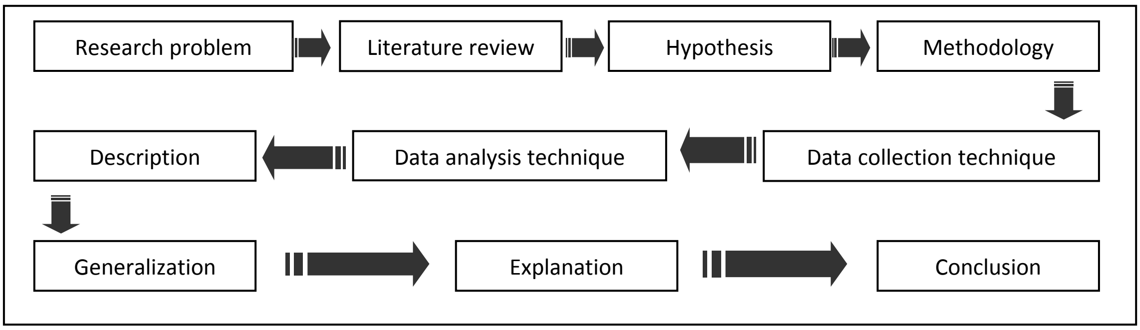

Figure 5.1 Process of quantitative research methodology

When applying quantitative research there are basically three methodologies available: Experimental, quasi-experimental and non experimental methods.

The **experimental** method needs a manipulation of one or more independent variables, to measure the effect of the independent variable to the dependent one, and the sample should be chosen randomly. Many experimental designs developed have been developed (Hernández et al., 2004):

- Design with post-test and control group.
- Design with pre-test, post test and control group.
- Solomon design of four groups.
- Design of multiple chronological series.
- Design of chronological series with stimulus repeated.
- Design with multiple treatment, one or more groups.
- Factorial Design.

A **quasi-experimental** design is one that looks rather like an experimental design but lacks the key ingredient: random assignment (Trochim & Donnelly, 2007). In quasi-experimental designs the groups have already been formed before the experiment. This situation is very common in an educational context, where the configuration of the groups can not be altered.

The quasi-experimental design is appropriate when the research takes place in natural educational scenarios and the lack of full experimental control is allowed. This control deficiency can be balanced with the repetition of experiments.

The main advantage of the quasi-experimental design is that it gives a solution to those problems where you can not do a research experiment, because you can not change the nature of the groups. In contrast, it presents the problem of a lack of control and precision. Because of this, many cause-effect relationships measured in variables could occur before the observation of the researcher and therefore fall outside his/her scope. However, comparison of the data groups allows you to draw conclusions about the relative effectiveness of each level of the independent variable.

There are many quasi-experimental designs (Anguera et al., 1998). Here the most commonly used are shown:

- Pretest-posttest design.
- Posttest design.
- Design with a non equivalent control group.
- Design with double pretest.
- Cohort design.
- Exchange treatment design.
- Inverted treatment design.
- Design without control group.
- Design with non equivalent dependent variable.
- Design with known assignation variable.

Due to the nature of the research in this thesis, which is the evaluation of what engineering students learn in SD courses, the type of design used is the quasi-experimental pretest-posttest design. This design (figure 5.2) requires a measurement before the administration of treatment (X) recorded in a single group of individuals (0_1) and one observation after its administration (0_2), since there is only one group of subjects.

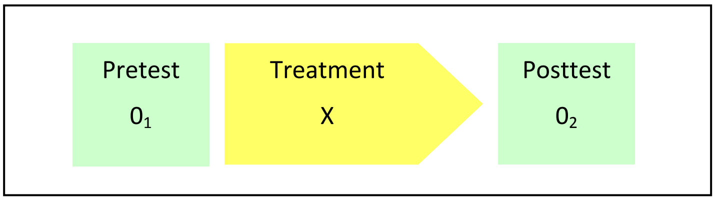

Figure 5.2 Scheme of a quantitative quasi-experimental pretest-posttest design

The foundation of this design is the comparison between the pretest and the posttest. Its main limitation is the lack of a control group without which it is difficult to establish causal arguments about the effect of the treatment (X). The effect of the treatment is the difference between the pretest and post-measures.

Non experimental methods can be described as the empirical and systematic search in which the researcher does not have direct control of the independent variables because their manifestations have already happened or because they are inherently non manipulable (Kerlinger, 2002). In this kind of research the independent variables can not intentionally be changed. The phenomena is observed as they occur in their natural context for later discussion. In the non-experimental research, it is not possible to manipulate variables or randomly assign participants or treatments because the nature of the variables is such that it prohibits their manipulation. The participants are observed with their distinctive features intact.

The non experimental research design can be classified in transversal (when there is only one collection of data) and longitudinal (when there are measurements over time). There are basically four kinds of design:

- Exploratory transversal design.
- Descriptive transversal design.
- Correlative-causal transversal design.
- Tendency longitudinal design.
- Group evolution longitudinal design
- Panel longitudinal design.

5.1.2 Education qualitative research methodology

Qualitative research methods were developed in the social sciences to enable researchers to study social and cultural phenomenon. The qualitative approach is based on phenomenology, in naturalistic observation and control, in subjectivism close to data, based on reality, aimed at making discoveries, explanatory, expansionist, descriptive, inductive, process-oriented, with real and deep data, not standardisable, holistic and with dynamic reality. Usually this method is based on data correlation without numerical measurements, such as descriptions and comments.

The principles of qualitative research are (Guba & Lincoln, 1985; Colas & Buendia, 1992; Anguera et al., 1998):

- Multiple conception of reality. There are many realities that can not be considered homogeneously, so there is diversity in the interpretation of that reality.
- The main scientific objective is to understand the phenomena.
- The investigator and the subject of inquiry are interrelated in such ways that they affect each other.
- It seeks an understanding of the description of individual cases. It intends to find out what is unique and specific to a given context and what is generic in other situations.
- The simultaneity of the phenomena and interactions makes it impossible to distinguish the causes and effects.
- Values are implicit in the observation, as reflected in the preference for a paradigm or choice of a theory.

Qualitative research methodology usually has four main phases (figure 5.3): Preparation, fieldwork, analysis and information. Adapted from Albert (2007).

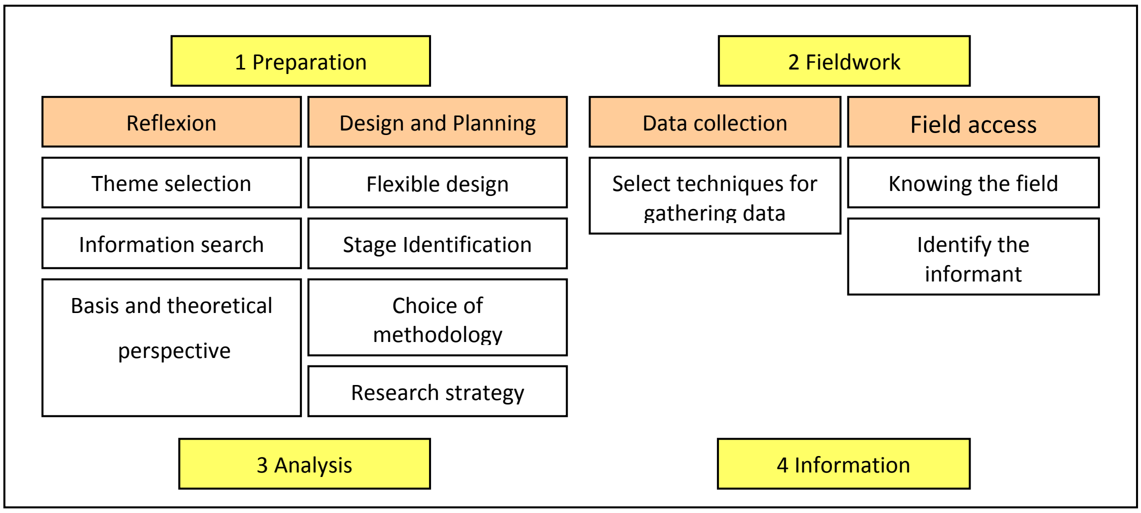

Figure 5.3 Process of qualitative research methodology

Although some social science researchers (Lincoln & Guba, 1985; Schwandt, 1989) perceive qualitative and quantitative approaches as incompatible, others (Patton, 1990; Reichardt & Cook, 1979) believe that the skilled researcher can successfully combine approaches. Different approaches allow us to know and understand different things about the world. Table 5.1 shows the characteristics of Quantitative and Qualitative Modes of Inquiry.

	Quantitative research methodology	Qualitative research methodology
Researcher Role	- Detachment and impartiality - Objective portrayal	- Personal involvement and partiality - Empathic understanding
Approach	- Begins with hypotheses and theories - Manipulation and control - Uses formal instruments - Experimentation - Component analysis - Seeks consensus, the norm - Reduces data to numerical indices - Abstract language in write-up	- Ends with hypotheses and grounded theory - Emergence and portrayal - Researcher as instrument - Naturalistic - Searches for patterns - Seeks pluralism, complexity - Makes minor use of numerical indices - Descriptive write-up
Purpose	- Generalisation - Prediction - Causal explanations	- Contextualization - Interpretation - Understanding actors' perspectives
Assumptions	- Social facts have an objective reality - Primacy of method - Variables can be identified and relationships measured - Ethics (outsider's point of view)	- Reality is socially constructed - Primacy of subject matter - Variables are complex, interwoven, and difficult to measure - Ethics (insider's point of view)

Table 5.1 Comparison of Quantitative and Qualitative research methodologies characteristics. Adapted from Glesne & Peshkin (1992)

5.1.3 Mixed research methodology

Mixed research is the one which involves collecting and analyzing quantitative and qualitative research strategies in a single study. Being aware that all methods have limitation, researchers felt that biases inherent in any single method could neutralise the biases of other methods. Among the different strategies of mixed research there are (Creswell, 2003):

- Sequential procedures, in which the researcher seeks to elaborate on or expand the findings of one method with another method.
- Concurrent procedures, in which the researcher converges quantitative and qualitative data in order to provide a comprehensive analysis of the research problem.
- Transformative procedures, in which the researcher uses a theoretical lens as an overriding perspective within a design that contains both quantitative and qualitative data. This lens provides a framework for topics of interest, methods for collecting data, and outcomes or changes anticipated by the study.

When selecting mixed research methods strategy of inquiry there are four areas to take into account: implementation, priority, integration and theoretical perspective (see table 5.2).

Implementation	- No sequence concurrent - Sequential-Qualitative first - Sequential-Quantitative first
Priority	- Equal - Qualitative - Quantitative
Integration	- At data collection - At data analysis - At data interpretation - With some combination
Theoretical perspective	- Explicit - Implicit

Table 5.2 Decision choices for determining mixed methods strategy of inquiry (Creswell, 2003)

Creswell (2003) identified six major strategies of mixed research; these are (Table 5.3):

- Sequential strategies:
  - *Explanatory*: This is characterised by the collection and analysis of quantitative data followed by the collection and analysis of qualitative data. The priority is typically given to quantitative data, and the two methods are integrated during the interpretation phase of the study.
  - *Exploratory*: This is characterised by the collection and analysis of qualitative data followed by the collection and analysis of quantitative data. The priority is typically given to qualitative data, and the two methods are integrated during the interpretation phase of the study.
  - *Transformative*: This has two data collection phases (quantitative and qualitative), one following the other. Both methods may be used first, and priority can be given to either the quantitative or the qualitative phase, or even both. The results of the two phases are integrated during the interpretation phase. It has a theoretical perspective to guide the study.
- Concurrent strategies:
  - *Triangulation*: This uses separate quantitative and qualitative methods as a means to offset the weaknesses inherent within one method with the strengths of the other method. Quantitative and qualitative data collection is concurrent, happening in one phase of the research study. Ideally, priority would be equal between the two methods, although in practical application the priority may be given to either approach. It usually integrates the results of the two methods during the interpretation phase.
  - *Nested*: The data collection is concurrent, and it has a predominant method that guides the project. Given less priority, the method (quantitative or qualitative) in nested within the predominant method (qualitative or quantitative). This nesting may mean that the embedded method addresses a different question to the dominant method or seeks information from different levels. The data collected from the two methods are mixed during the analysis phase of the project.
  - *Transformative*: This uses a specific theoretical perspective. This perspective is the driving force behind all methodological choices, such as defining the problem, identifying the design and data sources, analysing, interpreting, and reporting results throughout the research process. It can be triangulation or nested.

Strategies		
Sequential	Explanatory	QUAN → qual QUAN Data Collection → QUAN Data Analysis → qual Data Collection → qual Data Analysis → Interpretation of Entire Analysis
	Exploratory	QUAL → quan QUAL Data Collection → QUAL Data Analysis → quan Data Collection → quan Data Analysis → Interpretation of Entire Analysis
	Transformative	QUAL → quan Vision, Advocacy, Ideology, Framework QUAN → qual Vision, Advocacy, Ideology, Framework
Concurrent	Triangulation	QUAN + qual QUAN Data Collection ↓ quan Data Analysis QUAL Data Collection ↓ qual Data Analysis quan Data Analysis ↔ Data results compared ↔ qual Data Analysis
	Nested	Qual / QUAN ↓ Analysis of findings Quan / QUAL ↓ Analysis of findings
	Transformative	QUAN + QUAL Vision, Advocacy, Ideology Framework Quan / QUAL Vision, Advocacy, Ideology Framework

Table 5.3 Strategies of mixed research[1] (Creswell, 2003)

5.2 Research methods used for this thesis

In this study a mixed concurrent nested research strategy is used where the qualitative method is nested within the quantitative one. The two methods used are:

- A quantitative research methodology: Conceptual maps to measure SD learning and Horvath topography of Active learning education to assess the pedagogy.
- A qualitative research methodology: Open ended interviews.

The mixed research strategy has many assets. It provides a study with the advantages of both quantitative and qualitative data, and the researcher can gain perspectives from different types of data or from different levels within the study.

The following sections illustrate the pros and cons of these methodologies and the way they have been applied in this study.

5.3 Research on learning and pedagogy

One of the aims of this study is to evaluate the efficiency of certain pedagogies applied in sustainability courses in terms of SD learning. With that purpose two assessment tools are used: Conceptual maps to measure SD learning and Horvath topography of Active learning education to assess pedagogy.

5.3.1 SD understanding assessment tool: Conceptual maps

In order to evaluate the SD understanding of engineering students there are many possibilities: written assignment, test, written exam, oral exam, interview, questionnaire, conceptual maps, etc. In this study, taking into account that the sample is heterogeneous and large, and the characteristics of conceptual maps for evaluating understanding cognitive learning conceptual maps are considered as the appropriate assessment tool.

Conceptual maps (Cmap) were initially developed as a data analysis tool in 1972. Cmaps are graphical tools for organizing 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. 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 & Helden, 2004).

Concepts can be defined as a perceived regularity in events or objects, or records of events or objects, designated by a label (Novak & Cañas, 2008). The label for most concepts is a word, although sometimes more than one word is used.

Links between two concepts are words or phrases which specify the relationship between them.

Propositions are statements about an object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected by using linking words or phrases to form a meaningful statement. Sometimes these are called semantic units, or units of meaning. Figure 5.4 shows an example of a concept map that describes the structure of concept maps and illustrates the above characteristics.

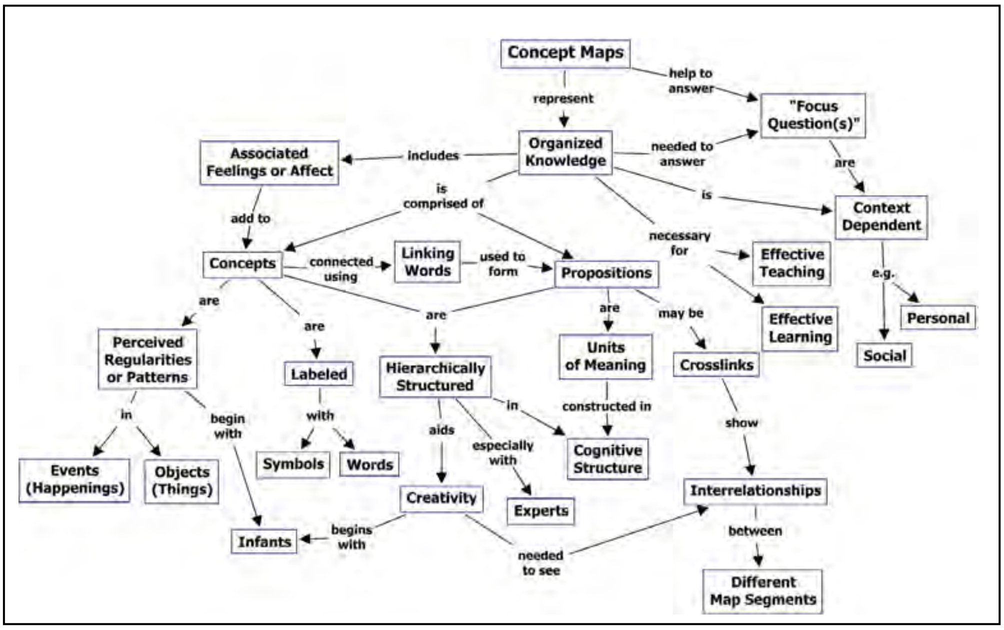

Figure 5.4 Concept map showing the key features of concept maps. Concept maps tend to be read progressing from the top downward (Novak & Cañas, 2008)

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).

5.3.2 Conceptual maps learning assessment

Concept maps have been widely used for many purposes and in many different contexts. They have been shown to be of use for (Mintzes et al., 1998, 2000; Novak, 1998; Novak & Gowin, 1984):

- providing a summary of a person's existing knowledge,
- identifying misconceptions,
- revealing gaps in understanding,
- promoting reflective thinking,
- designing curricula and instructional materials,
- ***assessing student learning,***
- evaluating program effectiveness,
- facilitating communication and arriving at shared understanding among members of groups,
- understanding the processes by which scientists construct new knowledge, and
- studying problems in epistemological foundations and assumptions.

Based originally on Ausubel et al. (1978) meaningful learning theory, Cmaps were developed to provide educators with a readily accessible tool to probe student's conceptual understandings and to encourage and support meaningful learning. Since then the use of Cmaps in knowledge assessment has spread widely (Novak, 1984: Ruiz-Primo, 2004, Freeman & Jessup, 2004, Gouveia et al., 2004) and is used for different purposes and in different fields, for example the field on ESD (Lourdel et al., 2007; Andrews et al., 2008; Lozano-Garcia et al., 2008; Segalas et al., 2008).

However Cmaps also have some limitations as assessment tools. Concept maps provide a useful and visually appealing way of depicting the structure of conceptual knowledge that people have stored in long-term memory. As a result, they offer a readily accessible way of assessing how well students see "the big picture." They are not designed to tap into the kind of process knowledge that students also need to solve novel problems or for the routine application of algorithmic solutions. Because they probe an individual's or a group's cognitive organization, they are very idiosyncratic and difficult to compare, either among individuals or groups, or across time for the same individuals or groups.

Degree of directedness	Concepts	Linking words	Structure
Low (construct the map)	No	No	No
	Provided	No	No
	Provided	No	suggested
	Provided	Provided	No
High (fill in the map)	Provided	Provided	provided
	Information delivered		

Figure 5.5 Concept map techniques according to directedness of the mapping tasks. Adapted from Ruiz-Primo (2004)

Among the cons of Cmaps the following can be highlighted:

- Comparisons among students are more difficult because concept maps tend to reveal the idiosyncratic way that students view a scientific explanation.
- Evaluation can become more time-consuming for the instructor, especially in large classes, unless some variation (such as Select & Fill-in) is adopted.
- If you score maps, it must be usec a consistent (and tested) scheme.

- Students who have developed a strong facility for rote learning of verbal knowledge sometimes find concept maps intimidating.
- Constructing concept maps is a demanding cognitive task that requires training.

The assessment of conceptual maps is directly related to the degree of directedness to the information provided to the students. This can differ from low-directed (students are free to decide which and how many concepts they include in their maps) to high-directed Cmaps (students are provided with the concepts, connecting lines, linking phrases and the map structure), a wide range of possibilities exist between these two ends. Figure 5.6 shows the spectrum of possibilities based on the degree of directedness when making a conceptual map depending on the information given beforehand on how to make a Cmap in terms of concepts, linking words and Cmap structure.

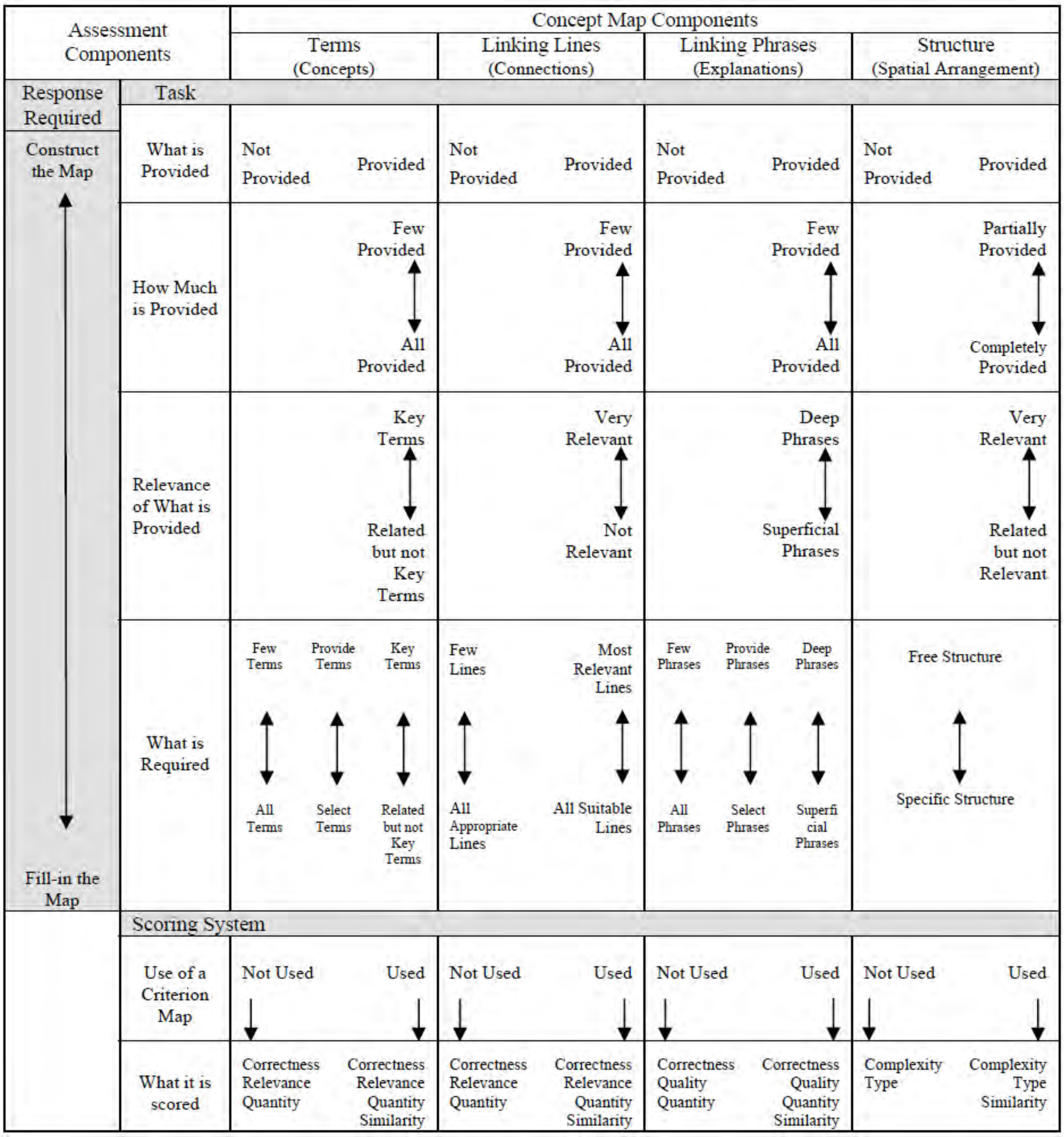

Figure 5.6 Framework considering some aspects of the nature of the mapping assessment tasks, response formats and scoring system (Ruiz-Primo, 2004)

The assessment of the Cmaps must fit the task the students were asked to do according to their directedness. Ruiz-Primo (2004) developed a framework which considers not only directedness but also the extent/amount of what is provided, their significance and what is required from the examiners. Depending on all these aspects the scoring system for the Cmap assessment differs. Figure 5.7 shows this framework where the assessment components are shaded. The decisions made about the mapping task and the scoring system are directly related to the map components (what components are provided and with what characteristics) and what is scored.

This study was carried out in different European schools of engineering, in sustainability related courses with different contexts. In order to facilitate the application of the assessment the survey task should not be very time consuming and easy to apply. Therefore the assessment with the lowest degree of directedness has been conducted, not providing any concept, linking lines, linking phrases or Cmap structure. This makes its application easier because student training in drawing conceptual maps is hardly needed. This allowed us to apply the procedure to a sample of around 500 students (1000 Cmpas).

The assessment components that were taken into account in the analysis are shown in figure 4.7: quantity of concepts, relevance of concepts, and quantity of links and complexity of the Cmap. This analysis is also adopted by other authors (Lourdel, 2007; Lozano-Garcia, 2008) when evaluating sustainability in Higher Education using conceptual maps.

<table>
<tr><td colspan="2" rowspan="2">Assessment components</td><td colspan="3">Concept map components</td></tr>
<tr><td>Concepts</td><td>Linking Lines</td><td>Structure</td></tr>
<tr><td rowspan="2">Response required</td><td colspan="4">Task</td></tr>
<tr><td rowspan="2">What is provided</td><td rowspan="2">Not provided</td><td rowspan="2">Not provided</td><td rowspan="2">Not provided</td></tr>
<tr><td>Fill in the map</td></tr>
<tr><td></td><td colspan="4">Scoring system</td></tr>
<tr><td></td><td>What is scored</td><td>Relevance
Quantity</td><td>Quantity</td><td>Complexity</td></tr>
</table>

Figure 5.7 Assessment component used in this study

5.3.3 Pedagogy evaluation: Horvath topography

In order to validate the pedagogy applied in the different case studies, two general levels were categorised:

- Passive learning: lecturing, writing exercises, problem demonstrations...
- Active learning: PBL, Problem base learning, case studies, etc.

In order to differentiate the different active learning methodologies the topography of approaches of active learning (Horvath et al, 2004) is used. The topography is represented as two orthogonal axes (focus and nature), as can be seen in figure 5.8. Each one involves a particular set of educational methods that exploit a wide variety of facilitators such as a problem, project, context, task, equipment, tool, computer program, library study, discussion forum, workshop, research, experiment, artefact evaluation, and so forth.

In the focus axis, individual, group and community-oriented approaches are identified. The differences along this axis can be understood as follows:

- The philosophy of the individual oriented approaches is that students with different backgrounds and interests may follow different learning paths adapted to personal needs (Twigg, 2002).
- The philosophy of group and community-oriented approaches takes into account the dynamic interaction and collaboration of multiple learners (Barron, 2000).

In the nature axis, instructive, explorative and constructive approaches of stimulated active learning are differentiated.

- Instructionalism presumes learning involves knowledge transfer and submission of learners (Coleman et al., 1997). Instructional education prescribes methods, processes and study materials through the intensive use of computer-based instructional systems (Reeves, 1993).

- Explorative approaches of active learning go beyond posing questions and seeking answers; they stimulate intentional searching for information and knowledge, and support aggregation of domain knowledge based on the development of hypotheses and theories (Paul, 1995). It has been observed that exploration embedded in real work context increases the authenticity of the learning tasks and increases the motivation of the learner (Oppermann, 2002).
- The theory of constructivist education explains that learning is a process of construction and confrontation of meaning rather than exploration and memorization of facts. In addition to the making of meaning, it emphasizes the social aspects of learning, interactions with the environment, distributed cognition and the endeavour of completion (Prawat & Floden, 1994).

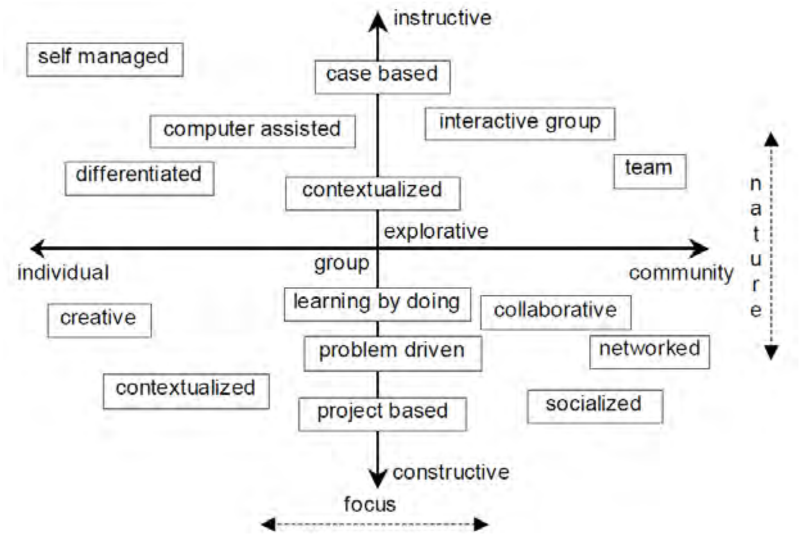

Figure 5.8 Topography of approaches of active learning (Horvath et al, 2004)

5.3.4 Pedagogy-Learning case studies

In this work concept mapping is applied to evaluating the knowledge acquired on SD by engineering students that take specific courses on sustainability. The study analyses over 500 engineering students from European Technological Universities, who took specific courses in SD. The results obtained allowed us, on the 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.

In this study the results are also analysed by gender, engineering speciality and nationality.

The results of the conceptual maps research are described in chapters 7 and 8 of this thesis.

5.4 Interviews

An interview is a conversation between two or more people (the interviewer and the interviewee) where questions are asked by the interviewer to obtain information from the interviewee. Its characteristics are:

- A relationship between two people.
- A way of symbolic bidirectional communication, preferably oral.
- Fixed and known aims.
- A control of the situation by the interviewer.

Its main advantages as a research tool are (Albert, 2007):

- This is an interpersonal relationship which is of great empathy.
- Flexibility: the interviewer can adapt the process to meet the needs of the interviewee.
- Observation. In addition to verbal information, the interviewer has the opportunity to observe the behaviour of the interviewee.

- Opportunity to record great amounts of information.
- Ability to gather information from people that otherwise would not have been possible.

In relation to its disadvantages:

- Relatively high cost: This refers to the investment in time and effort of the interviewer and the interviewee.
- The interference of biases that may have varied origins by both the interviewer and the interviewee.

Course	University	Cycle	Speciality
Sustainability & Technology (1)	Technical University of Catalonia	1st and 2nd	Various
Sustainability & Technology (2)	Technical University of Catalonia	1st	Various
Technology & Environment	Technical University of Catalonia	1st	Industrial engineering
Seminar on ST	Technical University of Catalonia	2nd	Various
Energy III project	Delft University of Technology	1st	Mechanical engineering
Societal aspect of information technology	Delft University of Technology	1st	Computer science
Global Chemical Sustainability	Chalmers University of Technology	2nd	Industrial Ecology + Innovative and sustainable chemical engineering
Sustainable Technology	Kiev Polytechnic Institute	2nd and PhD	System analysis
Technology & Sustainability	Eindhoven University of Technology	1st	Construction engineering
Technology & Sustainability	Eindhoven University of Technology	1st	Mechanical engineering
Experts on Sustainability	-	Lecturers and Professors	Various

Table 5.4 Characteristics of conceptual maps case studies

Interviews are one of the most used techniques to obtain information from people. From the research point of view interviews are useful for three main purposes:

- As an exploratory approach in order to help to identify variables and relationships, which can suggest hypothesis and guide other research phases.
- Be the main research tool. Then the questions of the interview are designed to measure the research variables.
- Can complement other methods to monitor unexpected results.

5.4.1 Interview design

There are many kinds of research interviews; nevertheless they can be classified in three groups: structured, semi-structured and unstructured.

A structured interview (also known as a standardised interview or a researcher-administered survey) is a quantitative research method commonly employed in survey research. The interviewer acts with a set scheme of interaction that incorporates presets questions in advance and that any interviewee should respond without too much freedom to respond. The objectives, content and techniques of acting are clearly fixed and planned in advance. The interviewer has no freedom to bring new questions to the verbal and non verbal information given by the interviewee. This affects the lack of depth on some topics that may be important for achieving the objectives of the investigation.

Unstructured interviews are those in which the interviewer directs the interview with a highly flexible schedule in the formulation of the questions and gives the interviewee greater freedom of response. This type of interview is characterized by not having to deal with certain goals or content. They are particularly suitable for establishing first contacts, indicating points of view, reaching initial agreements, and so on. In the unstructured interview, the interviewer may vary his/her strategy at any time to penetrate the conversation topics that seem more convenient, so getting better information. In this type of interview there's a lack of evaluation uniformity.

Semi-structured interviews share the advantages and disadvantages of previous designs. A semi-structured interview is flexible, allowing new questions to be brought up during the interview as a result of what the interviewee says. The interviewer in a semi-structured interview generally has a framework of themes to be explored.

In the study semi-structured interviews are used in order to evaluate the opinion of engineering experts on two main aspects: First on pedagogical strategies (Chapter 9) that best allow SD learning in engineering and second on curriculum design for SD (Chapter 10).

5.4.2 Interviews case studies

In order to know the opinion of experts on ESD in engineering, throughout the year 2005, the author spent three months in the Sustainability Departments of leading European universities on ESD:

- Department of Technology Dynamics and Sustainable Development, Delft University of Technology (Delft - The Netherlands).
- Center for Environment & Sustainability, Chalmers University of Technology (Goteborg - Sweden).
- SisTech, Sustainable Institute, Herriot-Watt University (Edinburgh - Scotland).

During the stays 45 experts from 17 European technological universities were interviewed (Segalas et al., 2007). The universities were selected for their experience on ESD in engineering: universities which offer courses and/or degrees on SD have a policy to introduce SD within the engineering curriculum.

The interview was divided into three aspects: ESD policy, curriculum design and learning tools. Appendix 1 shows the semi-structured interview guide used in the research; Appendix 2 contains the list and position of experts and finally in appendix 3 the interviews are transcribed.

Moreover, during the Engineering Education in Sustainable Development 2008 Conference held in Graz a workshop with ESD experts was organised where they were asked about the competences that engineering students may have when graduating in relation to SD. The results of this workshop are described in Chapter 10.

5.5 Conclusions

In this study a mixed concurrent nested research strategy is used where the qualitative method is nested within the quantitative one. The two methods used are:

- A quantitative research methodology: Conceptual maps to measure SD learning and Horvath topography of Active learning education to assess the pedagogy.
- A qualitative research methodology: Open ended interviews.

Conceptual map assessment has been conducted with the lowest degree of directedness, not providing any concept, linking lines, linking phrases or Cmap structure. Their application and evaluation are further described in chapter 7.

Regarding the interviews, study semi-structured interviews are used in order to evaluate the opinion of engineering experts in two main aspects: First, on pedagogical strategies (Chapter 9) that best allow SD learning in engineering and the second on curriculum design for SD (Chapter 10).

For the quantitative research methodology, 10 case studies were carried out in 5 European technological universities with a total sample of about 500 students.

For the qualitative research methodology two approaches were realised: Direct interviews to about 50 ESD experts of European HEIs and a workshop carried out during the last EESD conference held in Graz in September 2008.

The following chapters present the results of these research methodologies and their analysis.

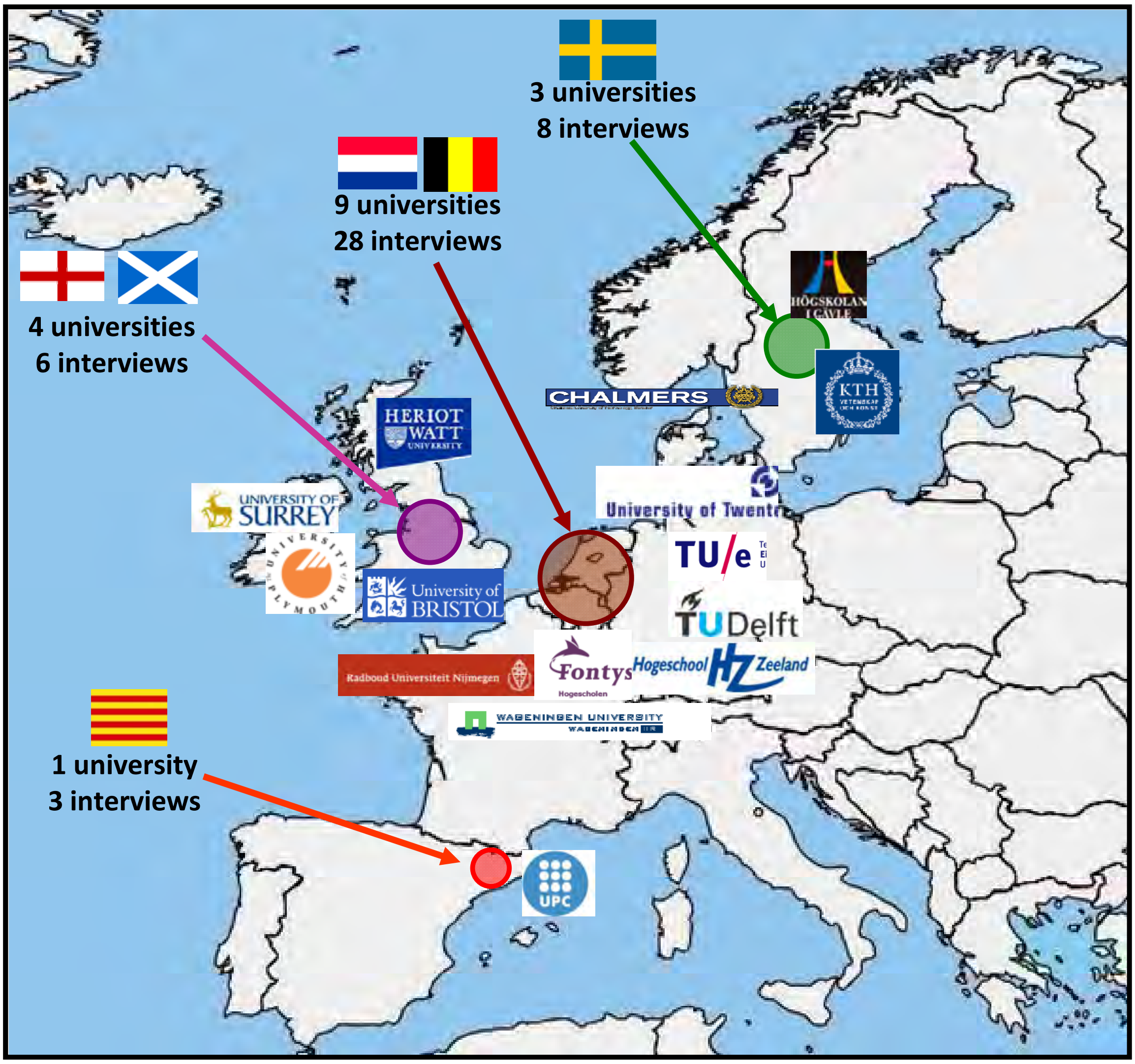

Figure 5.9 Interview case study universities

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Notes *(all the on-line documents have been checked in March 2009)*

[1] The notation in the figures mean:

- A "+" indicates a simultaneous form of data collection
- A "→" indicates a sequential form of data collection
- Capitalization indicates a priority on the quantitative or qualitative data analysis of the study
- "Quan" and "Qual" stand for quantitative and qualitative, respectively.
- Below each figure are specific data collection, analysis, and interpretation procedures
- Boxes highlight the quantitative and qualitative data collection.

6 Benchmarking evaluation of SD competences

This chapter analyses the SD generic competences that engineering graduates may have when graduating. Three cases studies in the introduction of sustainable development generic competences from Chalmers University of Technology (Sweden), Delft University of Technology (The Netherlands) and Technical University of Catalonia (Spain) are illustrated. Finally the commonalities of SD competences between the three universities are analysed, analysis that shows the need for a common framework in the definition of competences at international level.

6.1 Introduction

In chapter 2 of this work it is introduced the concept of learning outcomes and competences and their role in the EHEA qualifications framework and the "Dublin descriptors" competences. Moreover the state of the art in relation to SD competences in technological universities has been analysed. This analysis showed that there's a shared consensus on SD learning outcomes and competences for engineering graduates. Nevertheless all the examples illustrated are from supra-university institutions. In order to see what the real situation is at university level it is studied the work on sustainability learning outcomes for engineering graduates of three European technological universities that have demonstrated high ambitions for ESD in different activities in the last two decades as well as in their current visions (Holmberg et al., 2008). The three universities are Chalmers University of Technology (CUT) in Goteborg, Sweden, Delft University of Technology (DUT) in Delft, The Netherlands, and Technical University of Catalonia (UPC) in Barcelona, Spain. In the three cases the national and university contexts are analysed, because they can, and actually do, influence the competence definition of each university.

In all the cases the competences are classified in the three strands presented in chapter 2: Knowledge and understanding, skills and abilities and attitudes.

6.2 Chalmers University of Technology

6.4.1 National context

CUT is obliged to follow the Swedish law for higher education, which has included, since February 2006, a requirement that all higher education in Sweden should contribute to promoting SD. However, what this means in practice has not been fully established yet.

CUT has several Bachelors (three years) and Masters (five years) degrees of science in engineering programmes and has to follow the Swedish Degree Ordinance for these engineering degrees. For the Masters of Science in engineering degree, this means e.g. that: "the education should give prerequisites for students to gain knowledge and skills in designing products, processes, and work environment with respect to human possibilities and needs as well as to societal goals regarding social conditions, resource use, environment, and economy". The Swedish Agency for Higher Education made an evaluation of all Master of Science in engineering programmes in Sweden in 2005, in which all programmes were criticized for insufficient education on sustainable application of technology. In the next evaluation, in 2011, special emphasis will be put on measures that have been taken to accomplish this requirement in the Swedish Degree Ordinance.

The universities in Sweden are working independently on ESD issues but there are conferences and networks that can be used for exchange of experiences. The Swedish Agency for Higher Education arranges an annual national quality conference in which ESD is a natural part. Another relevant annual national conference is organized by the Swedish Research Association for SD (in short VHU), which was founded in February 2004. The aim of the VHU is to create a forum for discussion, interaction and cooperation between active scientists as well as individuals and organisations in society. A Swedish network, HU2, was initiated in 2006 with the aim of integrating SD in higher education. The network invites anyone working within education and organization at universities, as well as relevant authorities and student organizations, and there is an ambition to have a meeting every half year. A project (NLHU2) about SD learning outcomes for the first and second cycles has been conducted in connection to the network. In January 2008, the Swedish International Centre of Education for SD (SWEDESD) was started. The Centre is financed by the Swedish International Development Cooperation Agency (SIDA) and its purpose is to facilitate and support education and learning in the field of SD.

6.4.2 University context

CUT has recently adopted a new vision: “Chalmers - for a sustainable future”. In line with this vision, CUT is actively promoting ESD in its Bachelor and Master’s programmes. There is no Bachelor programme that is specialised in SD but the choice at CUT has been to strive to integrate SD into all programmes. There is a local requirement (that originates from a policy already created in 1985) that the Bachelors curriculum in all educational programmes should contain a compulsory course of five full-time weeks of studies, i.e. 7.5 ECTS, focusing on environment and SD. A first description of a desired content in such courses was elaborated by teachers in environment and SD in 2005. This is described by Lundqvist and Svanström (2008). An additional local requirement is that all five-year programmes must include 7.5 ECTS of courses in humanistic and social sciences (excluding economy and languages). There is a connection and some overlap between the two requirements and together they cover environmental and social aspects of SD. In this paper, only the first of the two requirements mentioned is evaluated.

The board at CUT decided in April 2006 to start a three-year project with the purpose of creating an organization for handling issues related to learning and ESD (Svanström et al., 2008a). The competences or learning outcomes for SD that are presented and analysed in this paper have been developed within this project, and are suggested as learning outcomes for the local requirement in environment and SD at CUT. They are based on earlier work and have been developed in contact with teachers, programme directors, students and people in the educational organization at CUT. However, the text will be reformulated based on the latest comments from this group. The current version was seen as slightly too ambitious for the first cycle (Bachelors level). The compulsory course in environment and SD at CUT is only a minimum requirement, and the overall goal at CUT is that ESD becomes embedded in all educational programmes and penetrates all courses. Within the ESD project, a resource group has the task of motivating and supporting teachers and programme directors, through individual interaction, towards integrating ESD in courses and programmes (Holmberg et al., 2008). ESD quality and embedment is being discussed at regular meetings at CUT involving different actors.

A new centre of learning for SD in technological sciences will be started at CUT shortly[1]. The purpose is to strengthen learning for SD within technological sciences by spreading information, supporting and organizing different activities, and starting up research within the field. Efforts will address internal learning activities as well as public learning and learning in elementary and high schools. The centre will take on the main responsibility for ESD issues.

The set of generic competences for first cycle in CUT are shown in Table 6.1.

	Competence
Knowledge and Understanding	- Knowledge about the sustainable development concept and the political ambitions.
	- Knowledge of the interface between the focus area of the profession and natural and social systems (environmental impacts at large).
Skills and Abilities	- Communication and cooperation with different actors. - Ability to handle shifts in perspectives (interdisciplinarity, dynamics over time, local and global considerations, geographical differences, and cultural, social and political perspectives)
	- Problem solving.
	- Ability to identify systems - to think holistically in order to be able to handle complexity and balance between different dimensions of SD (to discern patterns, to understand cause-effect relationships, to understand conceptual models of systems etc).
	- Ability to reflect on the professional role and responsibility as well as citizenship in relation to SD in a structured way
	- Critical and creative thinking.
	- Ability to separate facts from values.
	- Ability to identify ethical dilemmas and make decisions based partly on ethical considerations (accept that the decision may be based on both facts and ethical considerations).
	- Participatory decision-making, to be able to use democratic principles.
Attitudes	- Commitment for SD - important for active participation, self-discipline and changed behavioural patterns.
	- concern for SD.

Table 6.1 Generic competences description for first cycle at CUT

6.3 Delft University of Technology

6.4.3 National context

In the Netherlands, the Brundtland report of 1987 inspired the government to redirect environmental policies towards SD. This was expressed in the first National Environmental Policy Plan (NEPP) in 1989. The aim was to achieve “Sustainable Netherlands” within one generation. By law, the government was obliged to prepare a National Environmental Policy Plan every 4 years. In the second plan period the governmental research programme “Sustainable Technology Development” (1993-1998) was started up. It aimed at studying whether and how it would be possible to initiate innovation processes to create sustainable options to provide for people’s needs in the next generations (long term, up to 50 years) (Weaver et al., 2000). In this programme hundreds of participants from the Dutch Technology Community “learned by doing”. In the third plan period, the programme “Economy – Ecology - Technology” was institutionalized to set up projects to integrate economy, ecology and technology in medium terms: time to market 5 – 10 years. In the fourth plan, transition policies were launched to overcome persistent problems in the fields of energy, mobility, agriculture and biodiversity. In the early years of the new millennium, during the execution of the fourth plan, a government change placed attention on SD and the willingness to provide budgets under pressure. However, the urgency of climate change and rising energy prices soon reversed this trend.

6.4.4 University context

DUT was founded in 1842, as the first (and still the largest) institution to train academic engineers in the Netherlands. Its engineering training programmes were for a long time renowned but rather technocratic. The uproars of the seventies affected DUT considerably. With the introduction of new legislation in 1972, students and assistants could participate in the university decision-making processes. By the end of the seventies, environmental issues had affected some engineering curricula, although only marginally affected most other engineering curricula at DUT. The Brundtland report and the first NEPP of the Netherlands triggered a second wave of environmental awareness at DUT. This renewed interest in environmental issues resulted in some new initiatives, but they were all add-on. There were barely any changes in the major programmes of engineers, nor in research programmes, while at the same time, in the framework of the NEPP, important tasks were assigned to universities. In 1991, DUT adopted an environmental policy plan. This plan included the introduction of an environmental management system, and more scope for environmental issues in education and research. To implement the plan, a high level steering group chaired by Prof. Marcel de Bruin, head of the nuclear reactor institute, was formed. This steering group aimed to introduce 'SD' throughout the engineering curricula. However, the steering group's report did not lead to significant changes in the study programmes of DUT.

An important external event was that the government had consented in 1994 to 5-year curricula for engineers[2], and so there was scope for new courses. This scope was not to be filled by extra technology courses. Social skills of engineers were often regarded to be less than sufficient and therefore developing social skills became important. Moreover, it became politically unacceptable for most students to spend many more years studying than the official length of their study programmes. It was with this background that a new Committee for SD at DUT was installed in 1996. The committee's assignment was both to advise on - and to implement the integration of SD in both the education and research programmes at DUT. As the objective was to advise on integration in all study programmes, all study programmes had to be represented in the committee while at the same time the committee members should have a considerable teaching task, knowledge of (the impact of) SD and standing within the university community.

The committee regarded bridging the gap between (traditional) 'environmentalism' and 'engineering' as its first goal: SD had to become a challenge for engineers and the engineering profession. In line with the strategic vision of DUT, engineers graduating from DUT had to be prepared for the great technological challenges, especially solving questions related to SD. This implied that DUT had to educate engineers who could make 'SD' operational in technical scientific design and in the application of technology and technical systems. In November 1997 the committee proposed a plan consisting of three interconnected operations:

1. The design of an elementary course 'Technology in SD' for all students at DUT.
2. The integration of SD in all regular disciplinary courses, in a way corresponding to the nature of each specific course.
3. The development of a possibility to graduate in a SD specialization within the framework of each department.

From the start, the committee closely cooperated with the departments in a process of 'learning by doing'. In 1998, the learning objectives for a basic SD course at DUT were formulated.

The set of generic competences for first cycle in DUT are shown in table 6.2.

	Competence
Knowledge and Understanding	- Have a global insight in the mechanisms that underline sustainability problems.
	- Have knowledge of the concept and the framework of concepts related to sustainable development and can see the relation between their knowledge and skills and this societal challenge.
	- Have an understanding for the relation of technical systems and subsystems and for the social factors that partly determine the performance of a technology in practice.
	- Have a global insight into technical and scientific dimensions of sustainable development and be aware of the economic and social dimensions.
	- Acquiring understanding in the interrelation between product, process and environment, and the dynamics of technological change.
	- Knowledge of the main topics and models that can be applied to the use of technology to achieve integrated ecological and technological objectives.
Skills and Abilities	- To cooperate with other technical and non-technical disciplines in designing and managing technical systems, and to communicate adequately with other stakeholders/actors in the area surrounding the technical system in question.
	- To recognize the causes of sustainability problems not only at the level of subsystems, but are able to overcome their disciplinary boundaries in creating structural solutions.
	- Ability to apply knowledge and understanding in the engineering praxis.
	- Be capable of identifying directions for solutions for sustainability questions, and have an understanding of the implications of possible solutions: ▪ in the long term ▪ on other scale levels (geographically) ▪ on other system levels
	- Be capable of making a sound judgement between different directions of solutions, taking into account: ▪ uncertainties ▪ the dynamics of the technology ▪ the interest of different actors
Attitudes	- Acknowledge the challenge of contributing from their profession to sustainable development.
	- Are aware of the risks of the unsustainable use of resources which are available to mankind.

Table 6.2 Generic competences description for the first cycle at DUT

6.4 Technical University of Catalonia

6.4.1 National context

Pressure from the national higher education legislation towards sustainability at universities has been almost nonexistent in Spain. In the Bologna reform process, efforts have been mainly focussed on the potentially strong reorganisation of the curriculum in order to merge two different types of engineering schools (3 and 5 years long) and develop a framework which might be compatible to the EHEA.

This difficult reform has left little space for other profound debates, such as the ESD one. Within this context, only very few universities have tried to develop a particular profile related to environment or sustainability, such as at the UPC. This university has been one of the few pushing the Ministry of Education through the Spanish Rector's Conference to create some demand for legislation and available resources in that direction (CRUE, 2005), though without seeing any results as yet.

6.4.2 University context

UPC has shown a proactive approach towards the inclusion of environmental aspects in courses and programmes (from 1996 to 2005), and currently SD issues through its institutional strategic plans (Ferrer-Balas, 2004; Holmberg et al., 2008). Within the period 1996-2005, curriculum greening was approached as an incremental change, and environmental aspects were included within the curricula. However, these remained basically unchanged, and the students that are trained today do not differ significantly regarding sustainability competences from those trained in the 90s.

In 2006, with the help of an international expert's evaluation and an internal participatory process (Ferrer-Balas & Barceló, 2008), the UPC initiated a new strategy, called UPC Sustainable 2015, which aims to go one step further. External links and the explicit orientation towards sustainability and long-term issues are the core elements that should help to move more rapidly towards a new sustainable paradigm in technical education.

The new strategy is linked to the Bologna process, and aims to take advantage of this window of opportunity. The UPC is reorganizing all its degrees to the new model, and has thus created, in this order, a number of new Masters Programmes, and will start, in year 09/10, all its new 1st cycle degrees. While at the Masters level, new programmes on SD have been created, a key issue that remains is how the transversal integration of SD at the first cycle level will be done. For that, during the transition period, a series of activities have been developed, such as the individual interaction with lecturers (Holmberg et al., 2008) or the organization of participatory debates on sustainability and technical education. From these processes, two framework documents were derived: the UPC's Declaration of Sustainability, and a framework for the introduction of SD in first cycle programmes. The documents have been validated officially, together with approval in 2008 that "sustainability & social commitment" is a compulsory transversal competence for all UPC 1st cycle programmes. These documents are initial ESD guidelines for the schools and faculties that have to design their own degrees, and include the general competences and learning outcomes regarding SD that any 1st cycle graduate should acquire, which are those analysed in this study.

The set of generic competences for First cycle degrees in UPC are shown in table 6.3.

	Competence
Knowledge and Understanding	- To understand the current situation of the world and the challenges of our society from a sustainability perspective.
	- To know the causes that have brought society to the current un-sustainability and specially the role of technology.
	- To know the fundamentals of the Sustainability and Human Development paradigm.
	- To know how the scientific and technological developments have helped to cover basic needs and the development of environmental transformations capacities.
	- To know the basic tools and strategies for the introduction of sustainability criteria in the final thesis work and in the development of the profession.
Skills and Abilities	- Empathy, dialogue and cooperation.
	- Ability to solve problems and develop projects under the Sustainability paradigm.
	- Systemic thinking.
	- Critical thinking.
	- Promoting the social participation.
Attitudes	- Ethical sense and awareness of human and professional activity.
	- Peace culture.
	- Respect for the past, current and future generations.
	- Respect for the environment.
	- Respect for diversity.

Table 6.3 Generic competences description for first cycle at UPC

6.5 Comparison of SD Competences from case studies

In order to evaluate and compare generic SD competences for the first cycle in all three universities Bloom's and Krathwohl's taxonomy categories (Bloom, 1956; Krathwohl et al., 1973) are used.

Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation:

1 - **Knowledge**: Recall data or information.

2 - **Comprehension**: Understand the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.

3 - **Application**: Use a concept in a new situation or the unprompted use of an abstraction. Apply what was learned in the classroom into novel situations in the work place.

4 - **Analysis**: Break concepts or material into constituent parts, determining how the parts relate to one another and to an overall structure.

5 - **Synthesis**: Build a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.

6 - **Evaluation**: Make judgments about the value of ideas or materials.

In our work, the cognitive levels are applied to the competences related to *knowledge and understanding* and *skills and abilities*.

When evaluating the affective domain, which includes the manner in which people deal with things emotionally, such as feelings, values, appreciation, enthusiasm, motivation, and attitudes, Krathwohl et al. (1973) defined a set of five major categories, which in this work are used to evaluate *attitudes'* learning domain competences. These categories are listed from the simplest behaviour to the most complex:

1 - **Receiving:** Be aware of or sensitive to the existence of certain ideas, material, or phenomena and be willing to tolerate them.

2 - **Responding:** Commit in some small measure to the ideas, materials, or phenomena involved by actively responding to them.

3 - **Valuing:** Attach value to an object, phenomenon, or behaviour. Demonstrate a positive attitude, appreciation, belief, or commitment through expression or action.

4 - **Organization:** Organize (compare, relate, and synthesize) different values into the beginning of an internally consistent value system. Recognize a need to balance freedom and responsibility. Formulate a career plan. Adopt a systematic approach to problem solving.

5 - **Characterization by a value or value complex:** Have a pervasive, consistent, and predictable manner. Work independently and diligently. Practice cooperation in group activities. Act ethically.

The definition of the generic competences by the three universities (tables 6.1, 6.0 and 6.3) do not present a unique pattern when describing them, this divergence makes their analysis and comparison difficult. However, an effort has been made to group them under key words that integrate their definitions.

As has been presented in the descriptions above, the three universities developed their sets of SD competences in the learning domains for first cycle programmes through different processes and in different periods. Tables 6.4 to 6.6 show the sets of sustainability competences of each university in the three learning domains (Knowledge and understanding, Skills and abilities and Attitudes), clustered by key words, with their level of learning according to Bloom's taxonomy (BT) for cognitive learning (1-Knowledge, 2-Comprehension, 3-Application, 4-Analysis, 5-Synthesis, 6-Evaluation), and to Krathwohl's taxonomy (KT) for affective learning (1-Receiving, 2-Responding, 3-Valuing, 4-Organization, 5-Value complex) indicated.

Table 6.4 Knowledge and Understanding competences analysis

Key word	DUT	BT[+]	UPC	BT	CUT	BT
World current situation		0	To understand the current situation of the world and the challenges of our society from a sustainability perspective.	2		0
Causes of unsustainability	Have a global insight into the mechanisms that underline sustainability problems.	2	To know the causes that have brought society to the current un-sustainability and specially the role of technology.	1		0
Sustainability fundamentals	Have knowledge of the concept and the framework of concepts related to sustainable development and be able to see the relation between their knowledge and skills and this societal challenge.	2	To know the fundamentals of the Sustainability and Human Development paradigm.	1	Knowledge about the sustainable development concept and the political ambitions.	1
Science, Technology and Society	Have an understanding of the relationships of technical systems and subsystems and for the social factors that partly determine the performance of a technology in practice. Have a global insight into the technical and scientific dimensions of sustainable development and be aware of the economic and social dimensions. Acquiring understanding in the interrelationship between product, process and environment, and the dynamics of technological change.	2	To know how the scientific and technological developments have helped to cover the basic needs and the development of environmental transformations capacities.	1	Knowledge of the interface between the focus area of the profession and natural and social systems (environmental impacts in general).	1
Instruments for sustainable technologies	Knowledge of the main topics and models that can be applied to the use of technology to achieve integrated ecological and technological objectives.	1	To know the basic tools and strategies for the introduction of sustainability criteria in the final thesis work and in the development of the profession.	1		0

[+] Cognitive Bloom's Taxonomy (BT; 1-Knowledge, 2-Comprehension, 3-Application, 4-Analysis, 5-Synthesis, 6-Evaluation)

Table 6.5 Skills and Abilities competences analysis

Key word	DUT	BT[+]	UPC	BT	CUT	BT
Self-learning		0		0	Self-learning.	3
Cooperation and transdisciplinarity	To cooperate with other technical and non-technical disciplines in designing and managing technical systems, and to communicate adequately with other stakeholders/actors in the area of the technical system in question. To recognize the causes of sustainability problems not only at the level of subsystems, but also to be able to overcome their disciplinary boundaries in creating structural solutions.	3	Empathy, dialogue and cooperation.	3	Communication and cooperation with different actors. Ability to handle shifts in perspectives (interdisciplinarity, dynamics over time, local and global considerations, geographical differences, and cultural, social and political perspectives)	6
SD Problem solving	Ability to apply knowledge and understanding in the engineering praxis.	3	Ability to solve problems and develop projects under the Sustainability paradigm.	3	Problem solving,	5
Systemic thinking	Be capable of identifying directions for solutions for sustainability questions, and have an understanding of the implications of possible solutions: • in the long term • on other scale levels (geographically) • on other system levels	4	Systemic thinking.	6	Ability to identify systems - to think holistically in order to be able to handle complexity and balance between different dimensions of SD (to discern patterns, to understand cause-effect relationships, to understand conceptual models of systems etc).	4
Critical thinking	Be capable of making a sound judgement between different directions of solutions, taking into account: • uncertainties • the dynamics of the technology • the interest of different actors	6	Critical thinking.	6	Ability to reflect on the professional role and responsibility as well as citizenship in relation to SD in a structured way Critical and creative thinking. Ability to separate facts from values. Ability to identify ethical dilemmas and make decisions based partly on ethical considerations (accept that the decision may be based on both facts and ethical considerations).	4
Social participation		0	Promote social participation.	6	Participatory decision-making, to be able to use democratic principles.	6

[+] Cognitive Bloom's Taxonomy (BT; 1-Knowledge, 2-Comprehension, 3-Application, 4-Analysis, 5-Synthesis, 6-Evaluation)

Table 6.6 Attitudes competences analysis

Key word	DUT	KT+	UPC	KT	CUT	KT
Responsibility/ Commitment/ SD challenge acknowledge	Acknowledge the challenge to contribute from their profession to sustainable development.	3		0	Commitment for SD - important for active participation, self-discipline and changed behavioural patterns.	5
Respect/ Ethical sense/ Peace culture		0*	Ethical sense and awareness of human and professional activity. Peace culture.	4		0
Concern/ Risk awareness	Be aware of the risks of the unsustainable use of resources which are available to mankind.	3	Respect for the past, current and future generations. Respect for the environment Respect for diversity	3	concern for SD.	3

+ Affective Krathwohl's Taxonomy (KT: 1-Receiving, 2-Responding, 3-Valuing, 4-Organization, 5-Value complex)

*In TUDelft ethics competences are not included specifically within Sustainability because they have their own domain in the degrees description.

The analysis of *Knowledge and understanding* learning competences (Table 6.4) shows that there is significant consensus concerning the type of competences that are considered by the three universities. Only one competence is identified at just one university (the “world current situation”, at the UPC). The others are shared. Figure 6.1 graphically highlights the levels of learning under Bloom’s taxonomy. It is important to underline that the maximum level of learning in this domain is *Comprehension (2)* because, in fact, understanding is its main intention. Note that both the CUT and DUT have additional sets of required competences for the science, technology and society area, which are not included in this analysis.

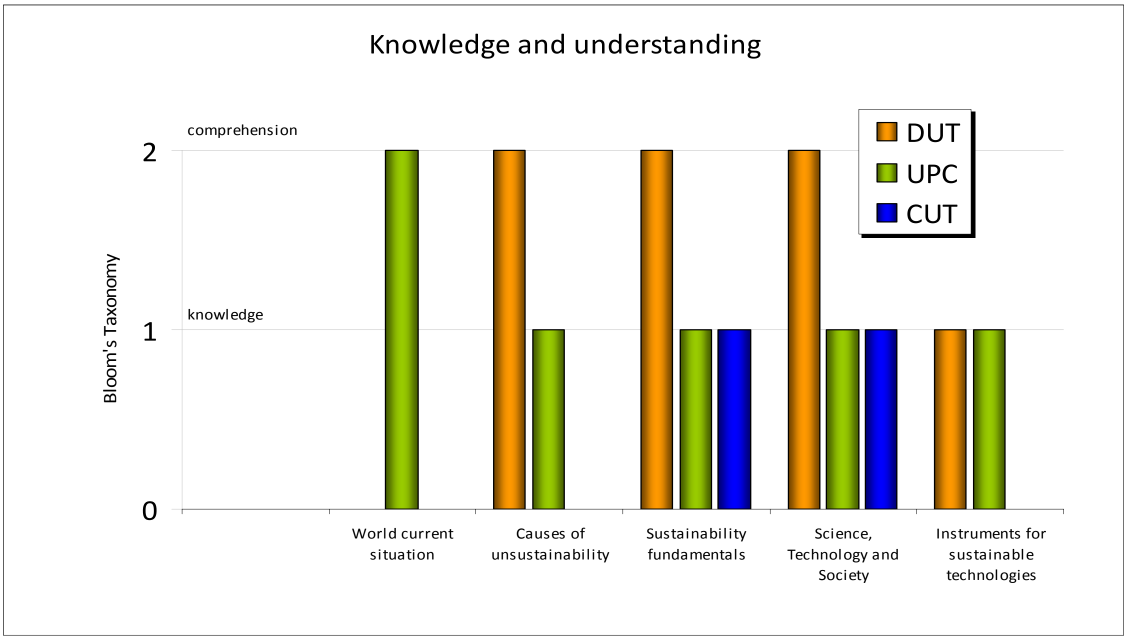

Figure 6.1 *Knowledge* and *understanding* competences levels of learning

In relation to *skills and abilities* learning competences, table 6.5 illustrates that there is also an important consensus for this area, both in the list of competences and in their level of learning. In figure 6.2 it can be seen that universities ask for the maximum level of learning for the competences related to systemic thinking, critical thinking and social participation, meanwhile self-learning, cooperation and SD problem solving are at the application level of learning.

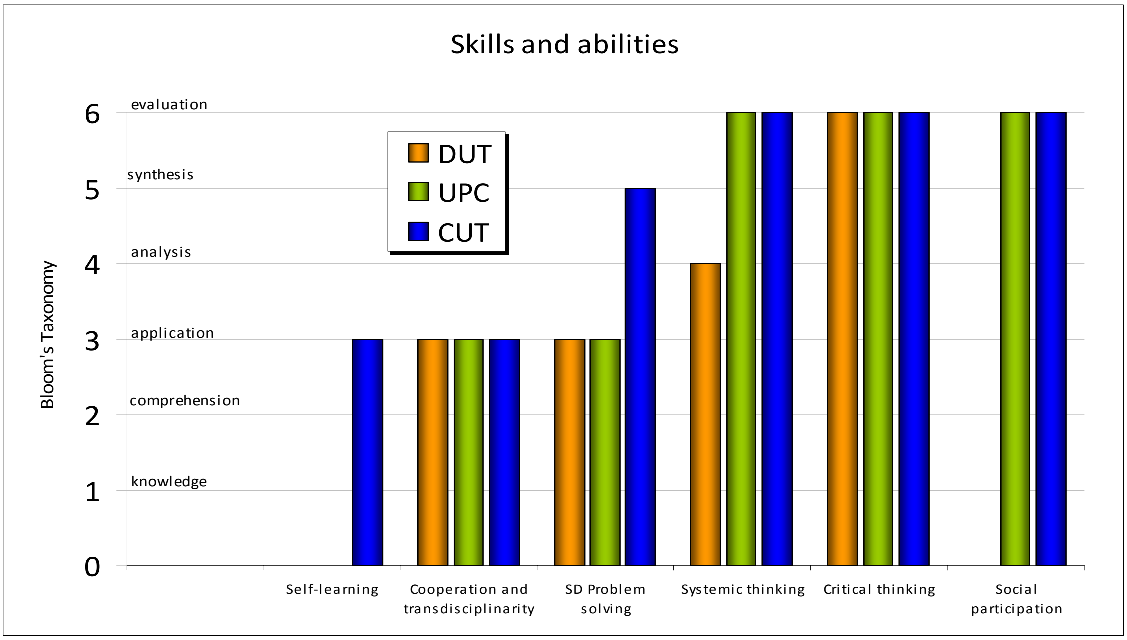

Figure 6.2 *Skills* and *abilities* competences levels of learning

Finally, the analysis of *attitudinal* competences, table 6.6, reveals that those competences are described in different ways at the three universities, which makes it more difficult to find appropriate key words that encompass the targeted learning. There is complete consensus only in that students should attain a certain level of concern or awareness of risks.

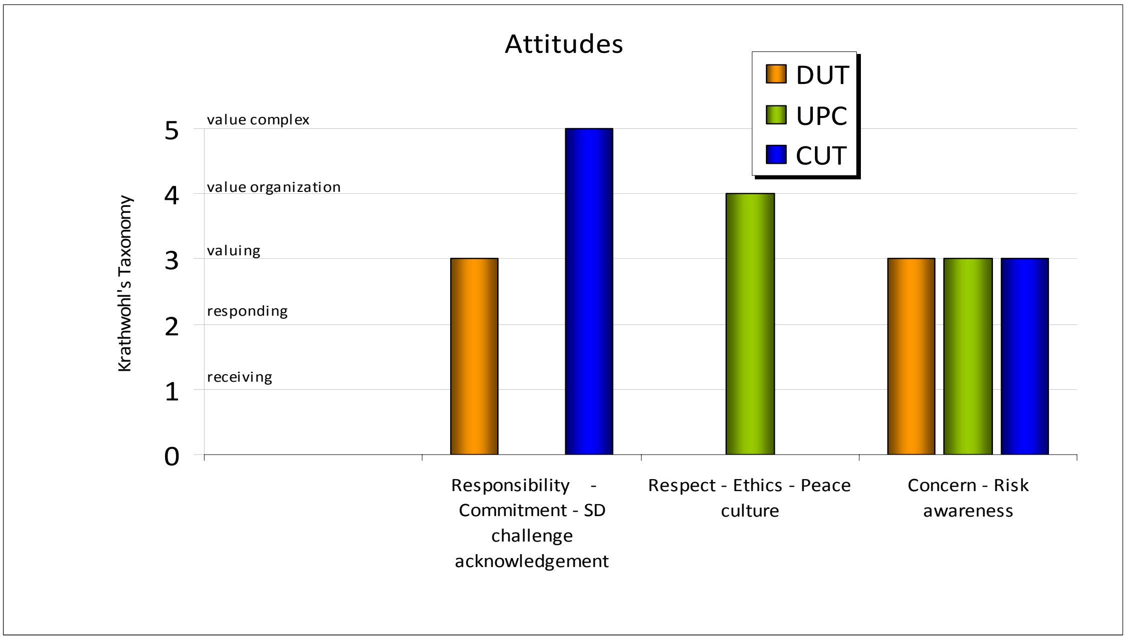

Figure 6.3 *Attitudes* competences levels of learning

The key words that were picked out to describe the competences can form the basis for a discussion on how descriptors could be described and can be used by other universities for benchmarking and learning. In another analysis of learning outcomes for ESD (Svanström et al., 2008b), some commonalities that were found concerned systemic or holistic thinking, the integration of different perspectives and skills related to problem-solving, critical thinking, creative thinking, self-learning, communication and team-work. In the attitudes area, ethics, concern, participatory decision-making and democratic principles are some of the key issues that were described. The competences listed for the three universities in this study are in line with generic ESD competences listed Svanström et al. (2008b).

When analysing the list of competences of the three universities, the main barrier in looking for commonalities between the three institutions is the way the competences are described. Sometimes the competences embrace a full branch of actions and sub-competences (e.g. Critical thinking), and in other examples the competences are described as a specific action (e.g. Ability to separate facts from values). This divergence of competences description complicates their classification under a common descriptor key word, as proposed in tables 1, 2 and 3. This reveals that the engineering academic community is not yet used to working with SD descriptors for competences and that this work can contribute to their development and to their integration in 1st cycle programmes.

Despite the differences in the list of competences and in the required levels of learning between the three institutions, it is clear that there are significant commonalities. The differences, however, point at areas that should be reviewed at each of the universities. The reason behind differences is not always likely to be differing opinions on what should be included but rather that competences are formulated under different conditions (some competences might just have been forgotten) and in different ways by different people. They also reflect the culture in which they were formed. This work is therefore part of an important learning process on how to formulate SD competences in a comparable way but also on how to be explicit about the required learning, also for things that in a certain culture go without saying.

6.6 Conclusions

In this chapter three case studies have been carried out in relation to sustainability competences for engineering first cycle graduates in three Technological Universities (CUT in Sweden, DUT in the Netherlands and UPC-Barcelona in Spain) using the EHEA descriptors. The cross-comparison, using Bloom's and Krathwohl's taxonomy, as well as a key-words' grouping of competences has allowed the observation of similarities and divergences in the way the three universities formulate (and prioritise) what has to be learnt in SD at the first cycle level.

It has been shown from the case studies that there is a strong convergence in the fundamental meaning of competences, although scarce matching among the descriptions formulated. The analysis of competences showed divergences in their descriptions, which makes it difficult to benchmark the programmes in different universities. Nevertheless, the aim of listing competences is to make the learning of a certain programme clear and understandable. Therefore progress needs to be achieved towards more similar descriptors to allow the EHEA system to make use of the transferability of European degrees, also in the domain of SD. Rather than homogeneity, what is missing is harmoniousness.

The definition of competences is a learning process. This study shows that the definition of SD competences still has to be much improved in order to facilitate their integration in the engineering curricula.

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[1] The new Centre on learning for SD in technological sciences started in January 2009.
[2] Thereby reversing the 1984 decision that all academic programs in Netherlands should be 4 years.

7 Conceptual maps. Assessment tool for sustainability learning

This chapter explains the methodology for assessing the learning acquired by students when taking an SD related course. Conceptual maps are introduced as an appropriate assessment tool. Then 10 categories taxonomy of SD concepts is defined and compared with previous taxonomies. Afterwards two indexes are defined for evaluating conceptual maps: Category relevance and complexity. After that their evaluation procedure is described with one example. Next a reference Conceptual map is characterized based on the semantic analysis of reference SD documents and the assessment of ESD experts' conceptual maps. Finally the sensibility of conceptual maps to evaluator effect is evaluated.

7.1 Introduction

This chapter describes the methodology used in our analysis and the characteristics of the case studies carried out. Conceptual maps (Cmaps) definition, structure, description and their use as a tool for learning assessment are presented in chapter 5 of this work.

The study is based in Cmaps assessment with the lowest degree of directness, not providing any concept, linking lines, linking phrases or Cmap structure. The assessment components taken into account in this analysis are: the number of concepts, the relevance of concepts, the number of links and the complexity of the Cmap. This analysis is also adopted by other authors (Ahlberg, 2004; Jaen & De Pro, 2006; Gregorio & Freire 2006; Lourdel, 2007; Lozano-Garcia, 2008; Andrews et al., 2008) when evaluating sustainability in Higher Education.

7.2 Methodology

In this work concept mapping is applied to evaluating the knowledge acquired on SD by engineering students that take specific courses on sustainability. The study analyses the learning effects of specific courses on SD for over 500 engineering students from European Technological Universities. The results obtained allow us, on the one hand, to evaluate 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 improvement produced by the courses in the students' understanding of Sustainability.

Due to the nature of our research, evaluation of what engineering students learn in SD courses, the design used is the quasi-experimental pretest-posttest design. This design (figure 7.1) requires a Cmap before the learning activity (L_A) recorded in a single group of individuals ($Cmap_1$) and one observation after its administration ($Cmap_2$), since there is only one group of subjects.

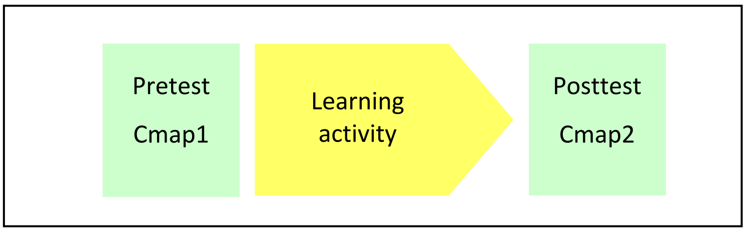


Figure 7.1 Scheme of a quantitative quasi-experimental pretest-posttest design applied in the study

The foundation of this design is the comparison between the pretest and the posttest. Its main limitation is the lack of a control group without which it is difficult to establish causal arguments about the effect of treatment (L_A). The effect of treatment is the difference between the pretest and post-measures.

Following this scheme, students are asked to draw a conceptual map about concepts that are relevant to sustainability twice: before taking the course and after taking it. No concepts are given but the initial concept sustainability, so students are free to use all the concepts they think are relevant to it. Students have 15 minutes to draw the Cmap.

7.2.1 Taxonomy analysis of sustainability concept

When evaluating Cmaps some aspects should be framed (Ruiz-Primo, 2004). On the one hand, in order to evaluate the width of 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 with sustainability the interrelationships between the categories are analysed.

The first practical questions that appear are: how to group the concepts? Under what categories? There are different taxonomies of categories for SD. The aim of our study is to find the best way to learn about sustainability, so the taxonomy developed by previous authors has been expanded (Lourdel, 2004; Carrera, 2007) in order to be more precise when analysing the courses and keep the possibility of a higher disaggregated analysis. Table 7.1 shows the different categories of taxonomy and their relation.

Categories		
UNESCO Chair UPC	**Lourdel (2004)**	**Segalas, Ferrer-Balas, Mulder**
1. Environmental	1. Environmental	1. Environment 2. Resources scarcity
2. Social	2. Social Cultural 3. Multidimensional approaches	3. Social impact 4. Values 5. Future (Temporal) 6. Unbalances (Spatial)
3. Economic	4. Economic, Scientific, Technological	7. Technology 8. Economy
4. Institutional	5. Procedural and political approaches	9. Education
	6. Actors and stakeholders	10. Actors and Stakeholders

Table 7.1 Taxonomy of Sustainable development categories used in this study

The concepts and aspects related to each category are:

- Category 1 (C1): **Environment** (Pollution, degradation, conservation, biodiversity, ecological footprint)
- Category 2 (C2): **Resources** scarcity (un-renewable resources, run out of materials, …)
- Category 3 (C3): **Social impact** (quality of life, health, risk management, ...)
- Category 4 (C4): Cultural & **Values** aspects (related to ethics, awareness, respect for traditions and cultures …)
- Category 5 (C5): **Future** dimension (future generations, scenario analysis, forecasting, backcasting, …)
- Category 6 (C6): **Unbalances** (the equity dimension, North-South cooperation, fair distribution of goods, fair use of resources, …)
- Category 7 (C7): **Technology** (Best Available Technologies, Industry, efficiency, clean-technologies, energy, impact of technology …)
- Category 8 (C8): **Economy** aspects (role of economy, fair trade, consumption, ...)

- Category 9 (C9): **Education** aspects (role of education, rise of awareness, education institutions, media role in education or disinformation, …)
- Category 10 (C10): **Actors and stakeholders** (role of governments, NGOs, rules, laws, international agreements, individuals and society, …)

7.2.2 Conceptual map analysis indexes

The analysis of conceptual maps can be quantitative or qualitative (Ruiz-Primo, 2004; Lourdel, 2004, Lozano-Garcia, 2008). In our study the quantitative analysis is used, specifically the following variables are measured:

- Number of concepts per student ($\overline{NC}$) evaluated as:

$$\overline{NC} = \frac{\sum_{j=1}^{j+NS} NC_j}{NS} \qquad \text{[Eq. 7.1]}$$

  Where NS is the number of students sample.

- Number of concepts per category (NC_i) [i ∈ (1, … , 10)]
- Number of links inter-category between concepts (*NL*). The links to the Sustainability concept are not considered.
- Number of students that give concepts to a specific category (NS_i) [i ∈ (1, … , 10)]

Two dimensions are evaluated: the category relevance, and the complexity of the Cmap.

Category relevance index

The category relevance provides information about what students think sustainability is most related to. 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. To evaluate it two indicators are used:

Concepts' distribution among categories (*CD*). It evaluates the distribution of concepts among categories, measured as the percentage of concepts devoted to a certain category:

$$CD_i = \frac{NC_i}{\sum_{i=1}^{i=NCa} NC_i} \qquad \text{[Eq. 7.2]}$$

Where: N_{Ca} is the number of categories.

Percentage of students that write concepts assigned to a certain category (SC), measured as:

$$SC_i = \frac{NS_i}{NS} \qquad \text{[Eq. 7.3]}$$

Where: *NS* is the sample number of students that participate in the observation.

The category relevance is calculated multiplying the two previous indicators:

$$CR_i = \frac{CD_i \times SC_i}{\sum_{i=1}^{i=NCa} CD_i \times SC_i} \qquad \text{[Eq. 7.4]}$$

Therefore the category relevance index takes into account the number of concepts and the percentage of students that relate sustainability to each category. Thus the possible deviation of Cmaps with a very high number of concepts in very few categories is normalised.

Complexity index

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

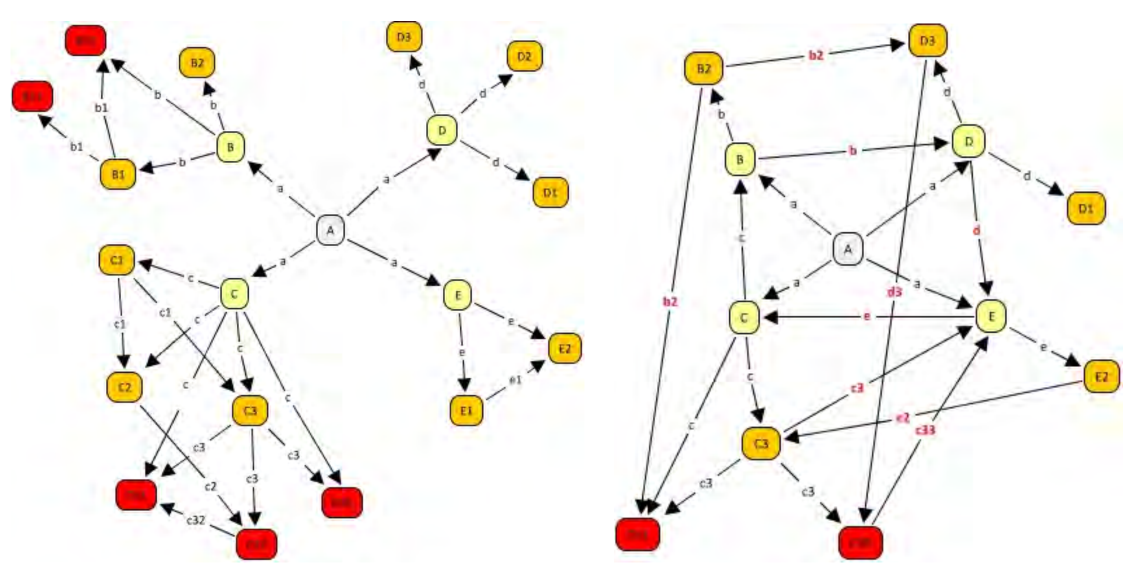
$$CO = \overline{NC} \times L_{Ca} \qquad \text{[Eq. 7.5]}$$

Average number of concepts per student ($\overline{NC}$).

Relative measure of the connections between different categories (L_{Ca}). This indicator normalises the number of link inter-categories by the number of categories and the number of students. It is calculated as follows:

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} \qquad \text{[Eq. 7.6]}$$

The complexity index can vary from zero to any value, depending on the number of concepts and the link inter-categories. Figure 7.2 shows the complexity increase from a branched Cmap (a) where there are no link inter-categories, where it can be seen that the links between the same category concepts do not count as a link, to a more complex Cmap (b) where there are fewer concepts but the categories are interlinked (links inter-categories are in red).



a) Low complexity [CO = 0] b) High complexity [CO >> 0]

Figure 7.2 Increase in complexity in Cmaps

These two indexes are evaluated before and after the students take the courses; these values refer to an entire group average conception, not individually.

In order to clarify the application of these indicators and their analysis the equations are applied to an example case. Figures 7.3 and 7.4 present the Cmaps of two students. In red the categorisation is highlighted. The links inter-categories are illustrated in blue.

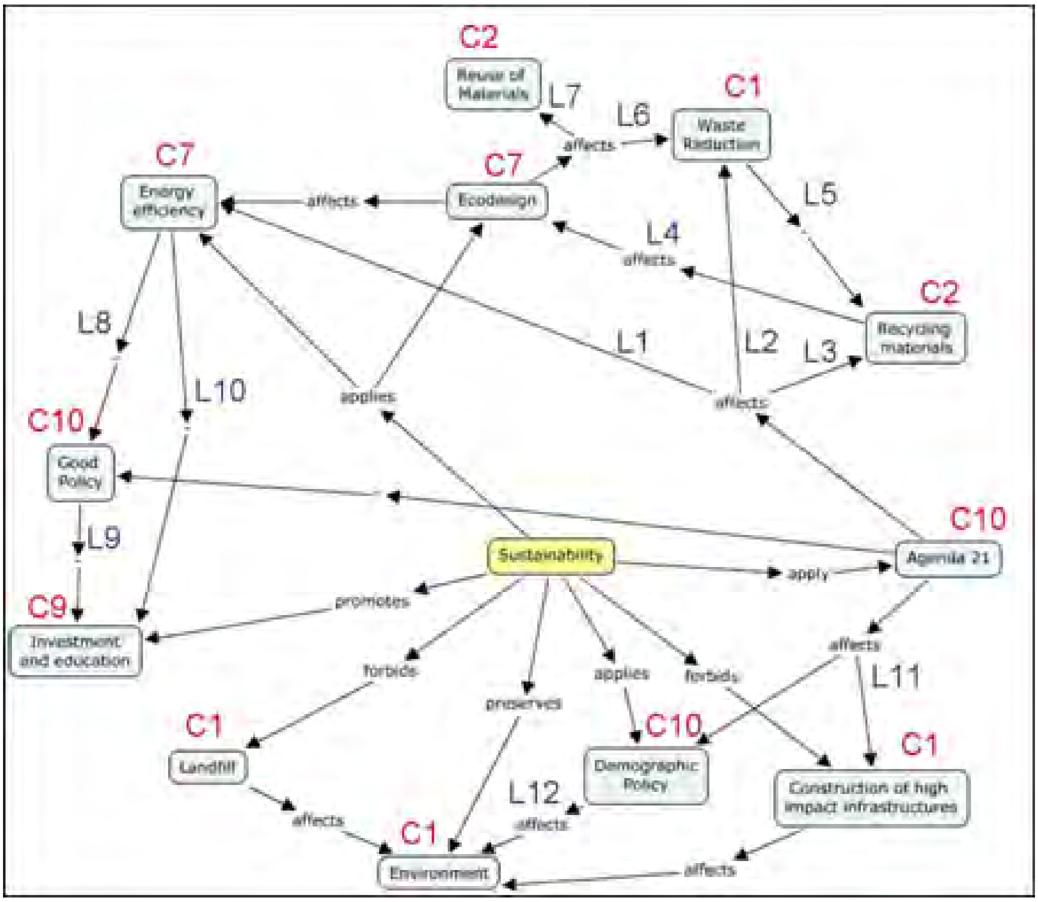


Figure 7.3 Example representation of a Cmap: Student 1

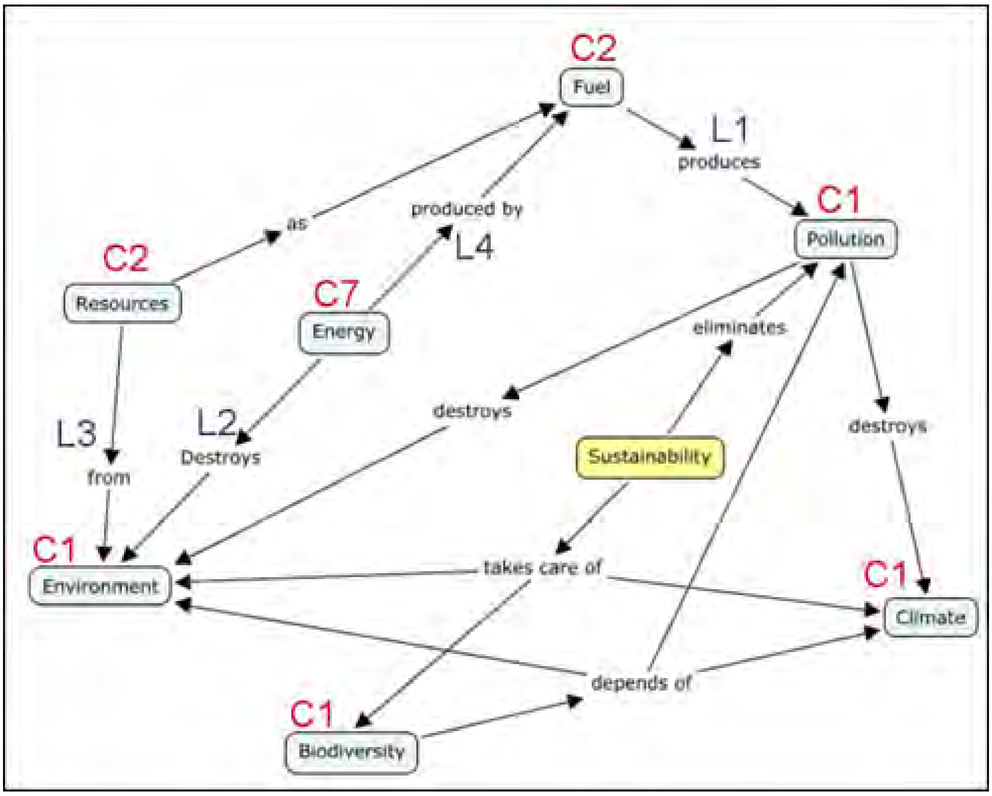


Figure 7.4 Example representation of a Cmap: student 2

From the Cmap examples next relevant information can be evaluated:

Variable		Example
Number of students	*NS*	2
Number of concepts student 1	NC_{S1}	12
Number of concepts student 2	NC_{S2}	7
Number of links student 1	NL_{S1}	4
Number of links student 2	NL_{S2}	12
Number of categories	N_{Ca}	10
Number of concepts per student (Eq. 7.1)	$\overline{NC}$	$\overline{NC} = \frac{\sum_{j=1}^{j=NS} NC_j}{NS} = \frac{NC_{S1} + NC_{S2}}{2} = 9.5$

Table 7.2 Variables evaluated from Cmaps example in figures 7.3 and 7.4

Therefore using the variables from table 7.2 the indicators values are:

<u>Category relevance index</u>

Applying Equation 7.4 the results are:

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	8	4	0	0	0	0	3	0	1	3
CD_i	42%	21%	0%	0%	0%	0%	16%	0%	5%	16%
NS_i	2	2	0	0	0	0	2	0	1	1
SC_i	100%	100%	0%	0%	0%	0%	100%	0%	50%	50%
CR_i	**43%**	**27%**	**0%**	**0%**	**0%**	**0%**	**18%**	**0%**	**3%**	**9%**

Table 7.3 Category relevance variables evaluated from both students of the example

Graphically:

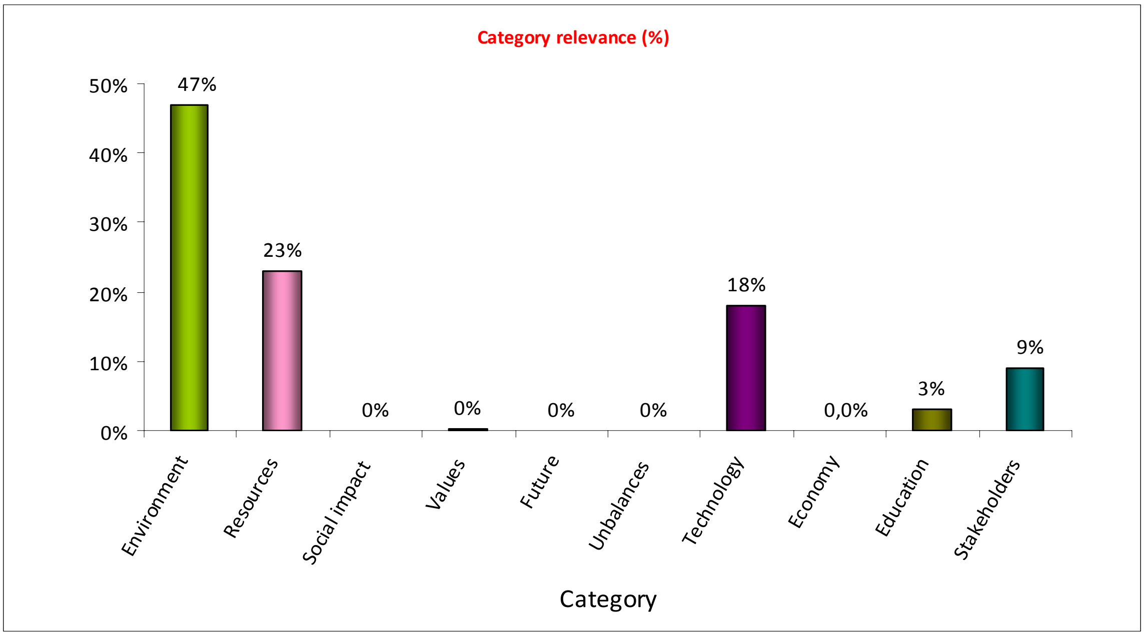


Figure 7.5 Category relevance distribution from Cmaps example in figures 7.3 and 7.4

Complexity Index

Figure 7.6 shows de partial number of links inter-categories

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Σ
C1-Environment		1	0	0	0	0	0	0	0	0	1
C2-Resources	2		0	0	0	0	1	0	0	0	3
C3-Social impact	0	0		0	0	0	0	0	0	0	0
C4-Values	0	0	0		0	0	0	0	0	0	0
C5-Future	0	0	0	0		0	0	0	0	0	0
C6-Unbalances	0	0	0	0	0		0	0	0	0	0
C7-Technology	2	2	0	0	0	0		0	1	1	6
C8-Economy	0	0	0	0	0	0	0		0	0	0
C9-Education	0	0	0	0	0	0	0	0		0	0
C10-Stakeholders	3	1	0	0	0	0	1	0	1		6
									Total		16

Table 7.4 Number of links inter-categories from both students example

Relative inter-category links *(Eq. 7.6)*:

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{4+12}{10 \times 2} = 0.8$$

Applying Equation 7.5 complexity index value is **7.6.**

The category relevance distribution shows the relevance that students give to each category of the taxonomy. In the example presented, students relate sustainability mostly to environment, followed by resources and technology. Stakeholders and Education are given little value. Some categories have not even been mentioned such as social impact, values, future, unbalances and economy. The category relevance index presents a direct picture of the situation. Therefore it is an absolute index.

The complexity index gives a relative value that should be compared within the same learning action (*pretest-posttest*) and/or with other learning activities. Therefore it is a comparative index.

7.3 Reference Conceptual map

There is not an ideal conceptual map in relation to Sustainability. First of all, because as many authors argue (Jickling, 2004; Leal Filho, 2000; Martin et al., 2005) the sustainability concept/definition evolves along time, and secondly because its conceptualisation differs with its spatial contextualisation (culture, traditions, society structure …) (Eagan et al., 2002; Fenner et al., 2006; Carew & Mitchell, 2008). Nevertheless, considering the technological universities' context of Western European countries, where this study is focused, it is possible to find a desirable value for the Cmap indicators described in the previous section: Complexity and Category relevance. With that purpose two analyses have been used in this study: semantic analysis of reference texts and experts' conceptual maps analysis.

7.3.1 Semantic analysis of reference texts

Lourdel (2004) in her PhD thesis proposed a semantic analysis of two reference texts in relation to the definition of SD (the semantic analysis is done to the French version of the texts):

- **Brundtland report** (CMED, 1989). Its targets were multilateralism and interdependence of nations in the search for a sustainable development path. The report sought to recapture the spirit of the United Nations Conference on the Human Environment - the Stockholm Conference - which had introduced environmental concerns to the formal political development sphere. It placed environmental issues firmly on the political agenda; it aimed to discuss the environment and development as one single issue. Its publication and the work of the World Commission on Environment and Development laid the groundwork for the convening of the 1992 Earth Summit and the adoption of Agenda 21, the Rio Declaration and the establishment of the UN Commission on Sustainable Development.

- **Agenda 21** (CNUED, 1992). Education, raising of public awareness and training are linked to virtually all areas in Agenda 21, and even more closely to the ones on meeting basic needs, capacity-building, data and information, science, and the role of major groups. The Declaration and Recommendations of the Tbilisi Intergovernmental Conference on Environmental Education organized by UNESCO and UNEP and held in 1977, have provided the fundamental principles for the proposals in this document.

The analysis of the reference documents were based on a 9 category taxonomy: *Environment*, *Social*, *Economy-Science-Technology*, *Means of execution* (action verbs from the semantic analysis), *Stakeholders*, *Spatial dimension*, *Temporal dimension*, *Policies* and *others*. Following her analysis, it can be seen that she reduced the number of categories to 6. Using this 6 category taxonomy the results obtained by Lourdel, when semantically analysing the second chapter of the Brundtland report (the one that defines SD) and the summary of the Agenda 21, in terms of category relevance are illustrated in table 7.5.

Category	Brundtland report	Agenda 21 summary
Environmental aspects	27%	14%
Socio cultural aspects	15%	6%
Multi-dimensional (spatial-temporal) aspects	13%	11%
Economy-Science-Technology aspects	14%	42%
Stakeholders aspects	5%	13%
Policy aspects	5%	1%
Others	21%	13%

Table 7.5 Category relevance of reference texts semantic analysis. Evaluated from Lourdel (2004)

7.3.2 Experts' conceptual maps

The participant experts in this survey were approached in two events:

- 1st week International Seminar on Sustainable Technology Development organised by the UPC under the framework of its Masters degree on Sustainable Development[1], June 2008 in Barcelona. The experts were professors of the seminar from the UPC, DUT and CUT.
- 4th Engineering Education in Sustainable Development Conference[2], October 2008 in Graz. The experts were participants in the conference with teaching experience in SD and/or researchers on EESD.

The results of the expert Cmaps analysis are:

Variable		Example
Number of experts	*NS*	19
Number total of concepts	NC_{S1}	377
Number total of links inter-categories	NL_{S2}	238
Number of categories	N_{Ca}	10
Number of concepts per expert (Eq. 7.1)	$\overline{NC}$	$\overline{NC} = \frac{\sum_{j=1}^{j=NS} NC_j}{NS} = \frac{377}{19} = 19.84$

Table 7.6 Variables evaluated from experts Cmaps

Therefore using the variables from table 7.6 the indicators values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	40	24	28	51	12	20	58	20	46	74
CD_i	11%	6%	7%	14%	3%	5%	15%	5%	12%	20%
NS_i	15	12	14	16	10	13	15	13	15	15
SC_i	79%	63%	74%	84%	53%	68%	79%	68%	79%	79%
CR_i	**11%**	**5%**	**7%**	**15%**	**2%**	**5%**	**16%**	**5%**	**13%**	**21%**

Table 7.7 Category relevance variables evaluated from experts Cmaps

From the category relevance index it is shown that the role of stakeholders is the most referenced (21%). It is interesting to underline the categories that are most frequent. Over 10%, and by order, these are *Technology*, *Values, Education,* and *Environment*. Finally the lowest referenced category is future aspects (2%).

Graphically:

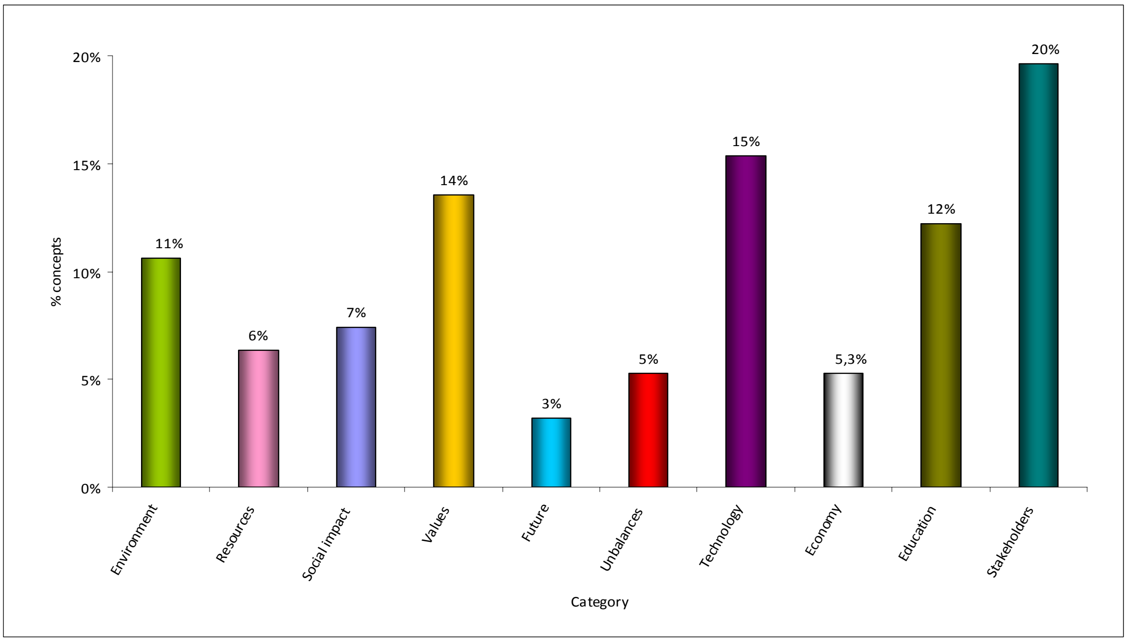


Figure 7.6 Concepts distribution of experts Cmaps

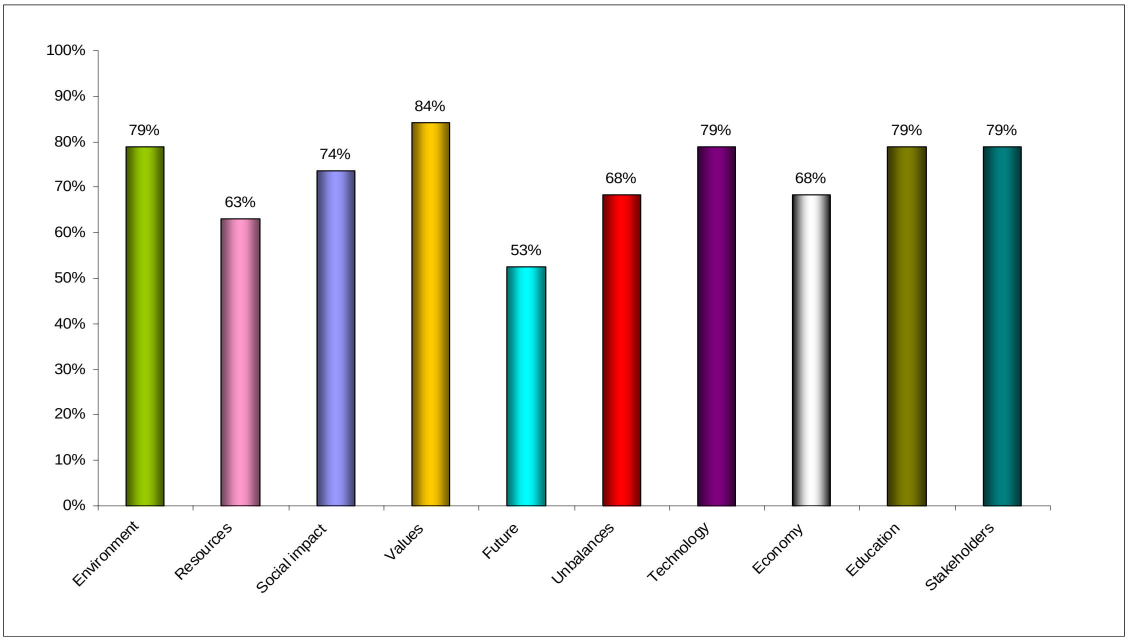


Figure 7.7 Percentage of experts per category distribution

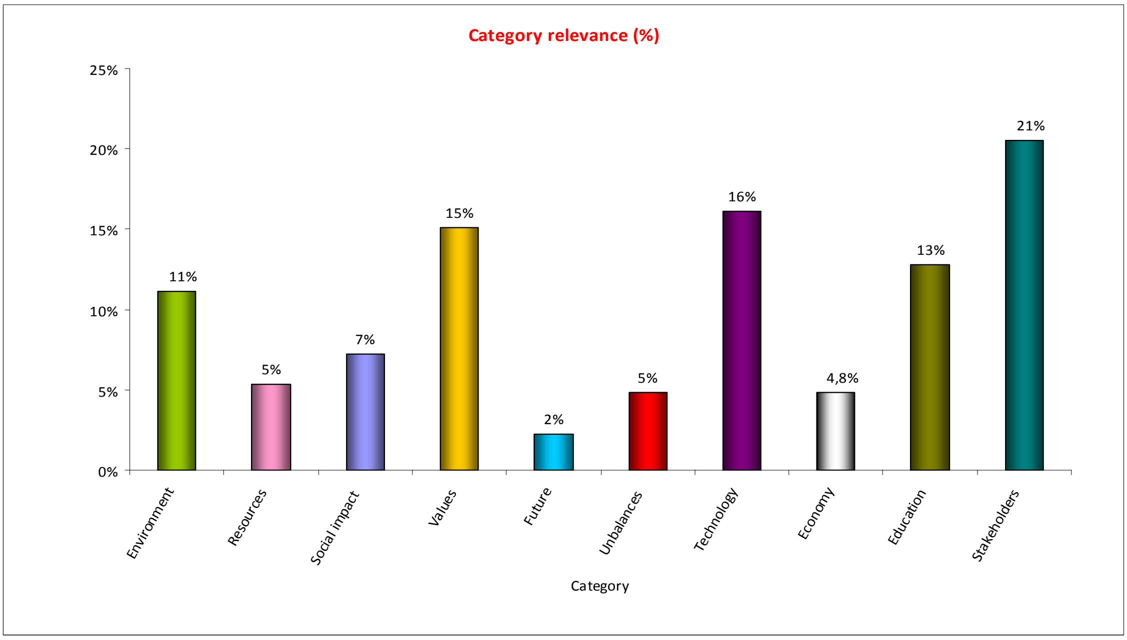


Figure 7.8 Category relevance of experts' Cmaps

Complexity Index

Table 7.8 shows the partial number of inter-category links where the most linked is *Stakeholders*, next are *Technology*, *Social* impact and *Environment* followed by *Values* and *Education* categories, meanwhile the *Future* category is the least linked. This low value for the *Future* category was expected taking into account that the number of concepts related to the future represents only 3% of the total number of concepts.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Σ
C1-Environment		12	6	3	3	3	13	4	1	3	48
C2-Resources			2	2	0	3	12	3	0	3	25
C3-Social impact				13	3	8	13	2	3	7	49
C4-Values					1	6	5	3	14	10	39
C5-Future						3	1	0	2	0	6
C6-Unbalances							2	3	3	3	11
C7-Technology								8	15	13	36
C8-Economy									1	11	12
C9-Education										12	12
C10-Stakeholders											0
Σ		12	8	18	7	23	51	23	39	62	
										Total	238

Table 7.8 Number of intercategory links from experts study

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{238}{10 \times 19} = 1.25$$

Applying Equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{24.80}$$

So far not much can be said about the complexity index as it is a relative indicator so when its value is compared against the values obtained by the other samples it would be possible to analyse their relevance.

Comparison of the results when using different taxonomies.

In order to validate the 10 categories taxonomy proposed in this work, the analysis of the experts' Cmaps in other taxonomies is presented.

4 categories taxonomy:

When defining the number of categories that it was decided to use a 10 categories' taxonomy in order to have a more precise diagnosis of the understanding of students. Nevertheless it is interesting to also evaluate it in a broader framework, thus the 4 categories taxonomy defined by the Sustainability Portal of the UNESCO Chair of Sustainability at UPC will be applied. All the case studies presented in chapter 8 will also show this broad framework assessment. The four categories defined by the UNESCO chair of Sustainability at UPC are (Carrera, 2007):

-Category 1 – Environmental.

-Category 2 – Social.

-Category 3 – Economic.

-Category 4 – Institutional.

The results of the expert Cmaps analysis are:

Variable		Example
Number of experts	*NS*	19
Total number of concepts	NC_{S1}	377
Total number of inter-category links	NL_{S2}	172
Number of categories	N_{Ca}	4
Number of concepts per expert (Eq. 7.1)	$\overline{NC}$	$\overline{NC} = \frac{\sum_{j=1}^{j=NS} NC_j}{NS} = \frac{377}{19} = 19.84$

Table 7.9 Variables evaluated from experts Cmaps. 4 categories analysis

Therefore using the variables from table 7.9 the indicators values are:

Category relevance index

Category	C_1	C_2	C_3	C_4
NC_i	64	111	78	120
CD_i	17%	29%	21%	32%
NS_i	17	18	18	18
SC_i	89%	95%	95%	95%
CR_i	**16%**	**30%**	**21%**	**32%**

Table 7.10 Category relevance variables evaluated from experts Cmaps. 4 categories analysis

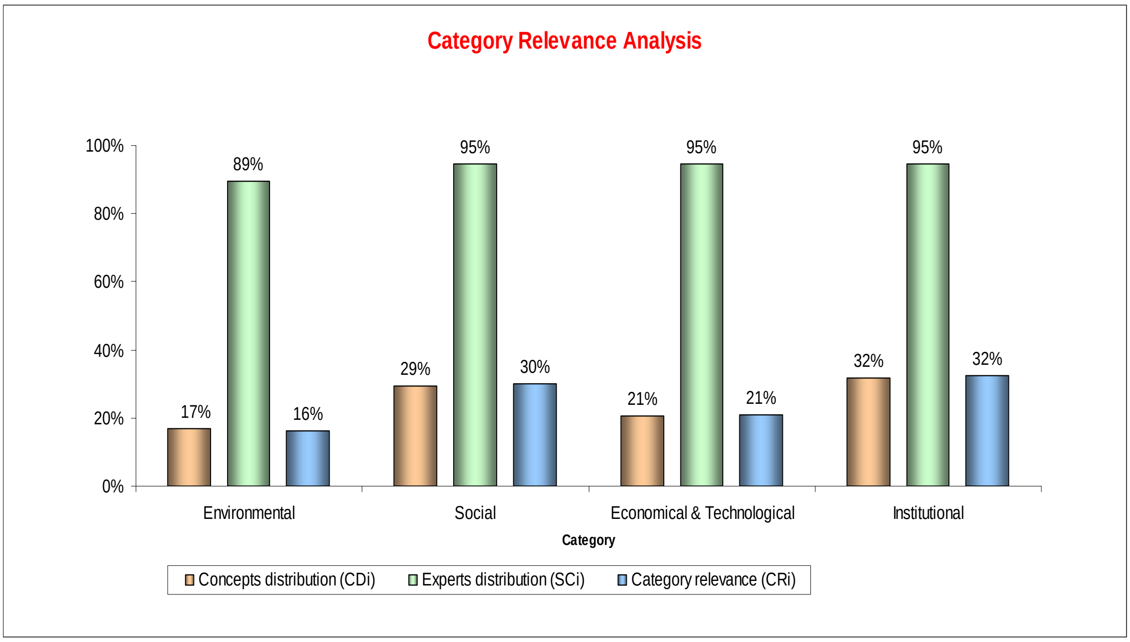


Figure 7.9 Category relevance variables evaluated from experts' Cmaps. 4 categories analysis

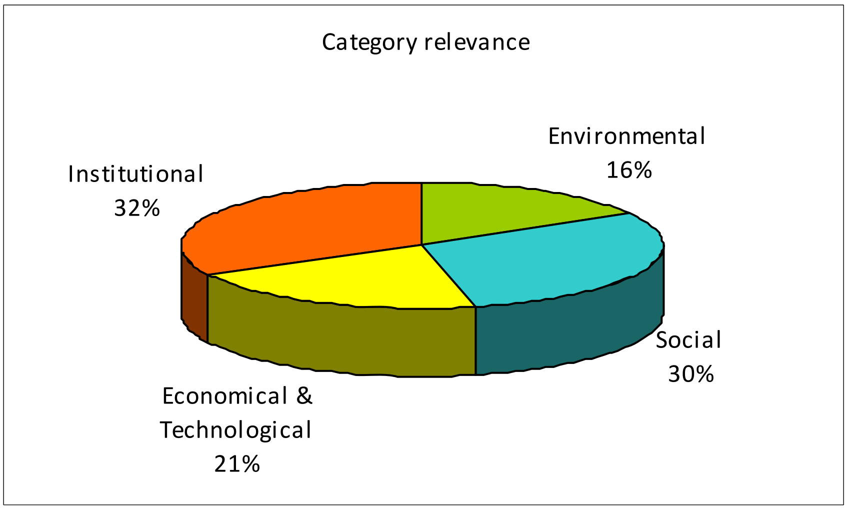


Figure 7.10 Category relevance variables evaluated from experts Cmaps. 4 categories analysis

Using the four category taxonomy it can be seen that the distribution of categories is very uniform, although the institutional (32%) and social (30%) categories are considered more relevant than economic (21%) and environmental (16%) ones.

Complexity index

Table 7.11 shows the partial number of inter-category links where the most linked is the *Institutional* category, while the *Environmental* and *Technological/Economic* categories are the least linked.

	C1	C2	C3	C4	Σ
C1-Environmental		22	32	7	61
C2-Social			29	42	71
C3-Technological/Economic				40	40
C4-Institutional					0
	0	22	61	89	
				Total	172

Table 7.11 Number of inter-category links from experts study. 4 categories analysis

Relative inter-category links *(Eq. 7.6):*

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{172}{4 \times 19} = 2.26$$

Applying Equation 7.5 the complexity index value is **44.8.**

<u>6 categories taxonomy:</u>

In order to compare the results of the experts' Cmaps with the semantic analysis of reference text the experts' Cmaps are also analysed using the next 6 categories taxonomy (Lourdel, 2004):

Category 1 – Environmental.

Category 2 – Social - cultural.

Category 3 – Multidimensional.

Category 4 – Economic-Scientific-Technological.

Category 5 – Procedural and political approaches.

Category 6 – Actors and Stakeholders.

The results of the expert Cmaps analysis are:

Variable		Example
Number of experts	*NS*	19
Number total of concepts	NC_{S1}	377
Number total of links inter-categories	NL_{S2}	202
Number of categories	N_{Ca}	6
Number of concepts per expert (Eq. 7.1)	$\overline{NC}$	$\overline{NC} = \frac{\sum_{j=1}^{j=NS} NC_j}{NS} = \frac{377}{19} = 19.84$

Table 7.12 Variables evaluated from experts' Cmaps. 6 categories analysis

Therefore using the variables from table 7.12 the indicators values are:

<u>Category relevance index</u>

Category	C_1	C_2	C_3	C_4	C_5	C_6
NC_i	64	79	32	78	46	74
CD_i	17%	21%	8%	21%	12%	20%
NS_i	17	18	15	18	15	15
SC_i	89%	95%	79%	95%	79%	79%
$\boldsymbol{CR_i}$	**18%**	**23%**	**8%**	**23%**	**11%**	**18%**

Table 7.13 Category relevance variables evaluated from experts Cmaps. 6 categories analysis

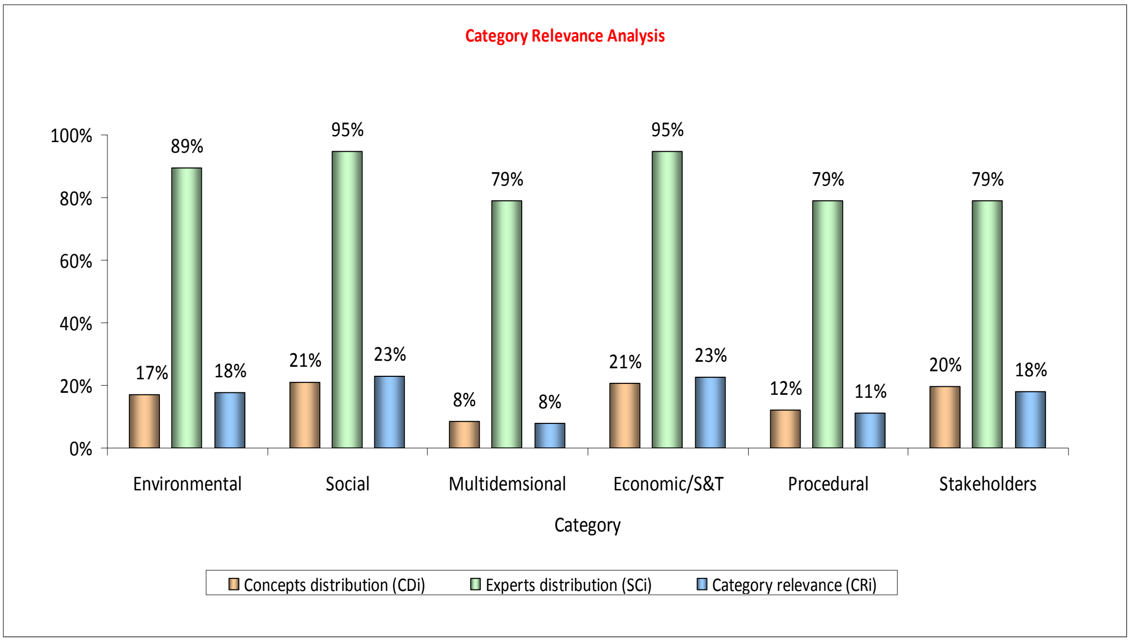


Figure 7.11 Category relevance variables evaluated from experts Cmaps. 6 categories analysis

Using the six category taxonomy it can be seen again that the distribution of categories is very uniform, although the *Social* (23%), *Economic/S&T* (23%), *Environmental* (18%) and *Stakeholders* (18%) categories are considered more relevant than *procedural* (11%) and *Multidimensional* (8%) ones.

Complexity index

Table 7.14 shows the partial number of inter-category links where the most linked is *Social*, while the *Multidimensional* category is the least linked. This low value for the *Multidimensional* category is normal taking into account that the number of concepts related to future is only 8% of total concepts.

	C1	C2	C3	C4	C5	C6	Σ
C1-Environmental		13	9	32	1	6	61
C2-Social			18	23	17	17	75
C3-Multidimensional				6	5	3	14
C4-Economic/S&T					16	24	40
C5-Procedural						12	12
C6-Stakeholders							0
Σ	0	13	27	61	39	62	
						Total	202

Table 7.14 Number of intercategory links from experts study. 6 categories analysis

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{202}{6 \times 19} = 1.77$$

Applying Equation 7.5 the complexity index value is **35.12**

Now it is possible to compare the three reference category relevance distributions. Figure 7.12 shows the distributions of Brundtland and Agenda 21 semantic analysis, plus the experts' Cmaps one.

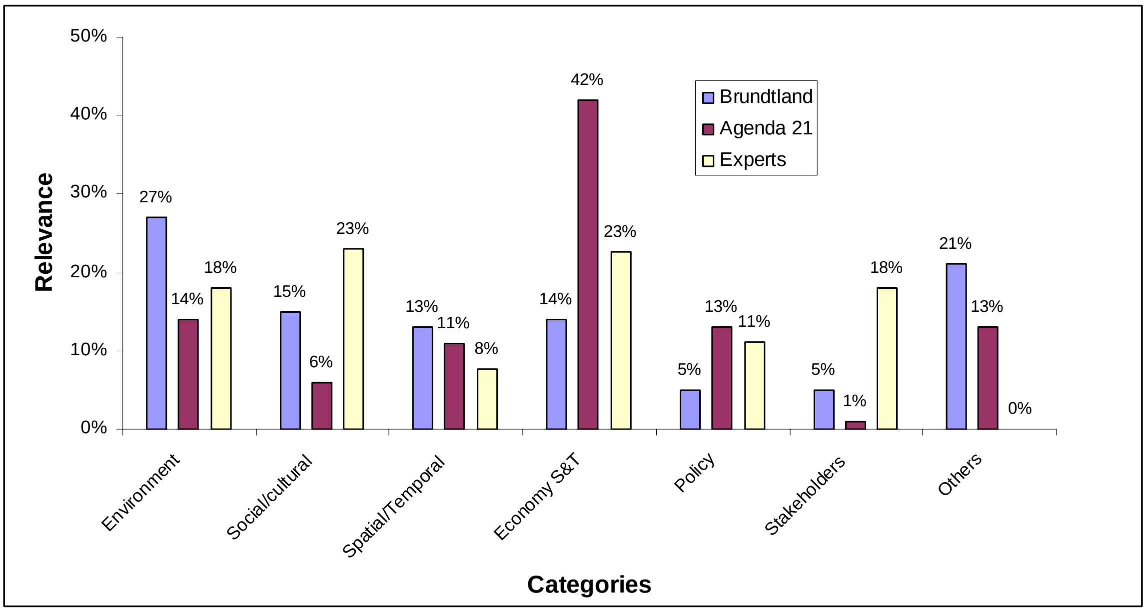


Figure 7.12 Category relevance comparison between key references on SD

There are many commonalities among the three references. Nevertheless some differences also appear. Both *Brundtland* and *Agenda 21* give high value to *Environment* and to *Economy S&T*, but low relevance to the *Socio/cultural* and *Stakeholders* categories. Meanwhile experts' Cmaps givegreat importance to these last two categories. This mismatch can be related to the evolution of the SD concept. The two referenced texts are about 20 years old (1987, 1992) and currently SD is more related to Stakeholder participation and social/cultural aspects than before. Thus it is proposed keeping the experts' Cmaps as a reference of category distribution, although it might be subject to criticism, keeping in mind the evolutionary conceptualization/definition of SD. This reference category distribution doesn't claim to homogenise the SD concept. It should be kept in mind that the reference texts analysed are agreed documents while the experts' Cmaps category distribution has not been discussed as such, but it has been obtained from the Cmaps of a set of experts.

7.4 Sensibility to the evaluator of Cmaps as an assessment tool

In order to analyse the evaluator variable effect the same sample of conceptual maps has been analysed by two different evaluators, and the results are compared. The evaluators are from different universities, countries and speciality:

- Evaluator 1: Industrial engineer Jordi Segalàs, senior lecturer at UPC (Spain).

- Evaluator 2: Chemical engineer and PhD Magdalena Svanström, assistant professor at CUT (Sweden).

The sample evaluated corresponds to Cmap1 from CUT-1 case study. The results are shown in the next tables and figures.

<u>Cmap$_1$: Before taking the course</u>

Variable		Evaluator 1	Evaluator 2
Number of students	*NS*	51	51
Number total of concepts	NC_{S1}	737	764
Number total of links inter-categories	NL_{S2}	421	530
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	14.45	14.98

Table 7.15 Case study CUT-1. Cmap$_1$: variables' value

Using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	192	69	59	15	19	6	265	28	21	46
CD_i	26%	9%	8%	2%	3%	1%	36%	4%	3%	6%
NS_i	49	29	31	10	16	5	45	22	16	23
SC_i	96%	57%	61%	20%	31%	10%	88%	43%	31%	45%
$\mathbf{CR_i}$	**34%**	**7%**	**7%**	**1%**	**1%**	**0%**	**43%**	**2%**	**1%**	**4%**

Table 7.16 Case study CUT-1. $Cmap_1$: Category relevance variables. Evaluator 1

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	137	94	58	19	17	4	327	31	16	58
CD_i	18%	12%	8%	2%	2%	1%	43%	4%	2%	8%
NS_i	47	36	32	14	13	3	46	24	14	25
SC_i	92%	71%	63%	27%	25%	6%	90%	47%	27%	49%
$\mathbf{CR_i}$	**22%**	**11%**	**6%**	**1%**	**1%**	**0%**	**51%**	**3%**	**1%**	**5%**

Table 7.17 Case study CUT-1. $Cmap_1$: Category relevance variables. Evaluator 2

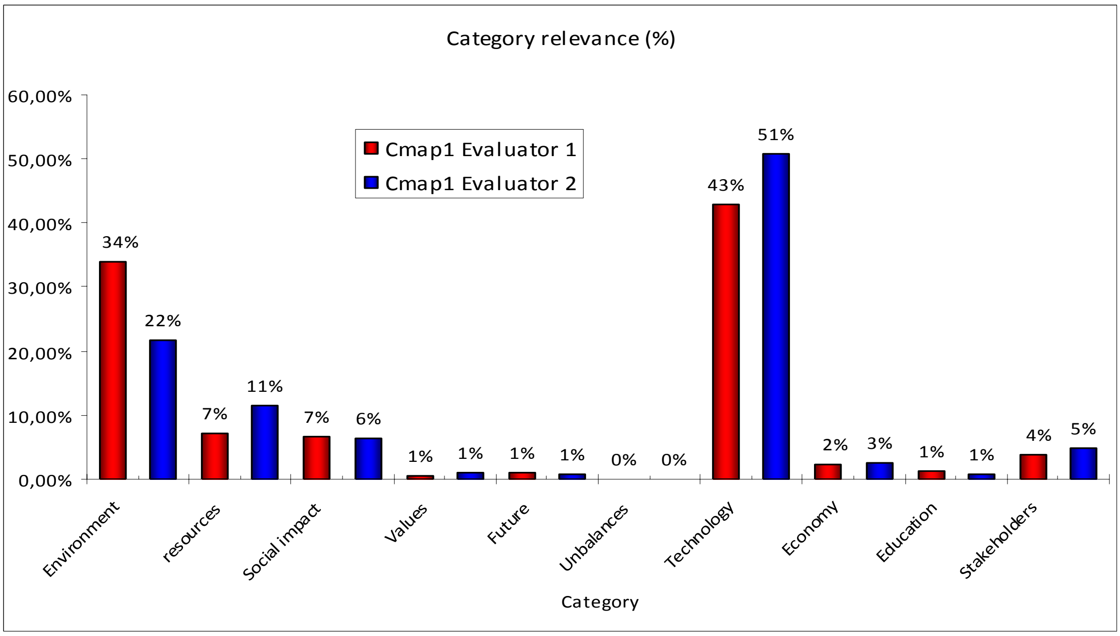


Figure 7.13 CUT-1 Comparison of $Cmap_1$ assessment by two different evaluators. 10 categories taxonomy

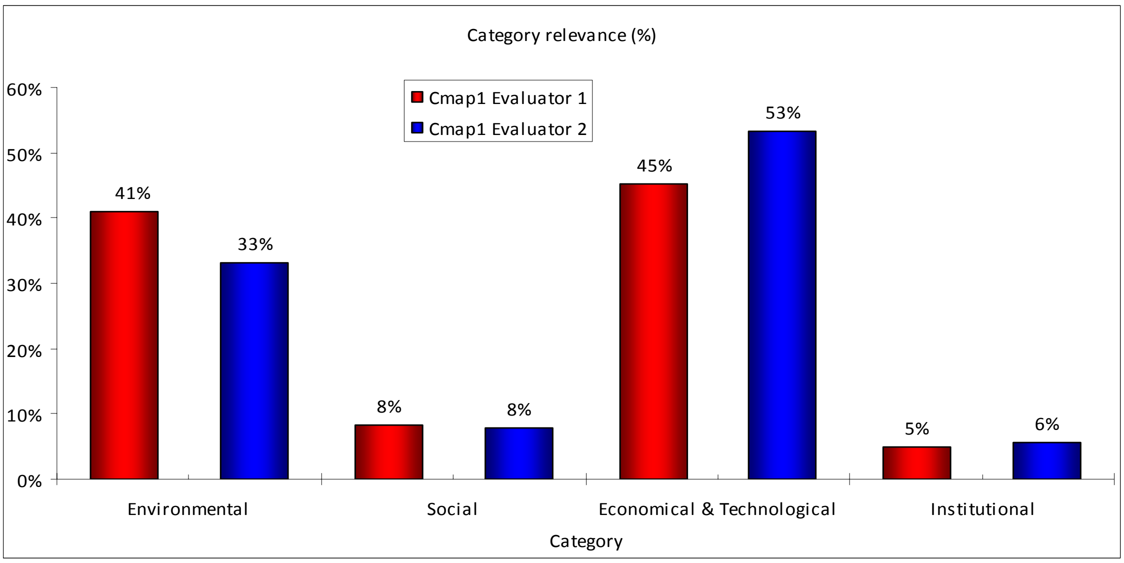


Figure 7.14 CUT-1 Comparison of $Cmap_1$ assessment by two different evaluators. 4 categories taxonomy

The average error in the category relevance index is 14 % which is mainly due to the misunderstanding of concepts related to technology and economy and to environment. The social and institutional values are similar. (See table 7.18)

	Environmental	Social	Economical & Technological	Institutional	
Cmap1 Evaluator 1	41,0%	8,3%	45,1%	5,0%	
Cmap1 Evaluator 2	33,1%	7,9%	53,2%	5,6%	
Evaluator 1 - Evaluator 2	7,92%	0,38%	8,12%	0,63%	Total
Error (%)	19%	5%	18%	13%	14%

Table 7.18 Case study CUT-1. $Cmap_1$: Category relevance index. Comparing two evaluators' results

Complexity Index

	Evaluator 1	Evaluator 2
Complexity index (CO)	11.93	15,57

Table 7.19 Case study CUT-1. $Cmap_1$: Complexity index. Comparing two evaluators' results

The error in the complexity index is 31% which is quite relevant.

7.5 Conclusions

The assessment methodology of Conceptual maps will consist of the evaluation of two indicators because it was shown that they provide the necessary information in order to evaluate the students' understanding cognitive domain:

The Category relevance index (*CR*). It provides information about what students think sustainability is most related to. This indicator is evaluated under a taxonomy of 10 categories: Environment, Resources, Social impact, Values, future, Unbalances, Technology, Economy, Education and Stakeholders. It is calculated taking into account the distribution of concepts in categories and the percentage of students that give concepts to a certain category.

The Complexity index (*CO*). It evaluates how rich and connected students see the concepts related to sustainability. In other words, how systemic or complex they perceive sustainability. It considers the average number of concepts per student and the relative number of connections between concepts of different categories.

A reference Conceptual map has been discussed taking into account two studies. First previous works on the semantic analysis of two reference texts in relation to the definition of SD: Brundtland report (CMED,1989) and chapter 32 of Agenda 21 (CNUED, 1992). Second an expert on the ESD conceptual map survey (see figure 7.12). This reference conceptual map will help to analyse the Cmaps assessment of courses by comparing the students' Cmaps before and after taking the courses to the reference Cmap.

When evaluating the sensibility of the assessment tool to evaluator effect, it has been shown that there are some differences between the results when two evaluators assess the same sample. However, in the category relevance index the differences are small (4% and 13%) when it comes to comparing the *Social* and *Institutional* categories. And in both cases the highest values are clearly given to "hard" categories like *Environmental* and *Technological & Economic*. Therefore these differences do not introduce a relevance error in the larger picture of the analysis. The two evaluators did not agree previously on how to evaluate the conceptual maps. Therefore a procedure of cmaps' assessment should be developed in order to get more accurate results.

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[1] http://www.upc.edu/english/estudis/masters-eees/fitxa_master.php?id_estudi=64&id_titulacio=128&cerca=1

[2] http://eesd08.tugraz.at/

8 Conceptual maps. Case studies

This chapter presents 10 case studies where specific courses on SD taught in five technological European universities are assessed using Conceptual maps. For each case study a description of the course (learning goals, content, pedagogy used, etc.) is introduced and both indexes, category relevance (CR) and complexity (CO) are evaluated. The results are compared with the reference indexes obtained from the experts' Cmaps. Moreover, an analysis of independent variables is presented (result by speciality, by gender, by year of studies, etc.).

8.1 Introduction

In order to evaluate the learning of Sustainability by engineering students in SD learning actions 10 case studies have been carried out in 5 universities from 4 European countries. In all the case studies students' conceptual maps are analysed, taken both before (Cmap1) and after (Cmap2) the learning activity (LA). Table 8.1 shows the relevant information of the learning activities evaluated. The following sections describe the courses and the results obtained from their Cmap analysis.

Code	University	Learning activity	ECTS	Sample (Cmap1/Cmap2)
UPC-1	Technical University of Catalonia	Technology & Sustainability	5	201/226
UPC-2	Technical University of Catalonia	Technology & Sustainability	5	35/43
UPC-3	Technical University of Catalonia	Technology & Environment	5	30/31
UPC-4	Technical University of Catalonia	International Seminar on Sustainable Technology	5	19/19
DUT-1	Delft University of Technology	Energy III	8 (0.7)	32/26
DUT-2	Delft University of Technology	Societal aspects of information technology	4	68/45
CUT-1	Chalmers University of Technology	Global Chemical Sustainability	7	51/53
KPI-1	Kiev Polytechnic Institute	Sustainable Development	3	23/17
EUT-1	Eindhoven University of Technology	Technology & Sustainability	3	10/28
EUT-2	Eindhoven University of Technology	Technology & Sustainability	3	60/18
			Total	529/506

Table 8.1 Case studies data

8.2 Case studies analysis

The cases studies are organized by universities. The Universities that have participated in the study are:

- Technical University of Catalonia (UPC) [Spain]: 3 courses and 1 seminar.
- Chalmers University of Technology (CUT) [Sweden]: 1 Course.
- Delft University of Technology (DUT) [The Netherlands]: 2 Courses.
- Kiev Polytechnic Institute (KPI) [Ukraine]: 1 Course.
- Eindhoven University of Technology (EUT) [The Netherlands]: 2 Courses.

8.3 Case studies at the Technical University of Catalonia

At the Technical University of Catalonia 4 study cases have been carried out.

8.3.1 UPC Case study 1: Technology and Sustainability

Case study Code: **UPC-1**			
University: **Technical University of Catalonia**			
Course name: **Technology and Sustainability**		Cycle: **1st and 2nd**	ECTS: **5**
Web: **http://www.catunesco.upc.edu/www/index.php?seccio=doc&pag=assig-14882**			
Pedagogy: **Distance learning course. Contents on Compact Disk. Participation in virtual forum (10%). Exercises (30%).**			
Date of survey: **2005**	Type of course: **Elective**	Sample $Cmap_1$: **201**	Sample $Cmap_2$: **226**
Students speciality: **All Technological specialities**			
Coordinator: **Enric Carrera**			
Objectives: To stimulate a new perception of reality and to change attitudes towards the environment. The course aims at increasing the students´ capacity for intervention and decision-making oriented towards sustainability.			
Program: The course is structured in 23 units. 1) The state of the world. Sustainable development 2) Basic ecology 3) Ecological and environmental economics 4) Impact of human activity on the atmosphere 5) Impact of human activity on the hydrosphere 6) Impact of human activity on the lithosphere 7) Examples of social un-sustainability 8) Examples of economic un-sustainability 9) Examples of environmental un-sustainability 10) Values. Ethics and environment 11) Science, technology and society 12) The information society: information and communication technologies (ICT) 13) Technological policies for sustainable development 14) Technologies and sustainability: energy 15) Technologies and sustainability: water management 16) Technologies and sustainability: waste management 17) Technologies and sustainability: noise and vibrations 18) Technologies and sustainability: materials 19) Technologies and sustainability: agriculture and food 20) Technologies and sustainability: mobility 21) Technologies and sustainability: architecture and town planning 22) Environmental management in business 23) Programs for Action. Agenda 21			

Table 8.2 Case study UPC-1. Course Technology and Sustainability

The results of the students' Cmaps analysis are:

$Cmap_1$: Before taking the course

Variable		Values
Number of students	*NS*	201
Number total of concepts	NC_{S1}	1408
Number total of links inter-categories	NL_{S2}	256
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	7,00

Table 8.3 Case study UPC-1. $Cmap_1$: Variables value

Therefore using the variables from table 6.1 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	401	205	104	59	10	9	401	16	71	63
CD_i	28%	15%	7%	4%	1%	1%	28%	1%	5%	4%
NS_i	171	100	76	44	9	7	166	14	55	42
SC_i	85%	50%	38%	22%	4%	3%	83%	7%	27%	21%
CR_i	**39%**	**12%**	**4%**	**1%**	**0%**	**0%**	**38%**	**0%**	**2%**	**2%**

Table 8.4 Case study UPC-1. $Cmap_1$: Category relevance variables

Graphically:

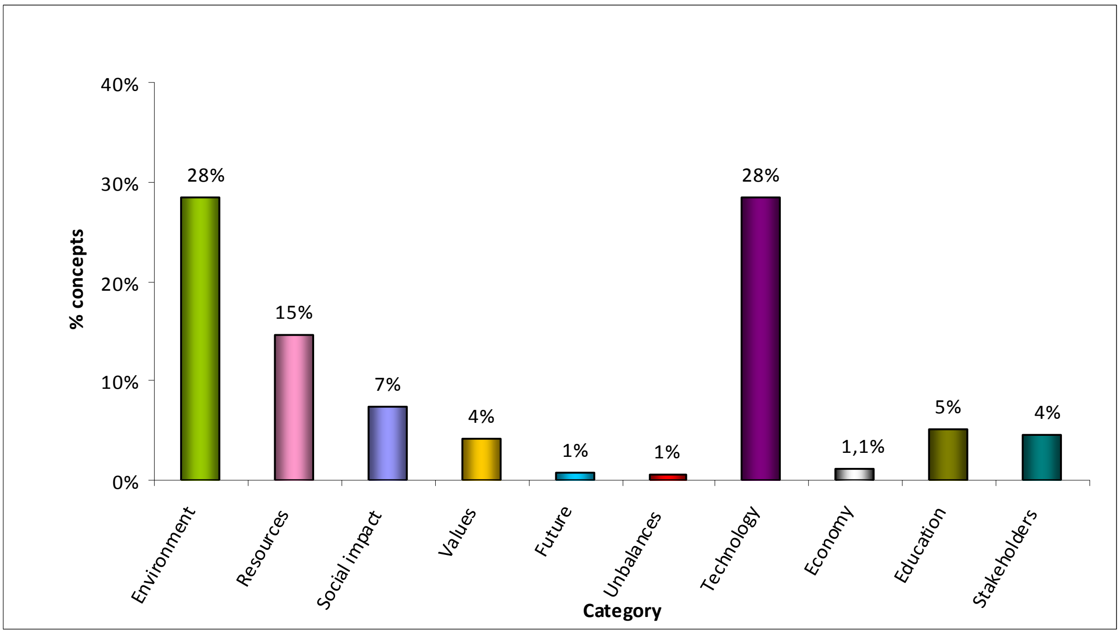

Figure 8.1 Case study UPC-1. $Cmap_1$: Concepts distribution

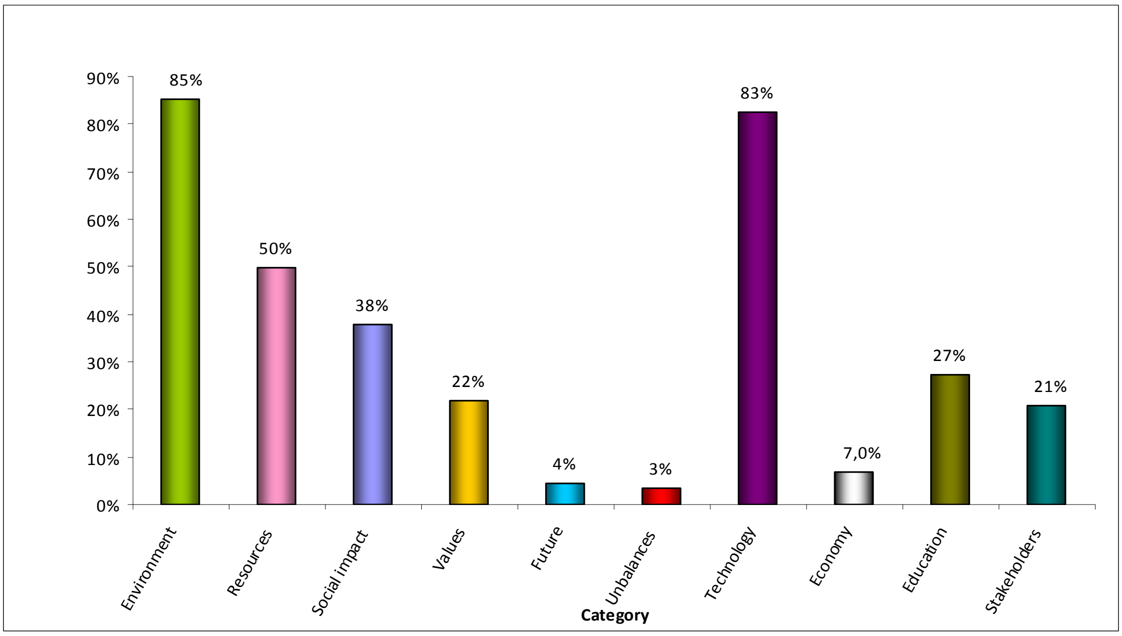

Figure 8.2 Case study UPC-1. $Cmap_1$: Percentage of experts per category distribution

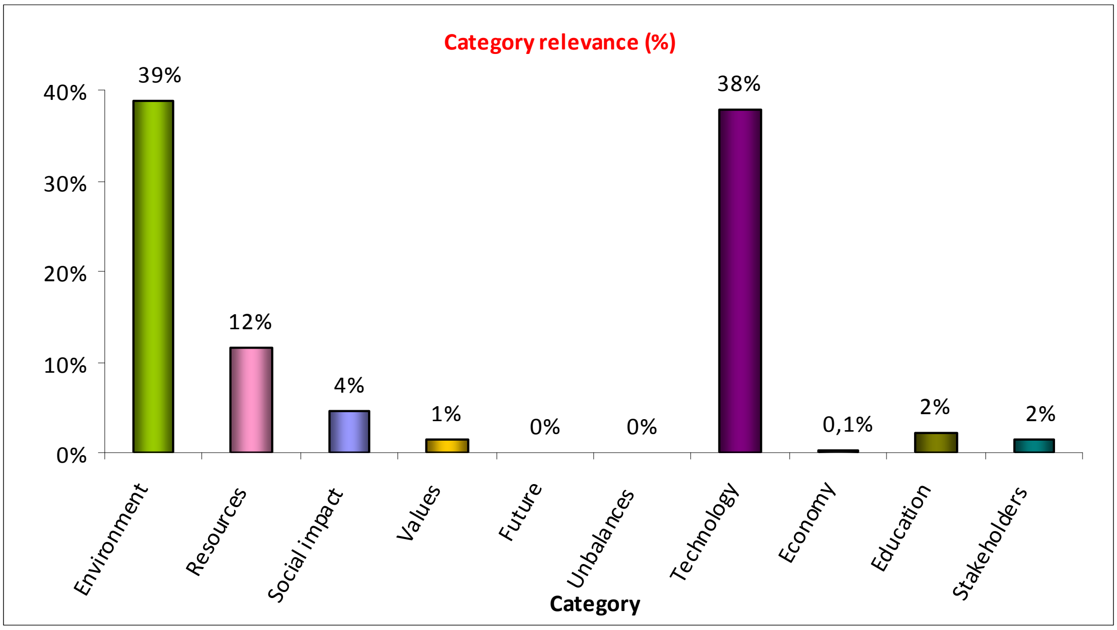

Figure 8.3 Case study UPC-1. $Cmap_1$: Category relevance index

From the category relevance index the role of *Environment* and *Technology* are the most referenced (39% + 38% = 77%). The next category relevance value is *Resources* with 12%. Finally, the other categories have little relevance.

Figure 8.4 shows the Category distribution under the four categories taxonomy. It shows that *Environmental* and *Technological/Economic* categories are (88%) seen as the most related to Sustainability by the students before taking the course.

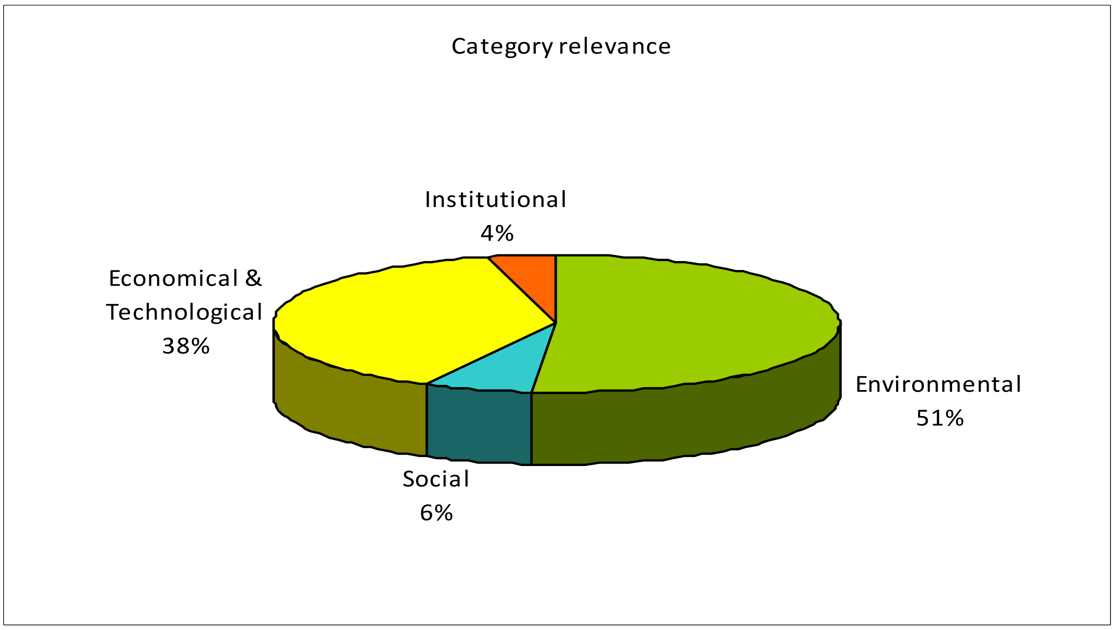

Figure 8.4 Case study UPC-1. $Cmap_1$: Category relevance index. 4 Categories taxonomy

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{256}{10 \times 201} = 0.13$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{0.91}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	226
Number total of concepts	NC_{S1}	5159
Number total of links inter-categories	NL_{S2}	1008
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	22.83

Table 8.5 Case study UPC-1. $Cmap_2$: Variables value

Therefore using the variables from table 8.5 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	1346	585	332	214	53	226	944	310	123	779
CD_i	26%	11%	6%	4%	1%	4%	18%	6%	2%	15%
NS_i	219	184	171	115	43	101	209	166	63	194
SC_i	97%	81%	76%	51%	19%	45%	92%	73%	28%	86%
CR_i	**31%**	**11%**	**6%**	**3%**	**0%**	**2%**	**21%**	**5%**	**1%**	**16%**

Table 8.6 Case study UPC-1. $Cmap_2$: Category relevance variables

Graphically:

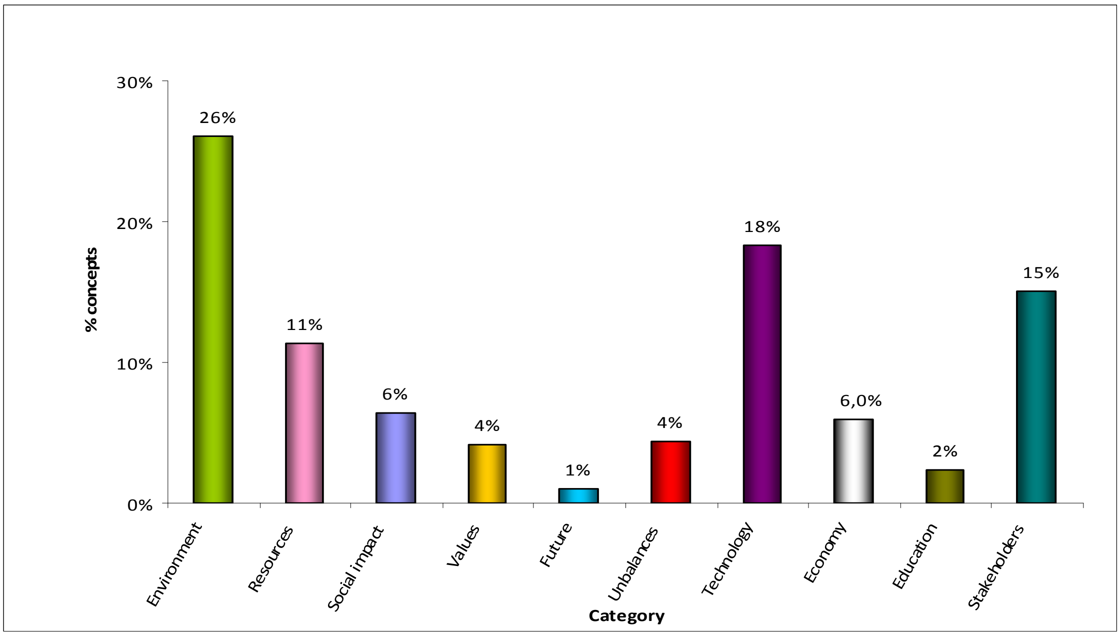

Figure 8.5 Case study UPC-1. $Cmap_2$: Concepts distribution

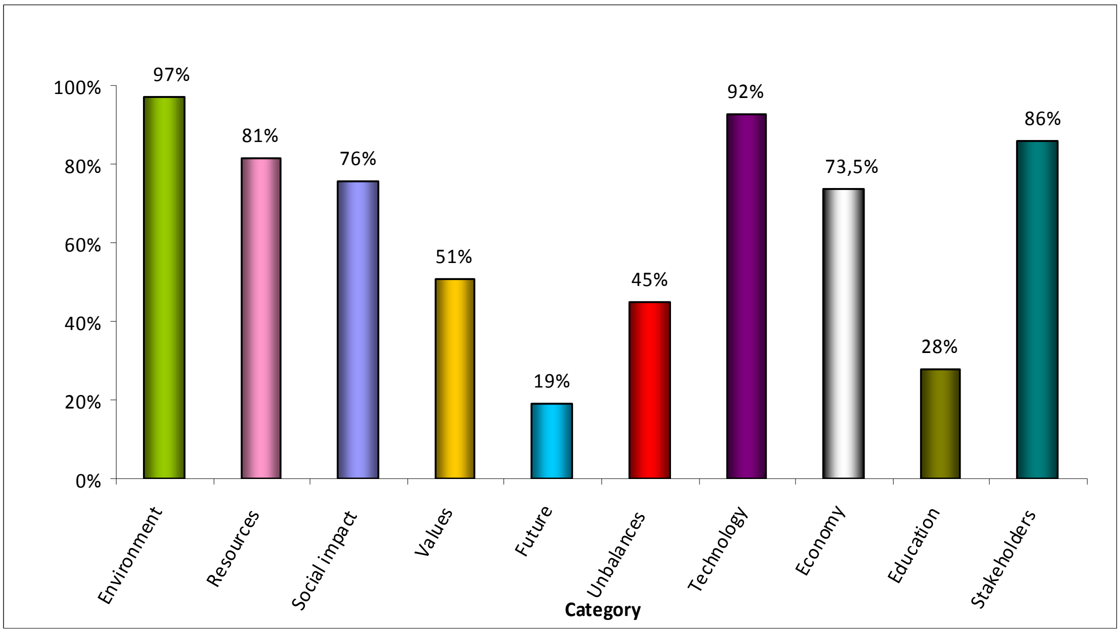

Figure 8.6 Case study UPC-1. $Cmap_2$: Percentage of experts per category distribution

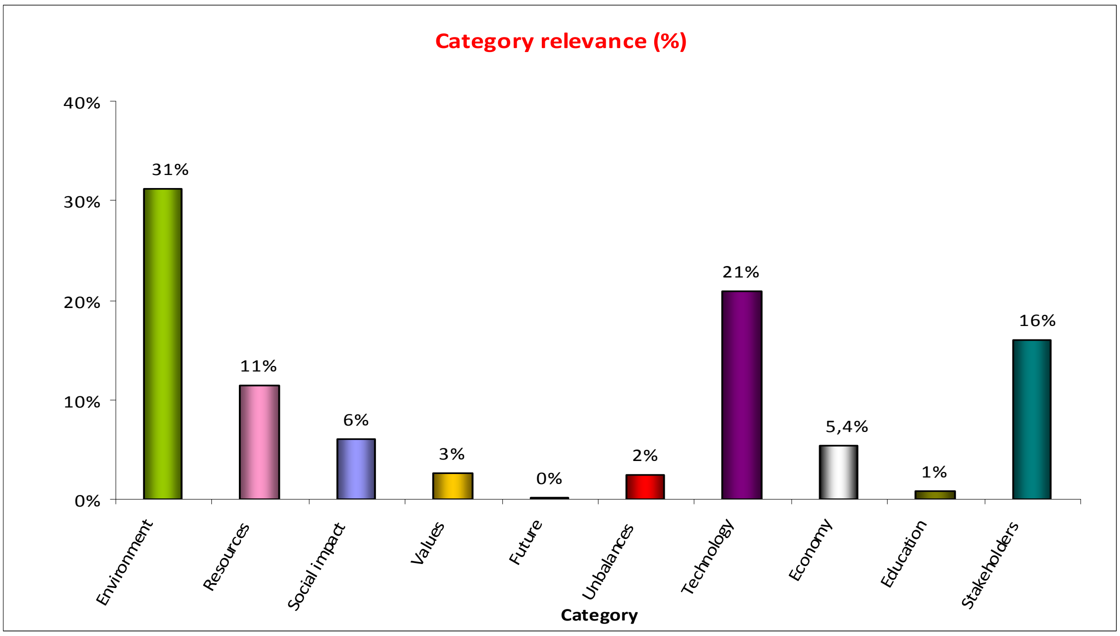

Figure 8.7 Case study UPC-1. $Cmap_2$: Category relevance index

From the category relevance index the role of *Environment* and *Technology* are still the most referenced (31% + 21% = 52%). Nevertheless other categories like *Stakeholders* (16%) and *Social impact* (6%) became more relevant. The analysis shows that *Future* (1%) and *Education* (2%) categories are considered almost irrelevant for sustainability.

Figure 8.8 shows the category distribution under the four categories taxonomy. It shows that *Environmental* and *Technological/Economic* categories (43+26 = 69 %) are still seen as the most related to sustainability. Nevertheless *Institutional* (17%) and *Social impact* (11%) categories also seem to be relevant for the students.

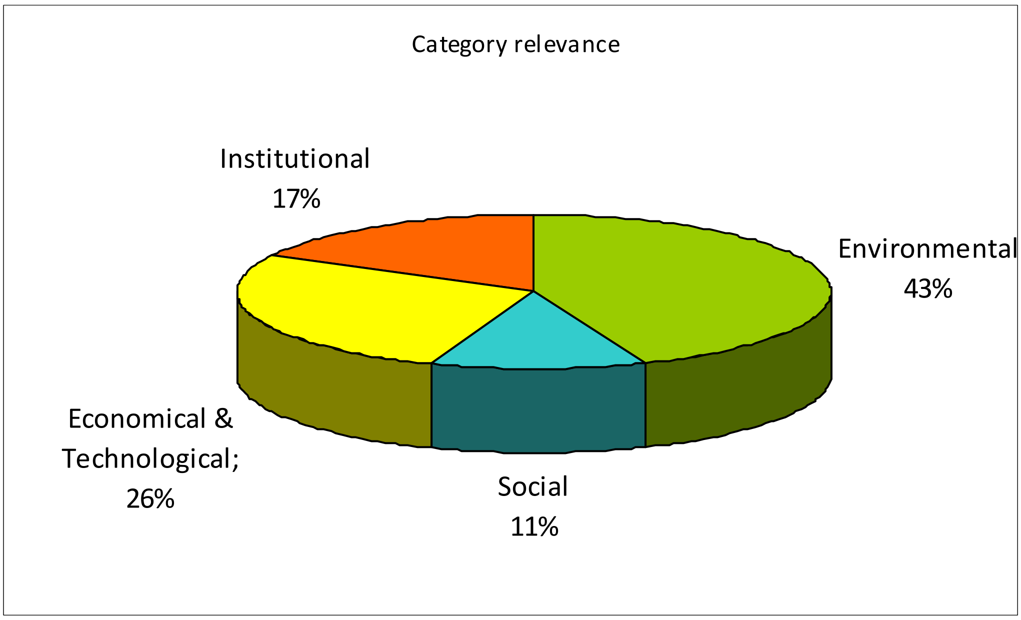

Figure 8.8 Case study UPC-1. $Cmap_2$: Category relevance index. 4 Categories taxonomy

<u>Complexity Index</u>

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{1008}{10 \times 226} = 0.45$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = 10.27$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.9 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts Cmap. In all categories, the results after having taken the course are closer to experts' Cmaps than the results before having taken it. This "improvement" in the category relevance index reveals that the course has enhanced the students' understanding of the sustainability concept. Nevertheless students, after taking the course, students still gave a lot of relevance to *Environmental* and *Technology* aspects and too little to the *Values*, E*ducation* and *Future* ones.

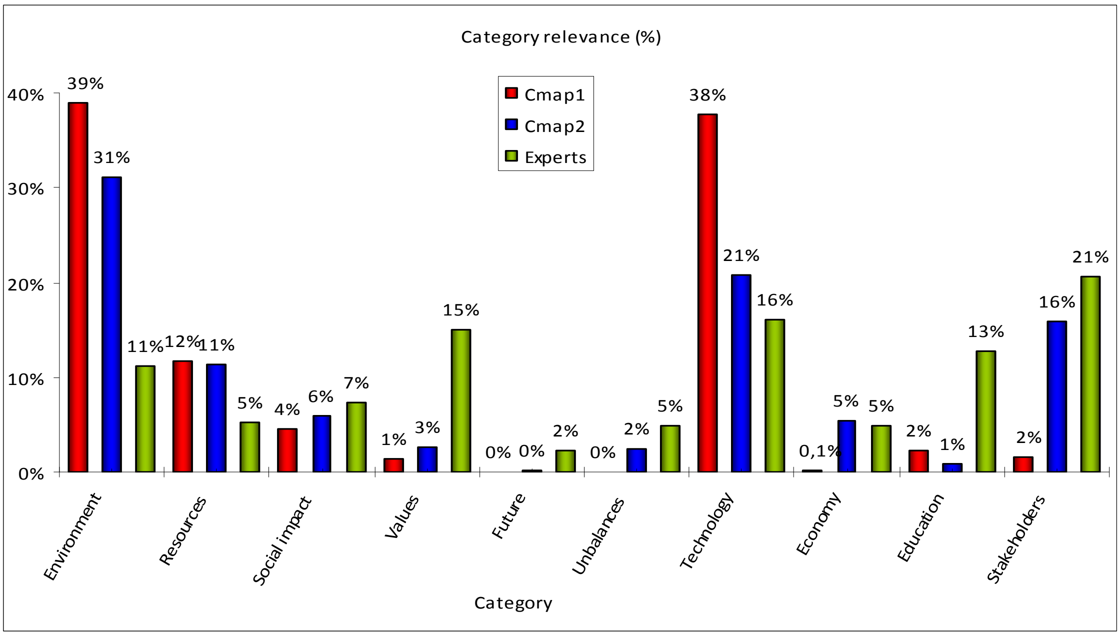

Figure 8.9 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

The analysis of the category relevance index under the four categories taxonomy (Fig 7.10), confirms the misunderstanding of engineering students, which before taking the course basically relate sustainability to *Environmental* and *Technological/Economic* aspects. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one. Nevertheless there is a lot of path for improvement.

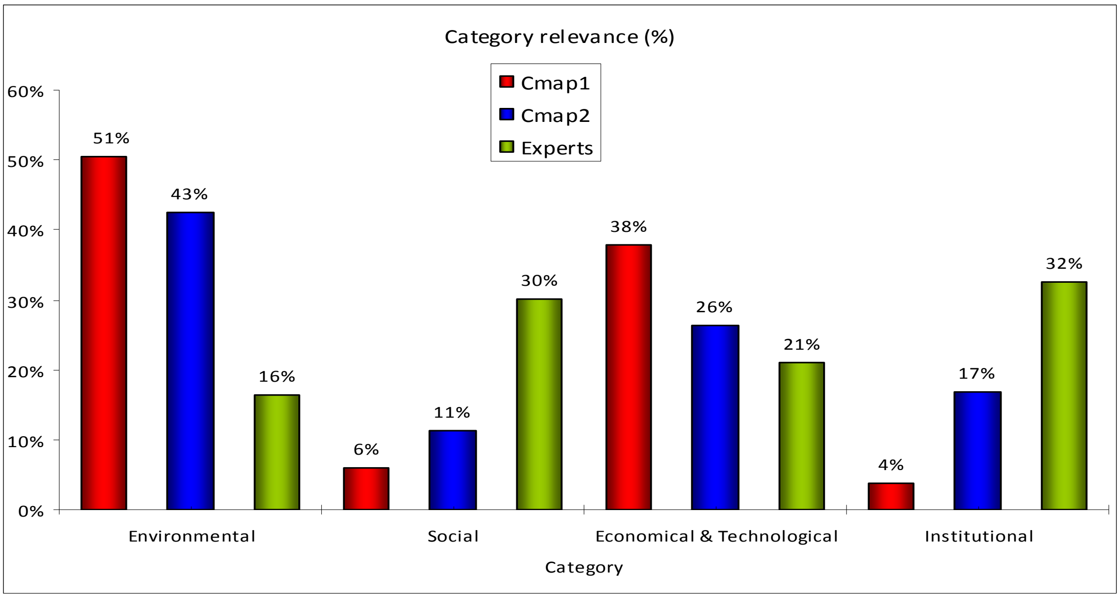

Figure 8.10 Case study UPC-1. Comparison of relevance indexes. 4 categories taxonomy

In relation to the complexity index for the results obtained in the three studies, table 8.7 shows that before taking the course the students saw sustainability as a non complex subject (*CO*=0.91), but after finishing it they see sustainability as more systemic (*CO*=10,27). Nevertheless, when comparing students against experts' values, their results are still far from the reference ones.

	Cmap1	Cmap2	Experts
Complexity index (CO)	0,91	10,27	24.80

Table 8.7 Case study UPC-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

From our analysis some improvement should be introduced in the course in order to increase the systematic view of sustainability (Complexity index) and the importance of social and institutional aspects in relation to the environmental and economic ones.

8.3.2 UPC Case study 2: Technology and Sustainability

Case study Code: **UPC-2**			
University: **Technical University of Catalonia**			
Course name: **Technology and Sustainability**		Cycle: **1st**	ECTS: **5**
Web: **http://www.catunesco.upc.edu/www/index.php?seccio=doc&pag=assig-51140**			
Pedagogy: **Distance learning course. Contents on CD. Participation in virtual forum (10%). Exercises (30%).**			
Date of survey: **2005**	Type of course: **Elective**	Sample $Cmap_1$: **35**	Sample $Cmap_2$: **43**
Students speciality: **Mechanics, Electronics, Electricity, Chemistry**			
Coordinator: **Jordi Segalàs**			
Objectives: To stimulate a new perception of reality and to change attitudes towards the environment. The course aims at increasing the students´ capacity for intervention and decision-making oriented towards sustainability.			
Program: The course is structured in 23 units. 24) The state of the world. Sustainable development 25) Basic ecology 26) Ecological and environmental economics 27) Impact of human activity on the atmosphere 28) Impact of human activity on the hydrosphere 29) Impact of human activity on the lithosphere 30) Examples of social unsustainability 31) Examples of economic unsustainability 32) Examples of environmental unsustainability 33) Values. Ethics and environment 34) Science, technology and society 35) The information society: information and communication technologies (ICT) 36) Technological policies for sustainable development 37) Technologies and sustainability: energy 38) Technologies and sustainability: water management 39) Technologies and sustainability: waste management 40) Technologies and sustainability: noise and vibrations 41) Technologies and sustainability: materials 42) Technologies and sustainability: agriculture and food 43) Technologies and sustainability: mobility 44) Technologies and sustainability: architecture and town planning 45) Environmental management in business 46) Programs for Action. Agenda 21			

Table 8.8 Case study UPC-2. Course Technology and Sustainability

The results of the students' Cmaps analysis are:

Cmap$_1$: Before taking the course

Variable		Values
Number of students	*NS*	35
Number total of concepts	NC_{S1}	295
Number total of links inter-categories	NL_{S1}	118
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	8,43

Table 8.9 Case study UPC-2. Cmap$_1$: Variables value

Therefore using the variables from table 8.9 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	83	58	22	2	2	1	75	6	15	18
CD_i	28%	20%	7%	1%	1%	0%	25%	2%	5%	6%
NS_i	32	22	18	2	2	1	27	6	10	8
SC_i	91%	63%	51%	6%	6%	3%	77%	17%	29%	23%
CR_i	**39%**	**19%**	**6%**	**0%**	**0%**	**0%**	**30%**	**1%**	**2%**	**2%**

Table 8.10 Case study UPC-2. Cmap$_1$: Category relevance variables

Graphically:

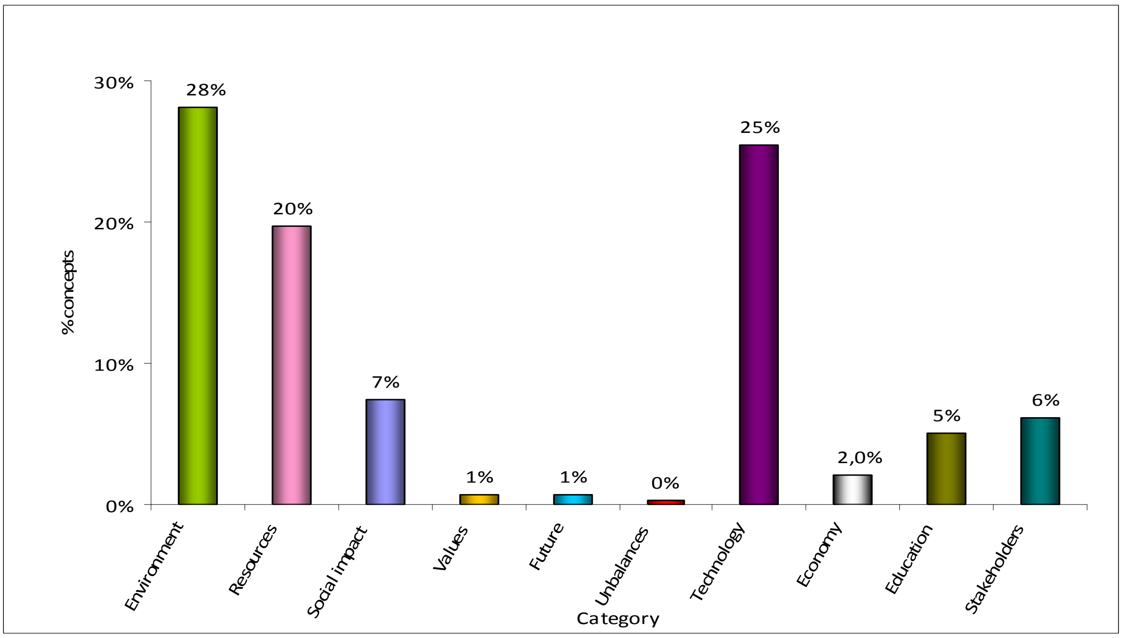

Figure 6.11 Case study UPC-2. Cmap$_1$: Concepts distribution

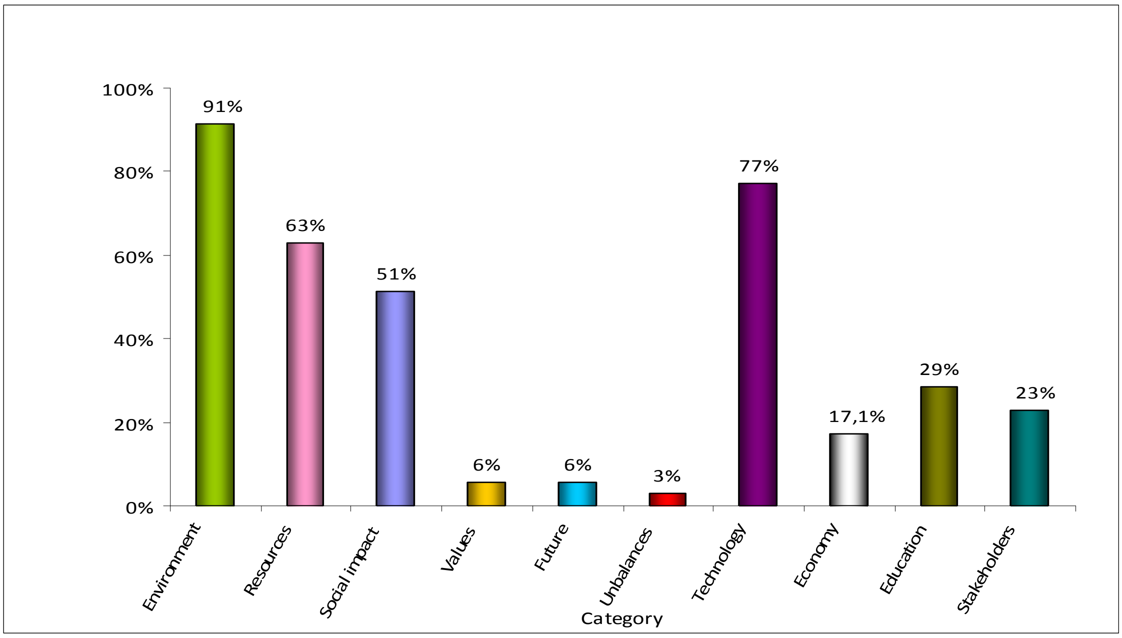

Figure 8.11 Case study UPC-2. $Cmap_1$: Percentage of experts per category distribution

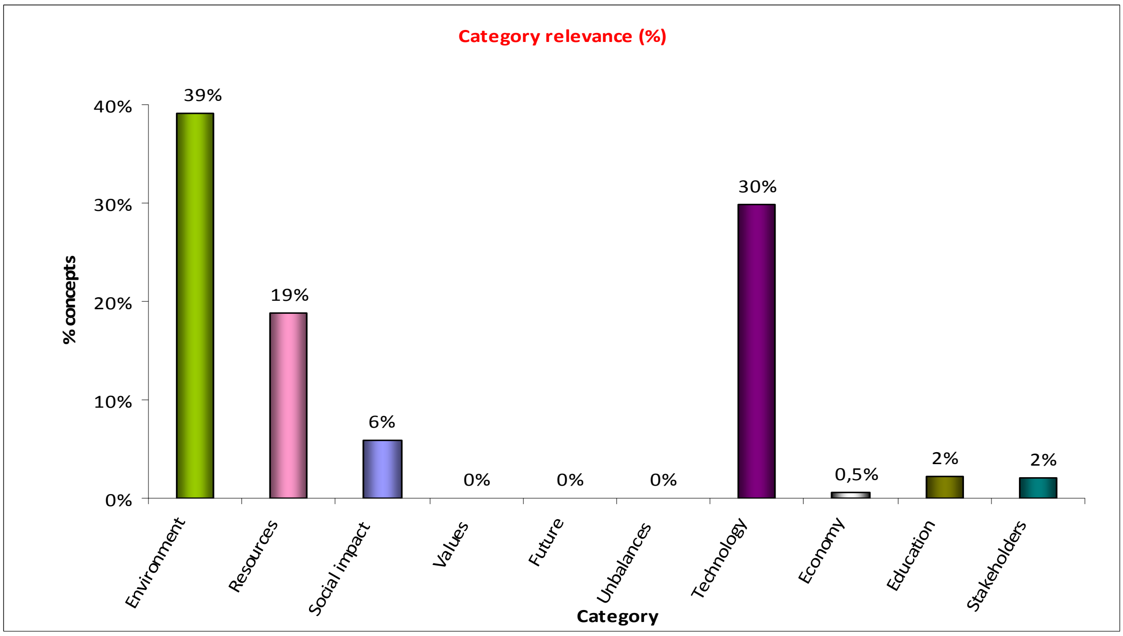

Figure 8.12 Case study UPC-2. $Cmap_1$: Category relevance index

From the category relevance index the role of *Environment* and *Technology* are the most referenced (39% + 30% = 69%). The next category relevance value is *Resources* with the 19%. Finally the other categories have little relevance.

Figure 8.13 shows the Category distribution under the four categories taxonomy. It illustrates that *Environmental* is taken as the most important category (58%) by far, followed by the *Technological/Economic* one (30%); Meanwhile *Social* and *Institutional* categories are given almost no relevance.

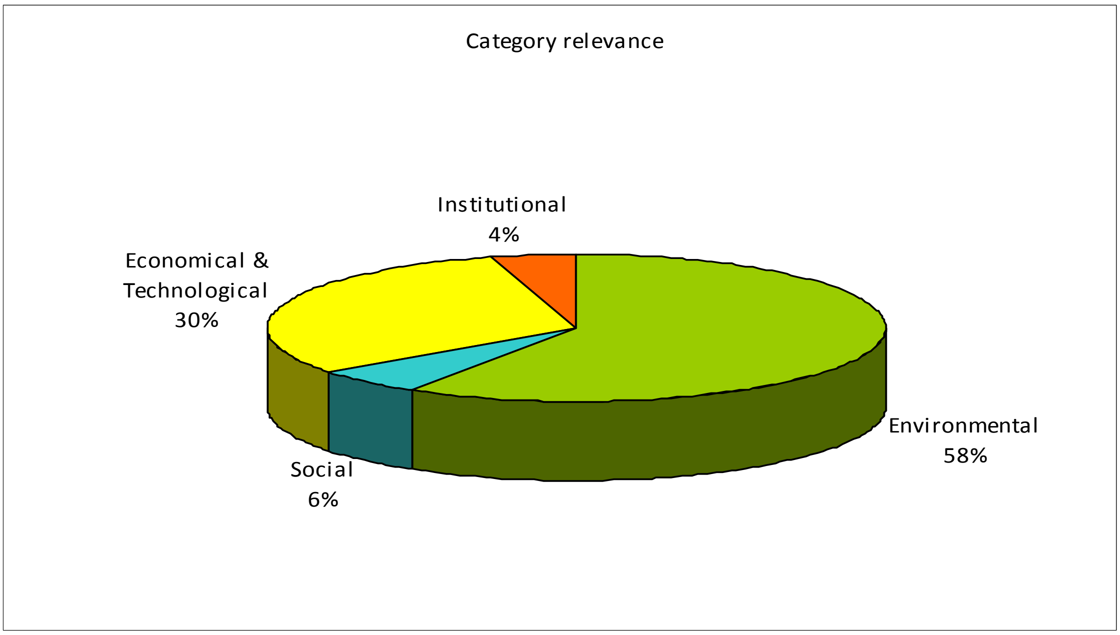

Figure 8.13 Case study UPC-2. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{118}{10 \times 35} = 0.34$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{2.87}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	43
Number total of concepts	NC_{S2}	1028
Number total of links inter-categories	NL_{S2}	220
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	23.91

Table 8.11 Case study UPC-2. $Cmap_2$: Variables value

Therefore using the variables from table 8.11 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	297	122	67	28	16	65	146	38	38	116
CD_i	29%	12%	7%	3%	2%	6%	14%	4%	4%	11%
NS_i	42	36	38	18	13	28	34	24	20	39
SC_i	98%	84%	88%	42%	30%	65%	79%	56%	47%	91%
CR_i	**34%**	**12%**	**7%**	**1%**	**1%**	**5%**	**14%**	**2%**	**2%**	**12%**

Table 8.12 Case study UPC-2. $Cmap_2$: Category relevance variables

Graphically:

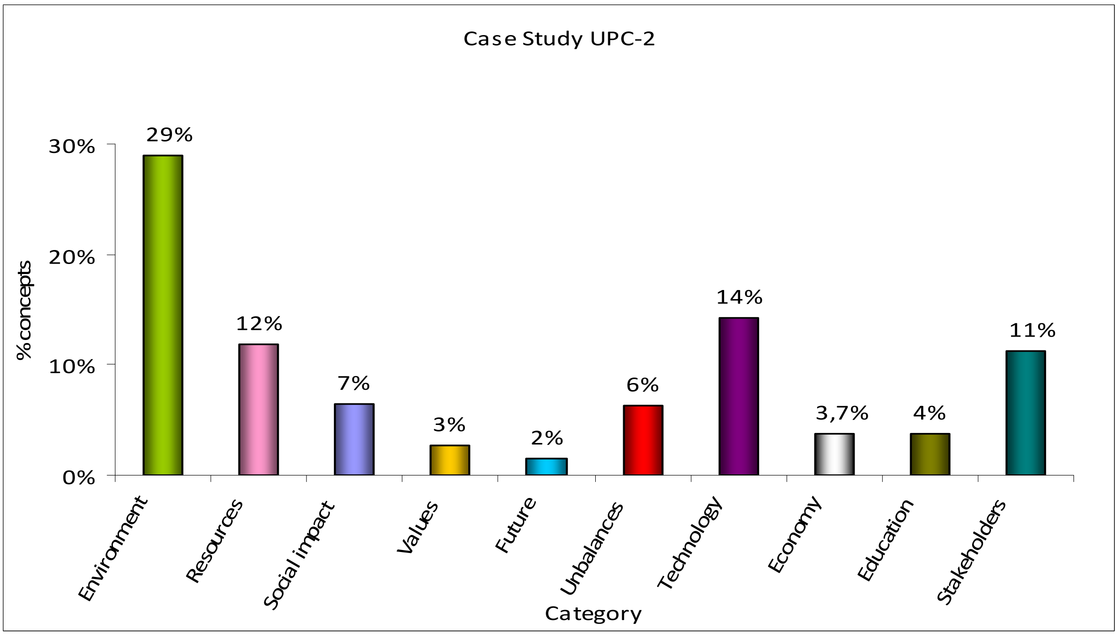

Figure 8.14 Case study UPC-2. $Cmap_2$: Concepts distribution

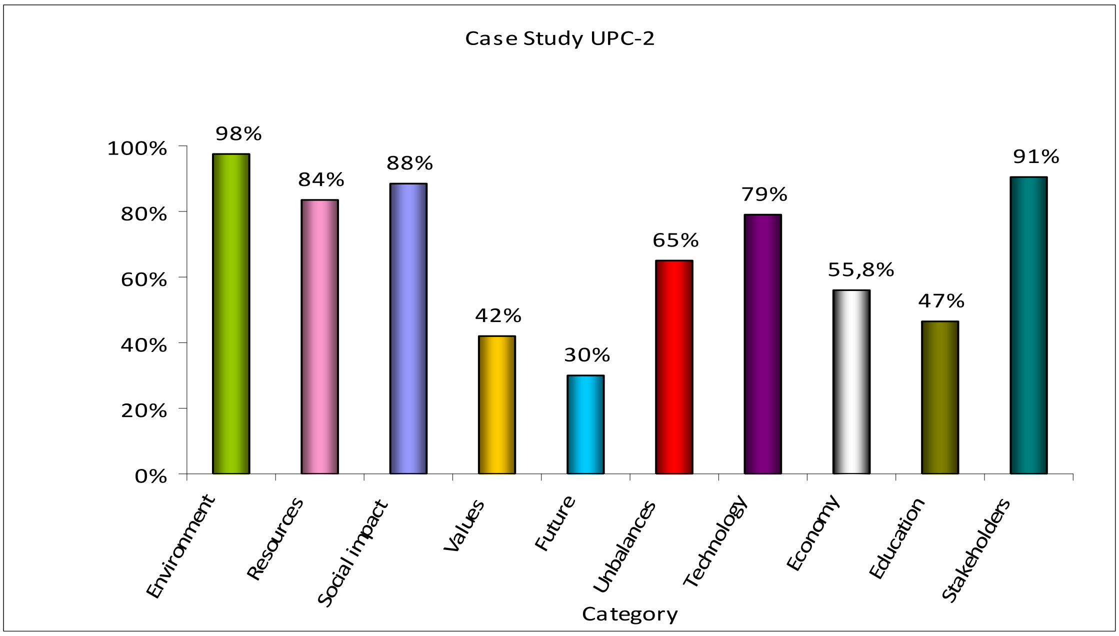

Figure 8.15 Case study UPC-2. $Cmap_2$: Percentage of experts per category distribution

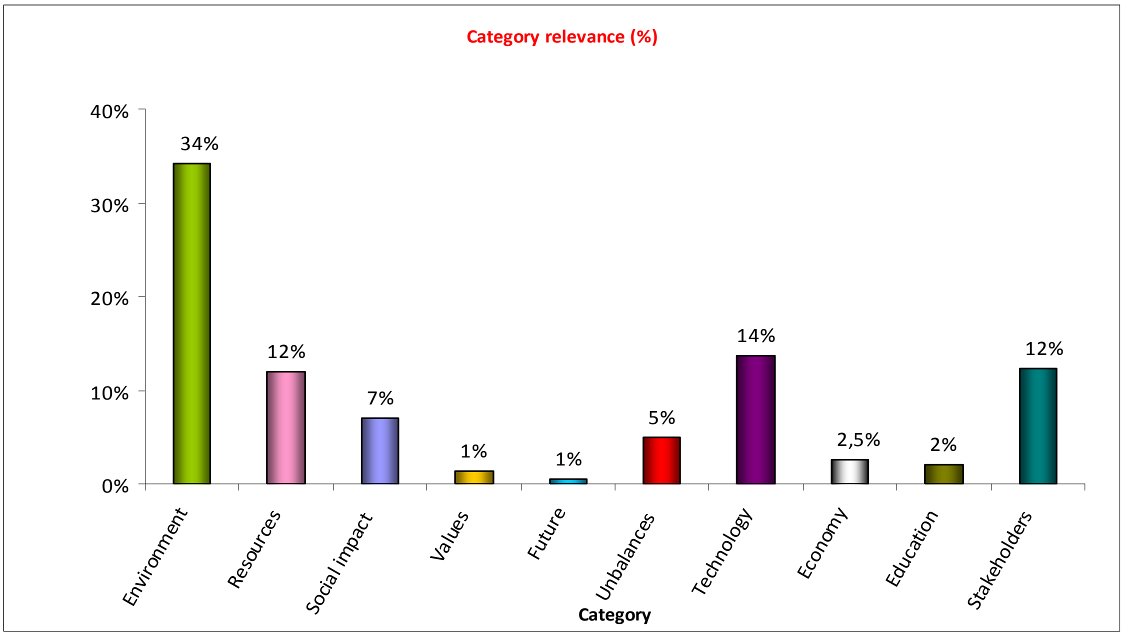

Figure 8.16 Case study UPC-2. $Cmap_2$: Category relevance index

From the category relevance index the role of the *Environment* (34%) category is still the most relevant. The following categories are *Technology*, *Resources* and *Stakeholders* with similar values. Finally, *Values* and *Future* are still given no importance

Figure 8.17 shows the Category distribution under the four categories taxonomy. It shows that *Environmental* is taken as the most important category (46%). The other three categories are uniformly distributed.

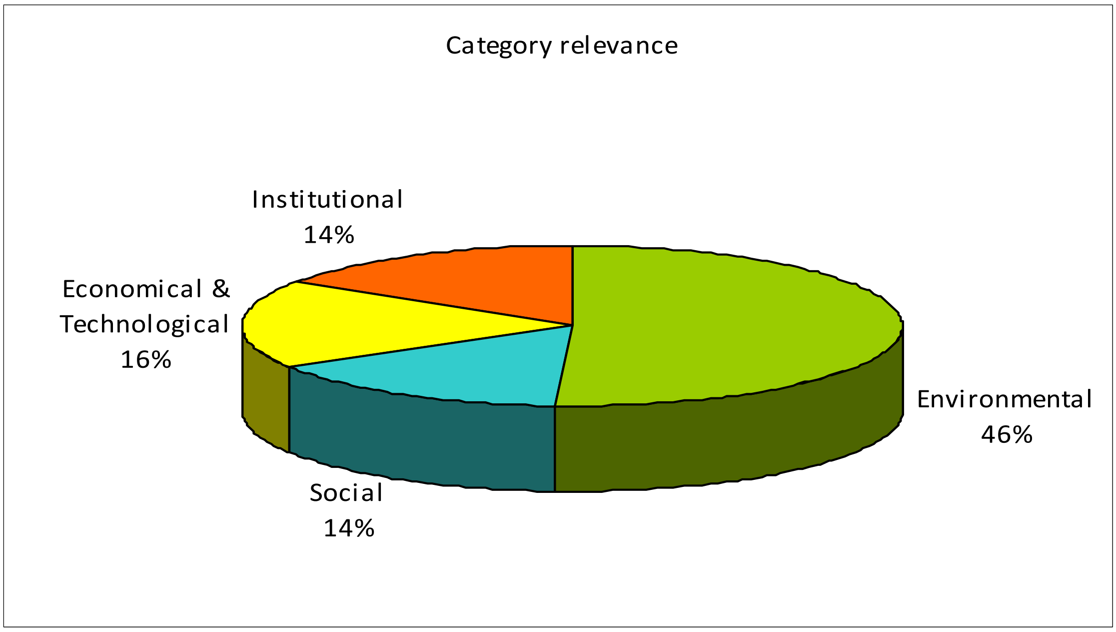

Figure 8.17 Case study UPC-2. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{220}{10 \times 43} = 0.51$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{12{,}19}$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.18 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to experts' Cmaps than the results before taking it. This "improvement" in the category relevance index reveals that the course has enhanced the students' understanding of the sustainability concept. Nevertheless, after taking the course, students still gave a lot of relevance to *Environmental* and *Technology* aspects and too little to the V*alues*, E*ducation* and F*uture* ones.

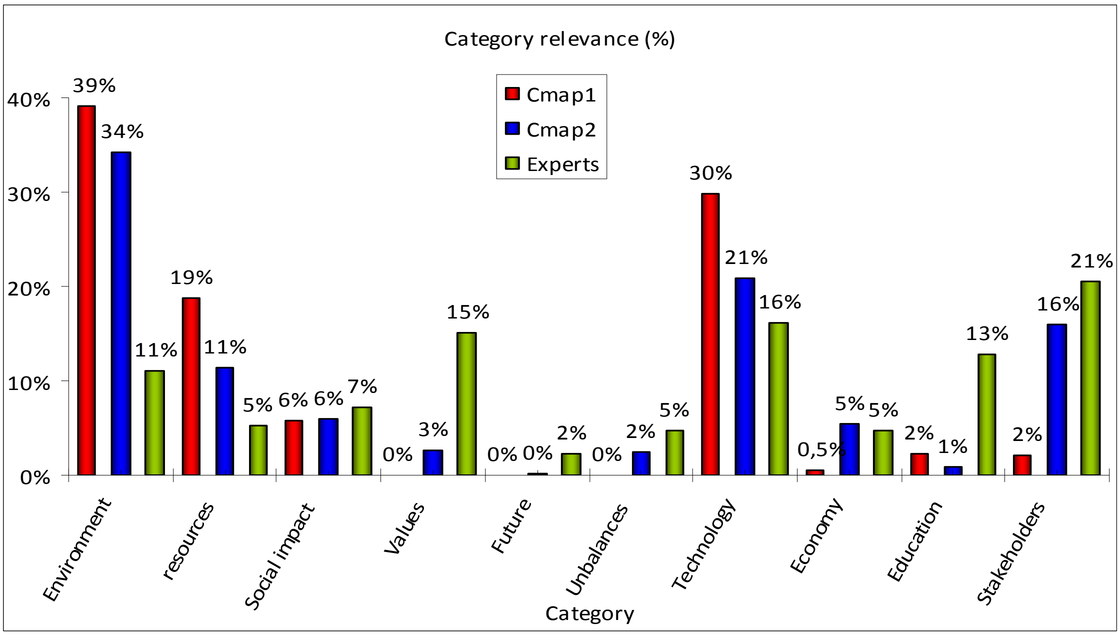

Figure 8.18 Case study UPC-2. Comparison of relevance index: Cmap_1-Cmap_2-Experts Cmap

The analysis of the category relevance index under the four categories taxonomy, Figure 8.19, confirms the misunderstanding of engineering students, who before taking the course basically relate sustainability to *Environmental* and *Technological/Economic* aspects. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one. Nevertheless, there is still room for considerable improvement.

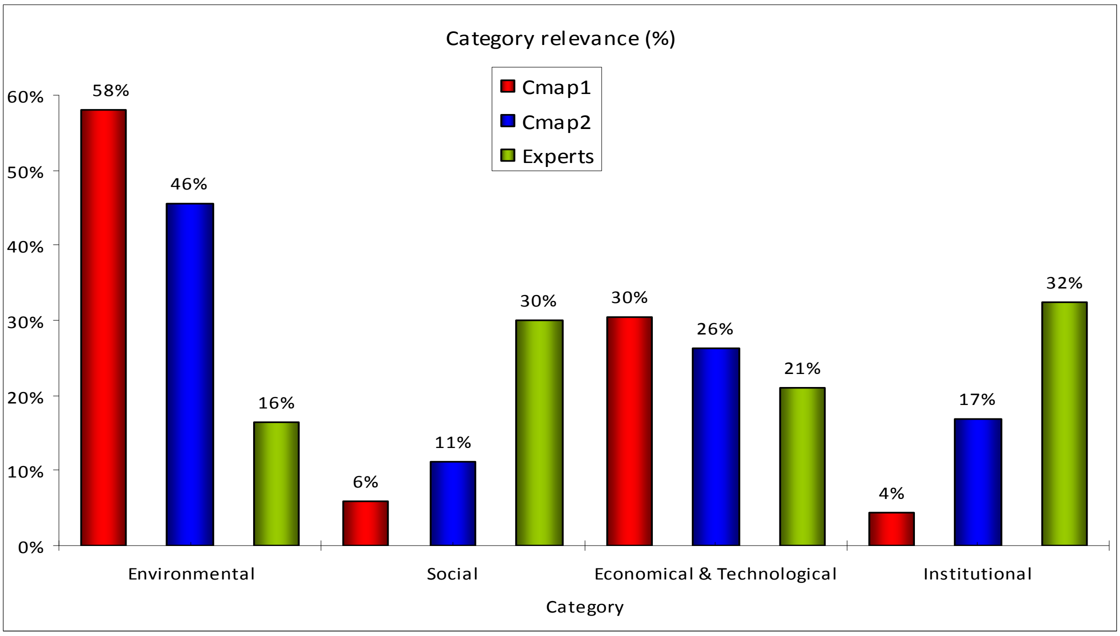

Figure 8.19 Case study UPC-2. Comparison of relevance index: Cmap_1-Cmap_2-Experts Cmap. 4 Categories

In relation to the complexity index, the results obtained in the three studies in table 8.13 show that, before taking the course, students saw sustainability as a not very complex subject (*CO*=2.87), but after finishing it, they see sustainability as more systemic (*CO*=12,19). Nevertheless, when comparing students against experts' values, their results are still far from the reference ones.

	Cmap1	Cmap2	Experts
Complexity index (CO)	2,87	12,19	24.8

Table 8.13 Case study UPC-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.3.3 UPC Case study 3: Technology and environment

Case study Code: **UPC-3**			
University: **Technical University of Catalonia**			
Course name: **Technology and environment**		Cycle: **1st**	ECTS: **5**
Web: **http://www.catunesco.upc.edu/www/index.php?seccio=doc&pag=assig-28679**			
Pedagogy: **Lecturing (60%), Cooperative learning, role play, students' presentations.**			
Date of survey: **2006**	Type of course: **Elective**	Sample $Cmap_1$: **30**	Sample $Cmap_2$: **31**
Students speciality: **Mechanics, Electronics, Electricity, Chemistry, Textile**			
Coordinator: **Beatriz Escribano**			
Objectives: To provide the basis for analyzing the environmental impacts of the use of technology in engineering from the perspective of Environmental Education and Sustainable Development. The student must achieve a level of awareness about environmental issues from a global point of view, from this level of sensitivity he should achieve an ethic of respect for the environment. Finally, students should be trained in available tools and technologies to improve their future professional intervention with a respect for the environment.			
Program: ECOLOGY FUNDAMENTALS - The concept and context of ecology - Ecosystems as functional unit - Biogeochemical cycles - Ecosystems functioning - Ecosystems dynamics - Biogeographic regions of the World IMPACTS OF HUMAN ACTIVITY ON THE ECOSFERA - Impacts on the atmosphere - Impacts on the hydrosphere - Impacts on the Lithosphere AUDITS, ENVIRONMENTAL MANAGEMENT IMPACT STUDIES IN COMPANIES. - Environmental Management Systems. ISO 14000 and EMAS - Environmental impact studies - Life Cycle Analysis - Cleaner Production (CP): Industrial Production Systems. CP Technologies - Eco-design AGENDAS 21 - Municipal Environmental Audits. Local Agenda 21 (examples) - Indexes of Sustainability INDUSTRIAL ECOLOGY - Definition. Systemic vision. Similarities to natural ecosystems - Study of the life cycles of materials and processes			

Table 8.14 Case study UPC-3. Course Technology and Environment

The results of the students' Cmaps analysis are:

Cmap$_1$: Before taking the course

Variable		Values
Number of students	*NS*	30
Number total of concepts	NC_{S1}	384
Number total of links inter-categories	NL_{S1}	82
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	12,08

Table 8.15 Case study UPC-3. Cmap$_1$: Variables value

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	*112*	*54*	*19*	*4*	*3*	*7*	*92*	*9*	*22*	*29*
CD_i	*29%*	*14%*	*5%*	*1%*	*1%*	*2%*	*24%*	*2%*	*6%*	*8%*
NS_i	*29*	*16*	*16*	*2*	*3*	*3*	*27*	*3*	*10*	*16*
SC_i	*97%*	*53%*	*53%*	*7%*	*10%*	*10%*	*90%*	*10%*	*33%*	*53%*
CR_i	**40%**	**11%**	**4%**	**0%**	**0%**	**0%**	**30%**	**0%**	**3%**	**6%**

Table 8.16 Case study UPC-3. Cmap$_1$: Category relevance variables

Graphically:

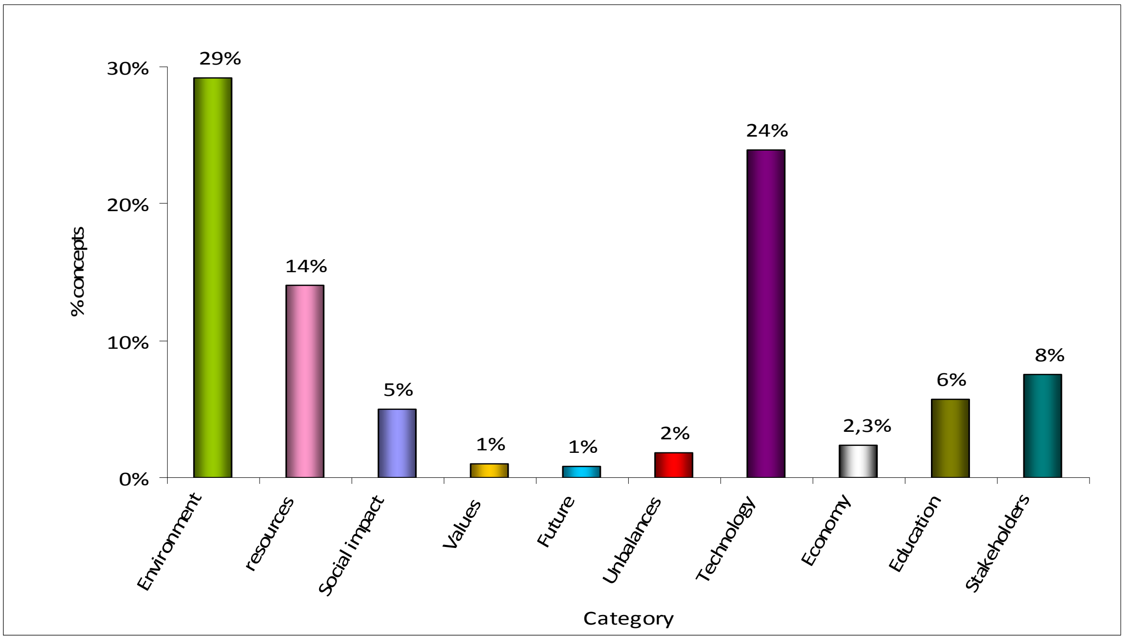

Figure 8.20 Case study UPC-3. Cmap$_1$: Concepts distribution

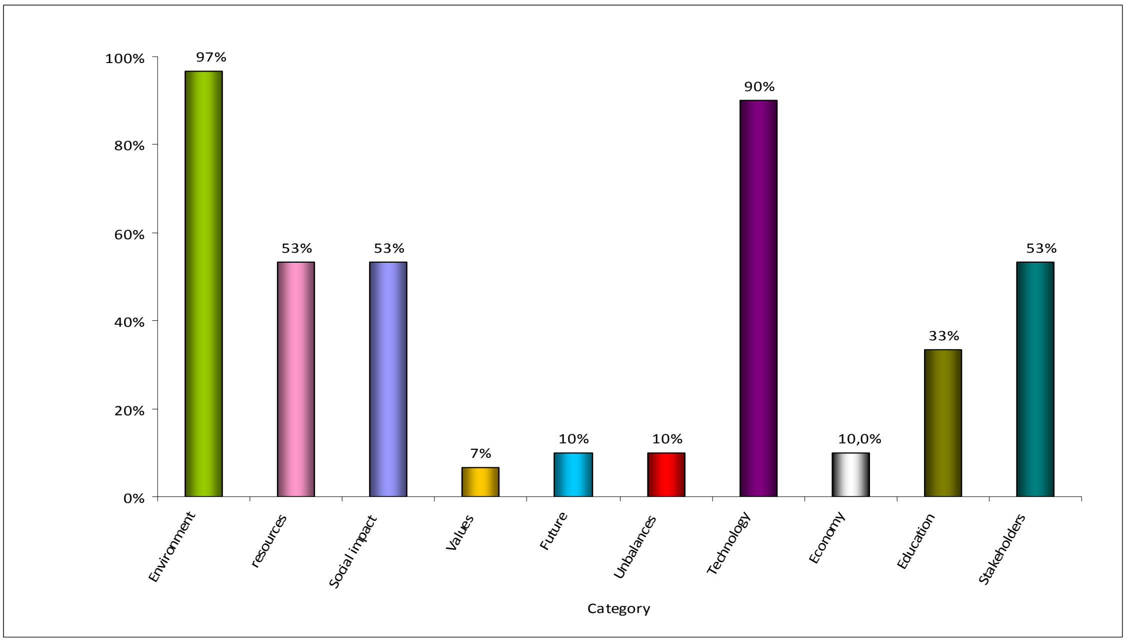

Figure 8.21 Case study UPC-3. $Cmap_1$: Percentage of experts per category distribution

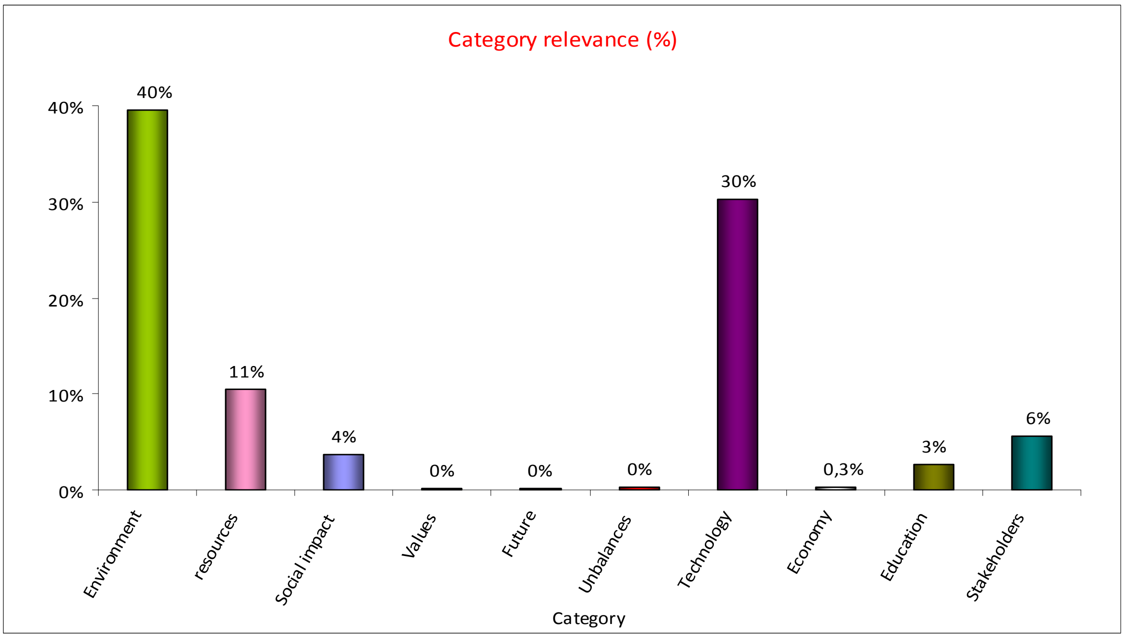

Figure 8.22 Case study UPC-3. $Cmap_1$: Category relevance index

From the category relevance index the *Environment* and *Technology* categories are the most referenced (40% + 30% = 70%). The next category relevance value is *Resources* with the 11%. Finally the other categories have little relevance, especially the *Values*, *Futures*, *Unbalances* and *Economy* ones.

Figure 8.23 shows the Category distribution under the four categories taxonomy. It illustrates that *Environmental* is considered by far as the most important category (50%), followed by the *Technological/Economic* one (31%); Meanwhile *Social* and *Institutional* categories are given almost no relevance.

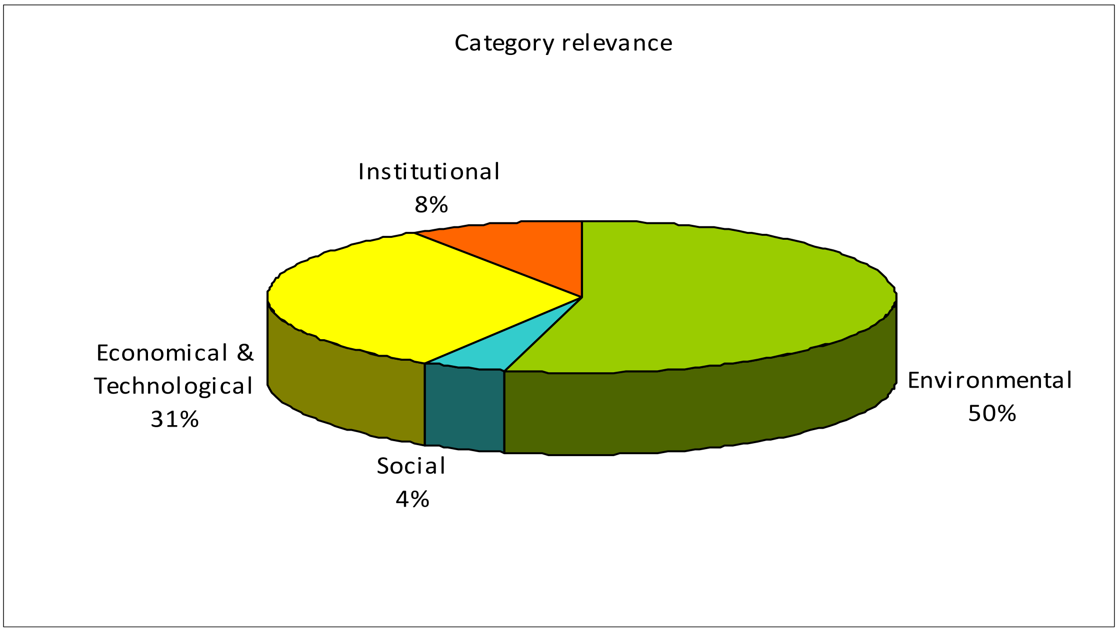

Figure 8.23 Case study UPC-3. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{82}{10 \times 30} = 0.27$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{3.26}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	31
Number total of concepts	NC_{S1}	858
Number total of links inter-categories	NL_{S2}	210
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	27.68

Table 8.17 Case study UPC-3. $Cmap_2$: Variables value

Therefore using the variables from the table 8.17 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	*196*	*102*	*41*	*20*	*8*	*19*	*141*	*59*	*57*	*209*
CD_i	*23%*	*12%*	*5%*	*2%*	*1%*	*2%*	*16%*	*7%*	*7%*	*24%*
NS_i	*21*	*19*	*18*	*8*	*3*	*7*	*21*	*16*	*16*	*20*
SC_i	*68%*	*61%*	*58%*	*26%*	*10%*	*23%*	*68%*	*52%*	*52%*	*65%*
$\mathbf{CR_i}$	***26%***	***12%***	***5%***	***1%***	***0%***	***1%***	***18%***	***6%***	***6%***	***26%***

Table 8.18 Case study UPC-3. $Cmap_2$: Category relevance variables

Graphically:

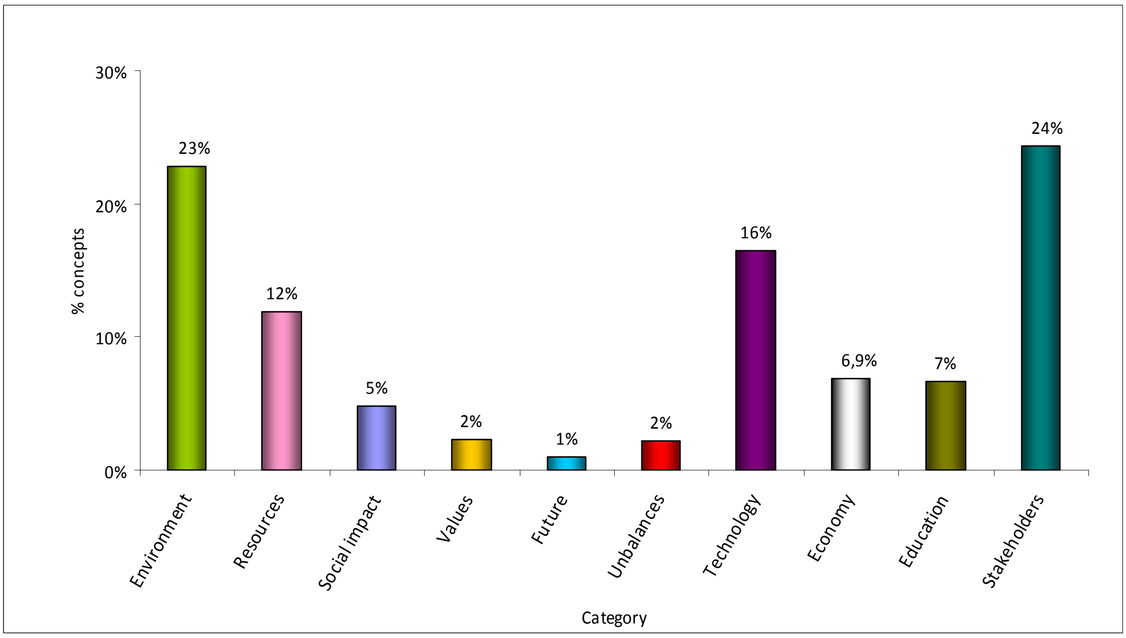

Figure 8.24 Case study UPC-3. $Cmap_2$: Concepts distribution

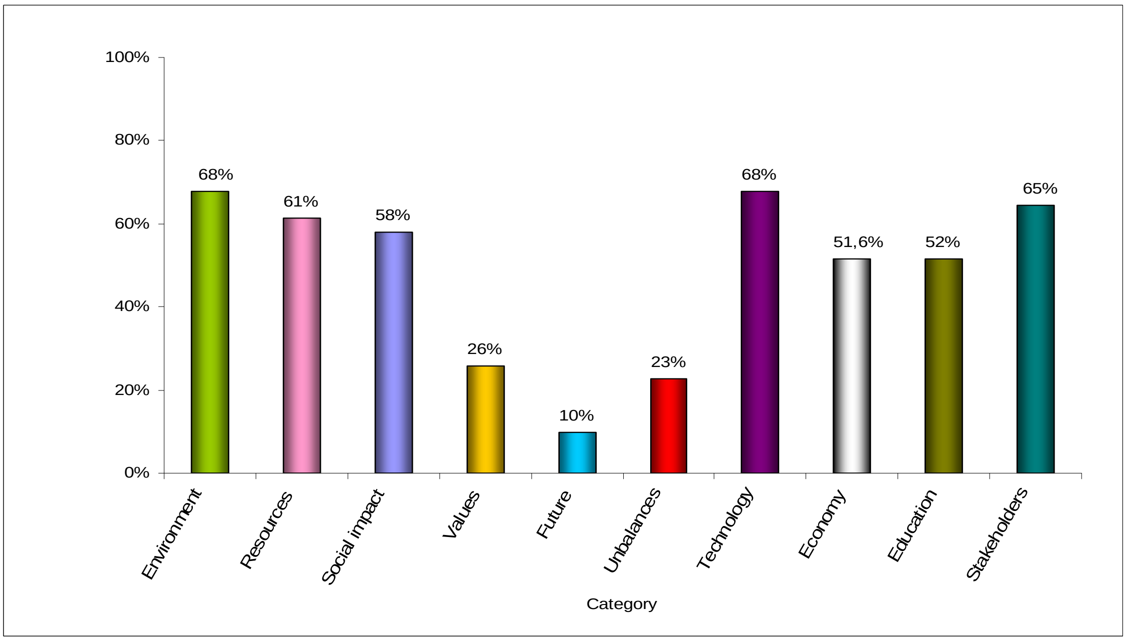

Figure 8.25 Case study UPC-3. $Cmap_2$: Percentage of experts per category distribution

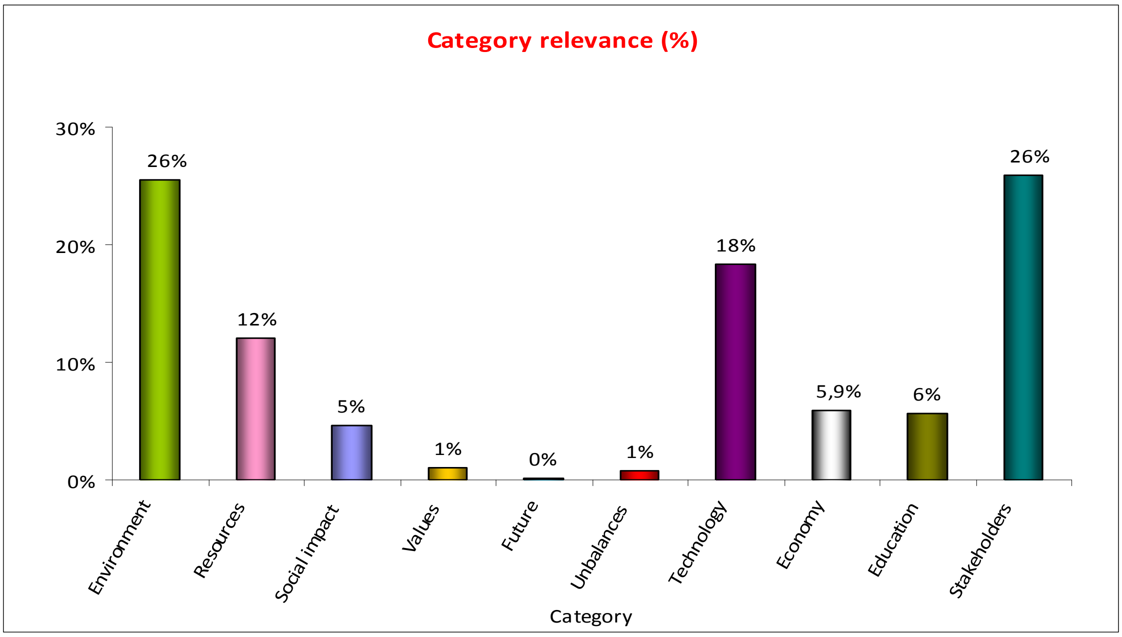

Figure 8.26 Case study UPC-3. $Cmap_2$: Category relevance index

From the category relevance index the *Environment* (26%) and *Stakeholders* (26%) categories are the most referenced, followed by *Technology* 18% and *Resources* (12%) ones. The next category relevance values are *Education*, *Economy* and *Social impact*. Finally the other categories have almost no relevance at all.

Figure 8.27 shows the Category distribution under the four categories taxonomy. It illustrates that there is a common share of relevance among *Environmental, Institutional and Technological/Economic* categories. Meanwhile the *social* category is given very little relevance.

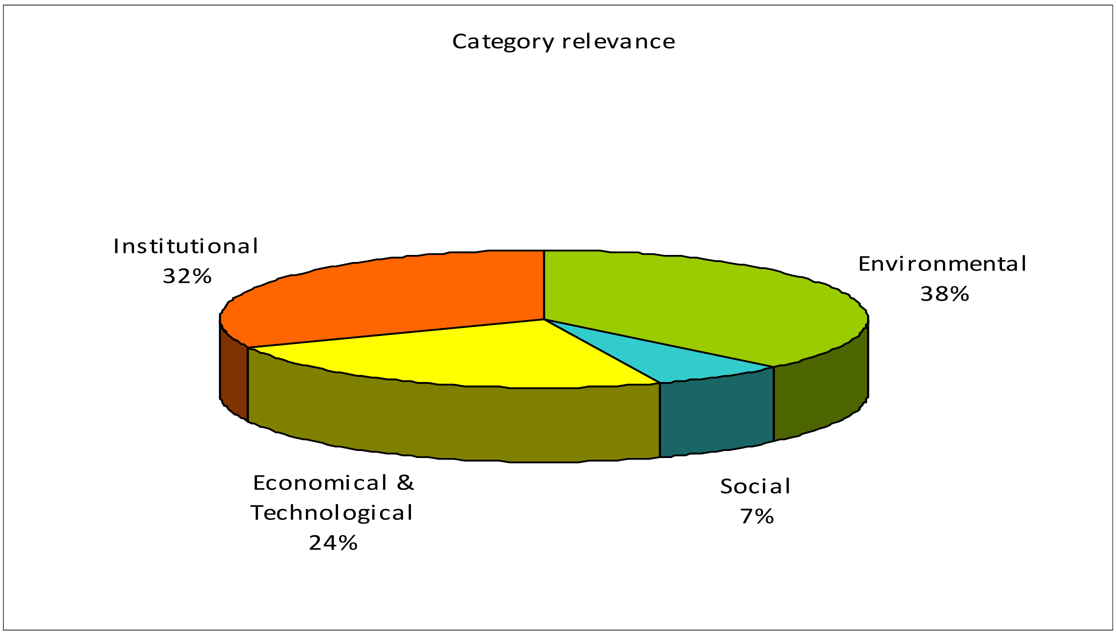

Figure 8.27 Case study UPC-3. $Cmap_2$: Category relevance index. 4 Categories

<u>Complexity Index</u>

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{210}{10 \times 31} = 0.68$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = 18.82$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.28 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. Although for *Resources* category the result after taking the course increases instead of decreasing towards the reference value. This "improvement" in the category relevance index reveals that the course has enhanced the students' understanding of the sustainability concept. Nevertheless students, after taking the course, still gave a lot of relevance to *Environmental*, *Resources* and *Technology* aspects and little to Values, *Unbalances* and *Future*.

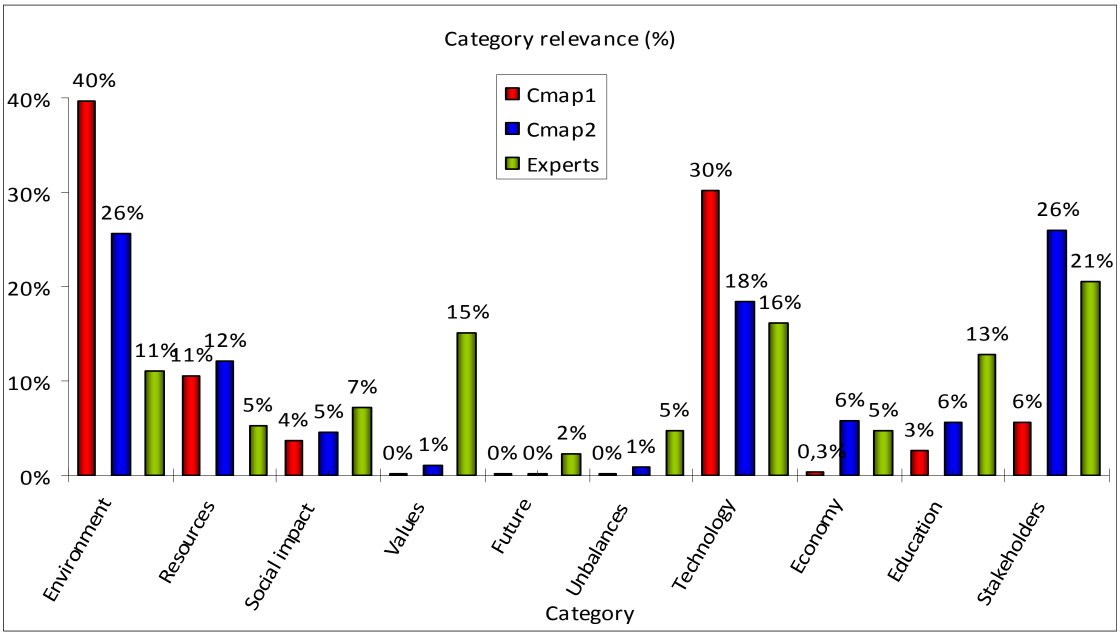

Figure 8.28 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

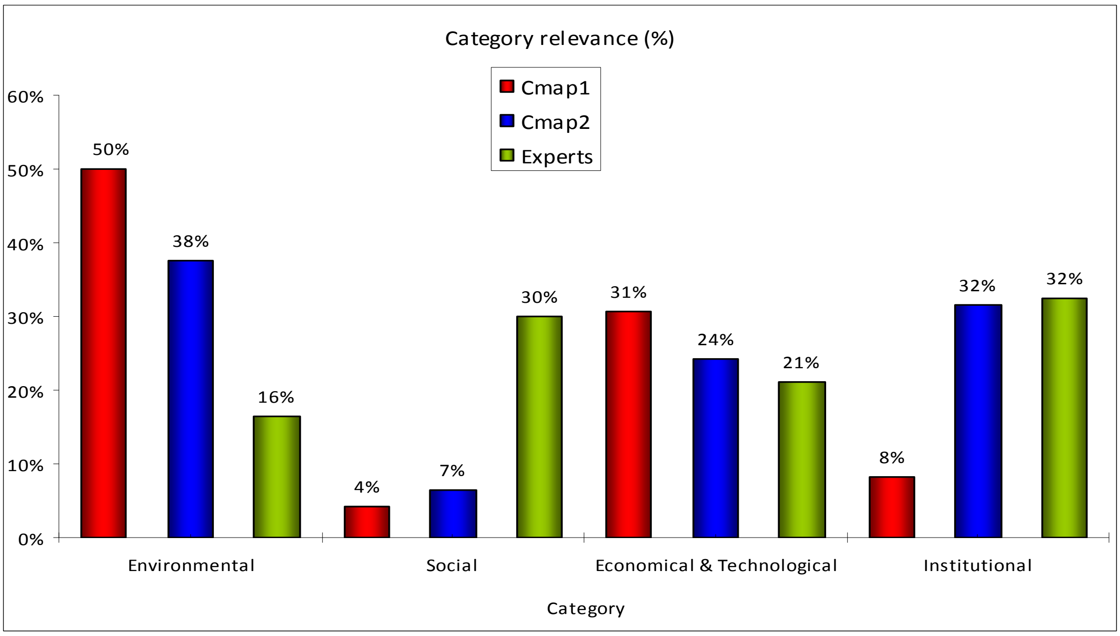

Figure 8.29 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, figure 8.29, confirms the misunderstanding of engineering students, who before taking the course basically relate sustainability to *Environmental* and *Technological/Economic* aspects. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one. Nevertheless there is considerable room for improvement.

In relation to the complexity index the results obtained in the three studies table 8.19 shows that before taking the course the students saw sustainability as a not very complex subject (*CO*=3,26), but after finishing it they see sustainability as more systemic (*CO*=18,82) becoming closer to the reference (*CO*=24.8).

	Cmap1	Cmap2	Experts
Complexity index (CO)	3.26	18.82	24.8

Table 8.19 Case study UPC-3. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.3.4 UPC Case study 4: International Seminar on Sustainable Technology

Case study Code: **UPC-4**			
University: **Technical University of Catalonia**			
Course name: **International Seminar on Sustainable Technology**		Cycle: **2nd**	ECTS: **5**
Web: **http://www.upc.edu/sostenible2015/menu2/Seminaris/Home**			
Pedagogy: **Lecturing (25%). Project based learning. Participation in forums. Workshops**			
Date of survey: **2008**	Type of course: **Elective**	Sample $Cmap_1$: **19**	Sample $Cmap_2$: **19**
Students speciality: Chemistry, Industrial Ecology, Sustainability, Industrial design, Architecture			
Coordinator: **Didac Ferrer**			
Objectives: The learning goals of the seminar were the following: - To increase the understanding of a SD in the long term and the role of technology therein embedded in systems. - To increase the capability of applying foresighting methods, like forecasting and backcasting. - To contribute to the development of scientific work competences of students. - To increase the capability of teachers in the approach of future imaging, forecasting and backcasting. - To equip the UPC with the insight and capability to transfer knowledge on future imaging and backcasting for sustainable development in the Masters in SD and further in Catalonia and Spain. - To become an experts' meeting point and create networking activities among different groups and institutions.			
Program: Lectures on: - STD, Forecasting and backcasting - Scale of the sustainability challenge: water in urban areas - Social change and the role of technology - Future development for sustainable technology Workshops on: - Foresighting I on the topic, but with different operationalizations e.g. context analysis, system analysis, stakeholder analysis, problem analysis, trend analysis. - Foresighting II. Scenario construction using the context scenario method developed at Shell. This focuses on driving factors with high impact and high uncertainty. - Backcasting I. Making desirable sustainable future visions that solve the (sustainability) problems. - Backcasting II. Using various backcasting questions, such as what is needed, who is needed, how it has come about, what are barriers and drivers there are. Forums: - Stakeholders forum on water issues. - Scientific forum on water issues.			

Table 8.20 Case study UPC-4. International Seminar on Sustainable Technology

The results of the students' Cmaps analysis are:

Cmap$_1$: Before taking the course

Variable		Values
Number of students	NS	19
Number total of concepts	NC_{S1}	373
Number total of links inter-categories	NL_{S2}	197
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	19.63

Table 8.21. Case study UPC-4. Cmap$_1$: Variables value

Therefore using the variables from table 8.21 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	86	23	25	41	17	11	43	24	27	75
CD_i	23%	6%	7%	11%	5%	3%	12%	6%	7%	20%
NS_i	18	10	13	15	9	7	15	11	13	17
SC_i	95%	53%	68%	79%	47%	37%	79%	58%	68%	89%
CR_i	28%	4%	6%	11%	3%	1%	12%	5%	6%	23%

Table 8.22 Case study UPC-4. Cmap$_1$: Category relevance variables

Graphically:

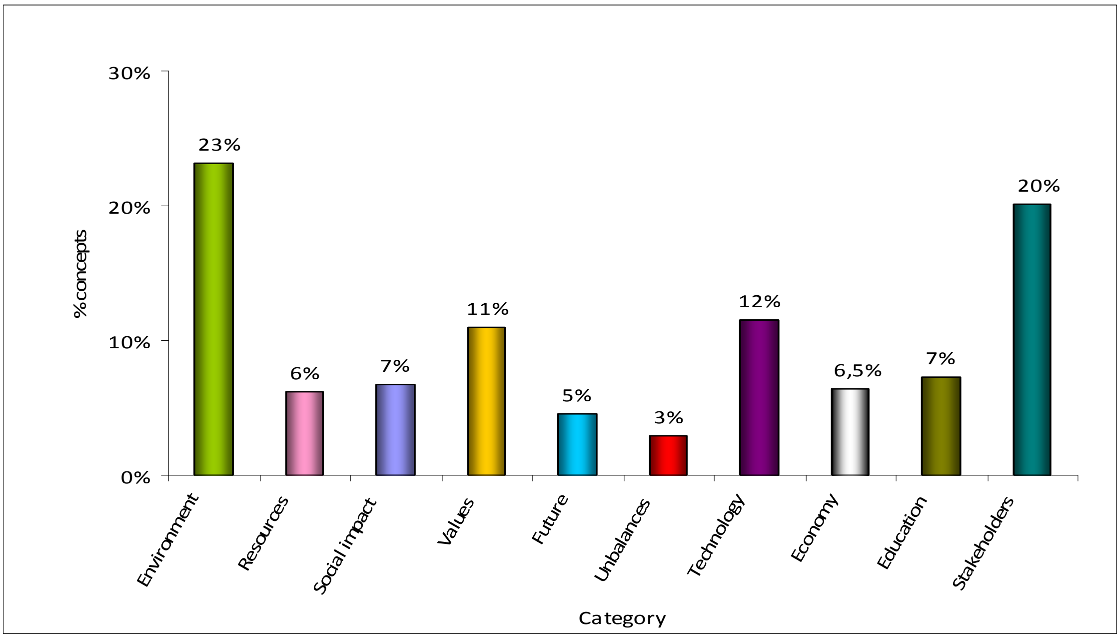

Figure 8.30 Case study UPC-4. Cmap$_1$: Concepts distribution

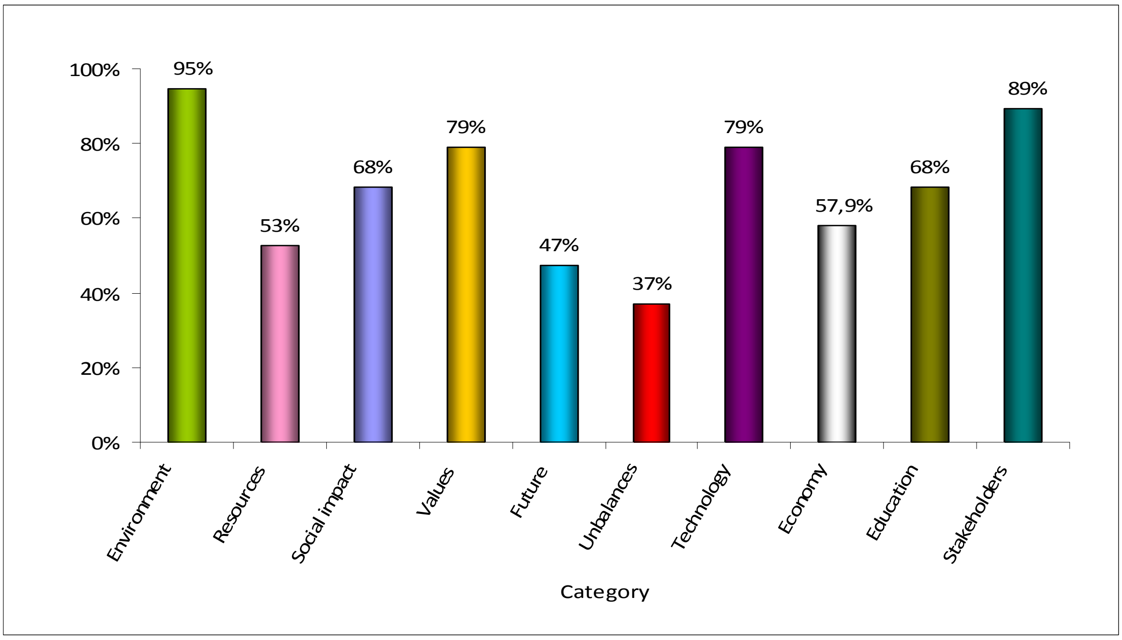

Figure 8.31 Case study UPC-4. $Cmap_1$: Percentage of students per category distribution

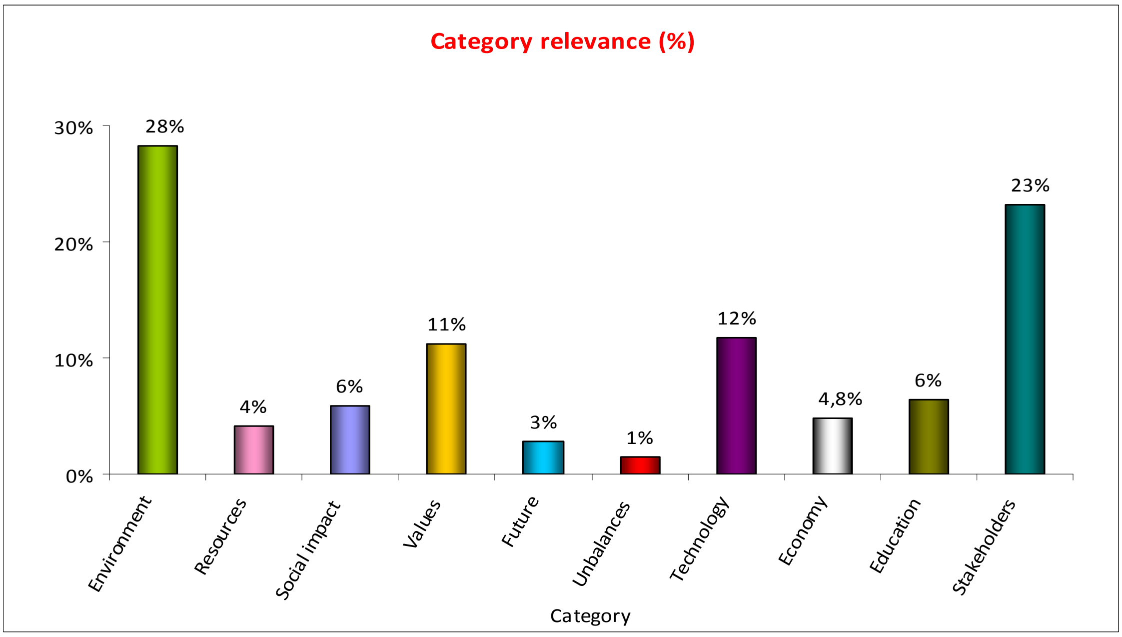

Figure 8.32 Case study UPC-4. $Cmap_1$: Category relevance index

From the category relevance index *Environment* (28%) and *Stakeholders* (23%) categories are the most referenced. The next category relevance values are for *Technology* and *Values*. Finally the other categories have approximately the same values but *Unbalances* has only a 1% of relevance.

Figure 8.33 shows the Category distribution under the four categories taxonomy. It illustrates that there are two categories, *Environmental* and *Institutional*, with a slightly higher relevance than the other two, *Social* and *Technological/Economic*. Nevertheless there is a fairly equal distribution among all of them.

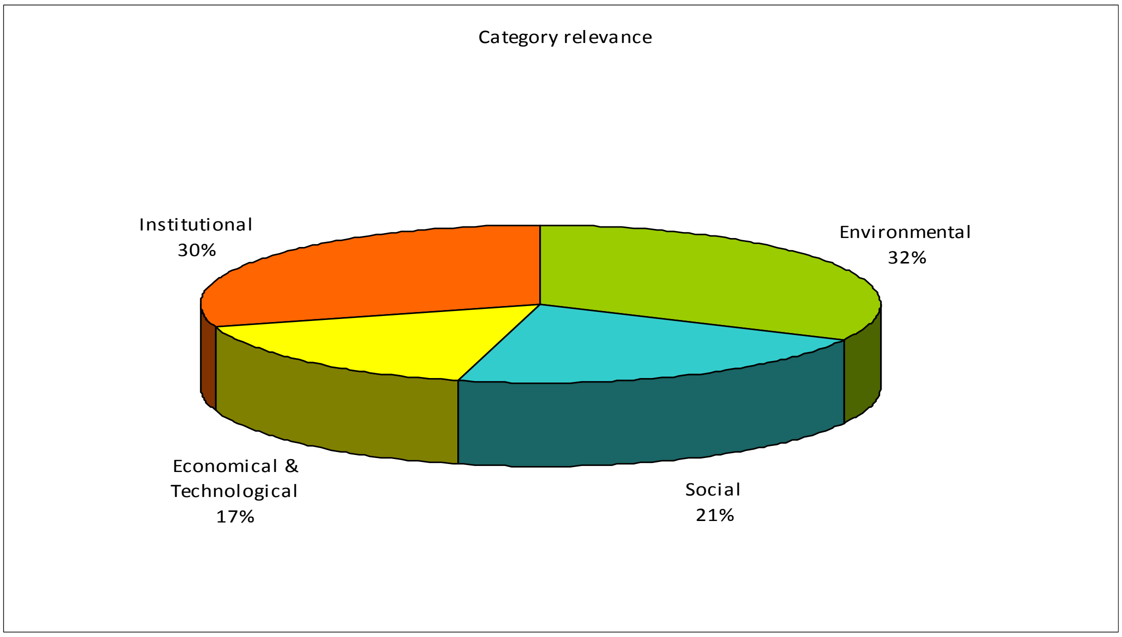

Figure 8.33 Case study UPC-4. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{197}{10 \times 19} = 1.04$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{20.35}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	19
Number total of concepts	NC_{S1}	306
Number total of links inter-categories	NL_{S2}	184
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	16.11

Table 8.23 Case study UPC-4. $Cmap_2$: Variables value

Therefore using the variables from table 8.23 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	37	19	23	51	9	13	54	17	40	43
CD_i	12%	6%	8%	17%	3%	4%	18%	6%	13%	14%
NS_i	15	12	10	16	7	7	18	14	15	14
SC_i	79%	63%	53%	84%	37%	37%	95%	74%	79%	74%
CR_i	**13%**	**5%**	**5%**	**19%**	**1%**	**2%**	**22%**	**5%**	**14%**	**14%**

Table 8.24 Case study UPC-4. $Cmap_2$: Category relevance variables

Graphically:

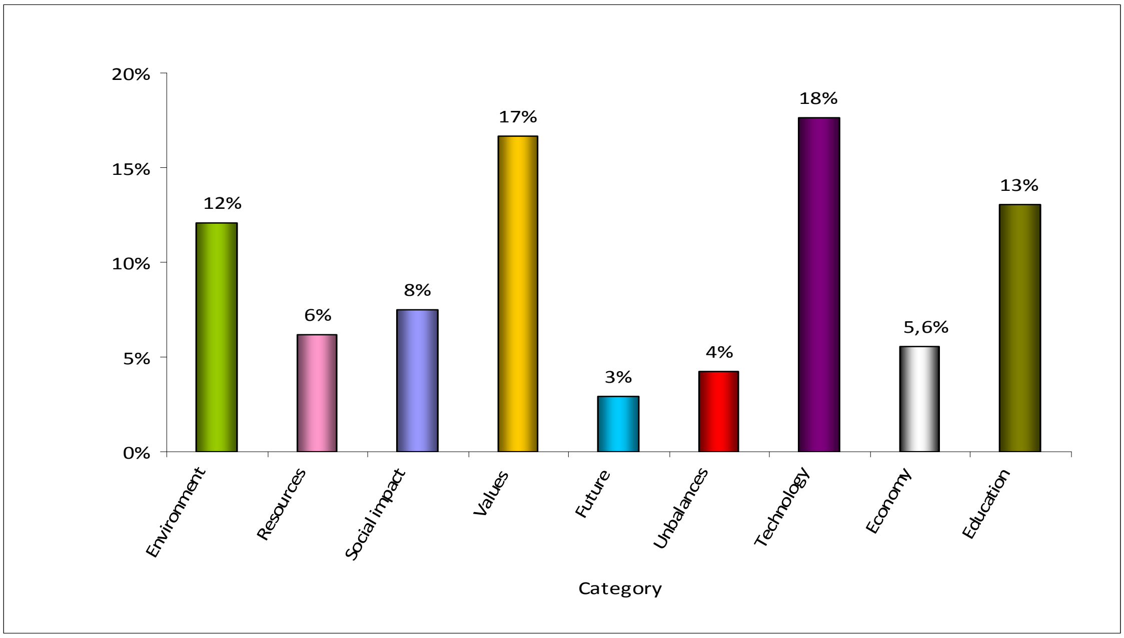

Figure 8.34 Case study UPC-4. $Cmap_2$: Concepts distribution

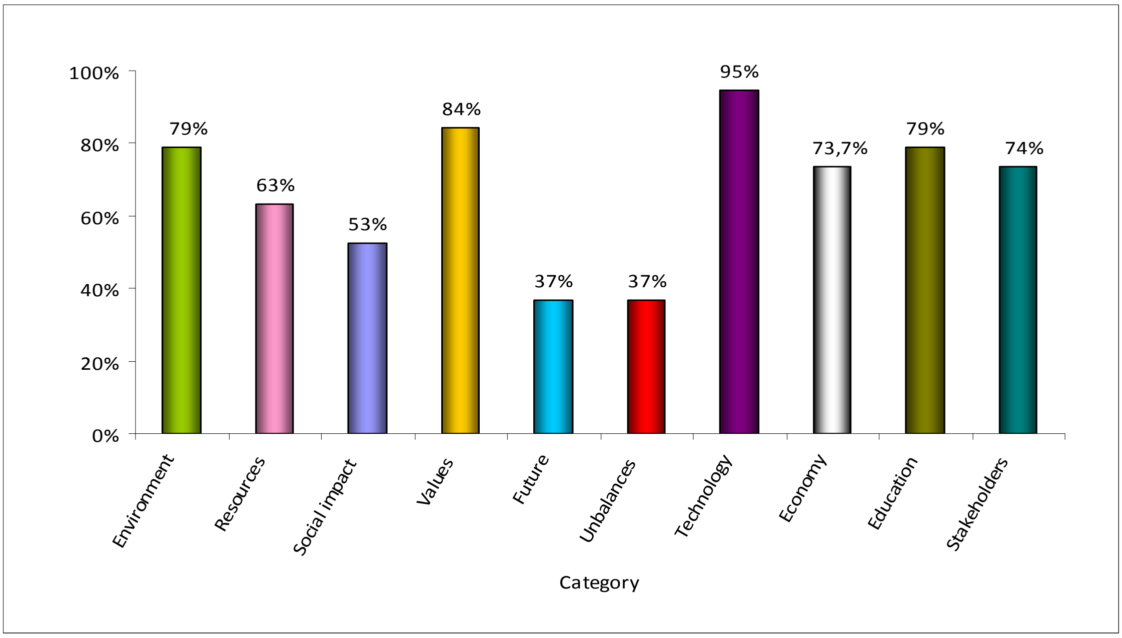

Figure 8.35 Case study UPC-4. $Cmap_2$: Percentage of experts per category distribution

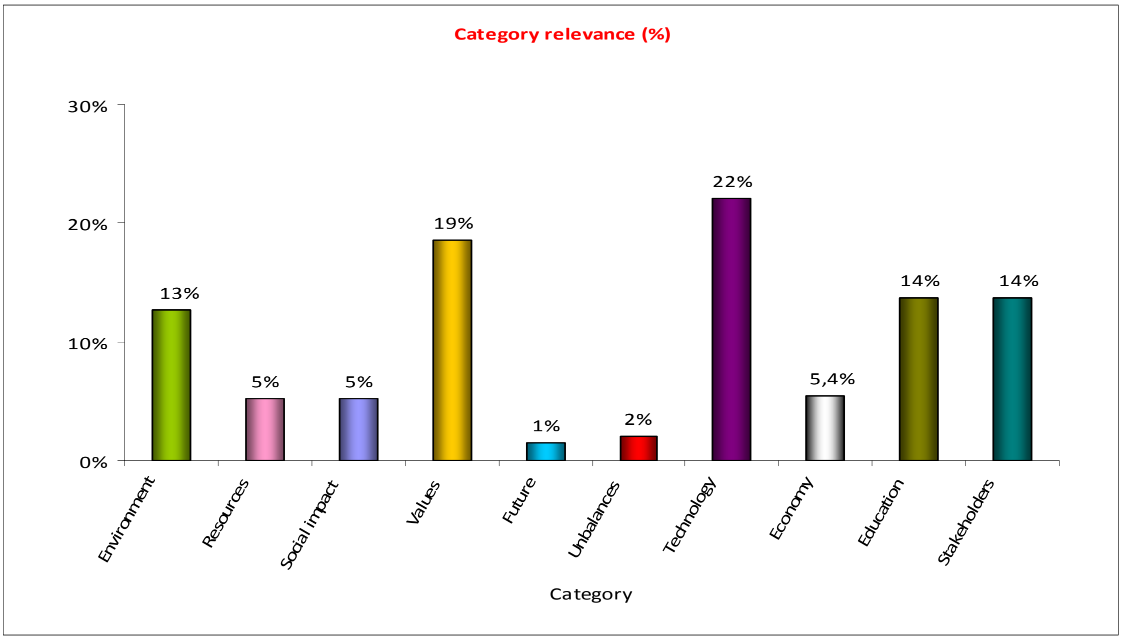

Figure 8.36 Case study UPC-4. $Cmap_2$: Category relevance index

From the category relevance index *Technology* (22%) and *Values* (19%) categories are the most referenced. The next category relevance values are for *Education*, *Stakeholders* and *Environment*. Finally the other categories have approximately the same values but *Unbalances* and *Future* with only a 2% and 1% of relevance respectively.

Figure 8.37 shows the Category distribution under the four categories taxonomy. It illustrates that there are three categories: *Technological/Economic*, *Social* and *Institutional*, with a slightly higher relevance than the *Environmental* one. Nevertheless there is a fairly equal distribution among all of them.

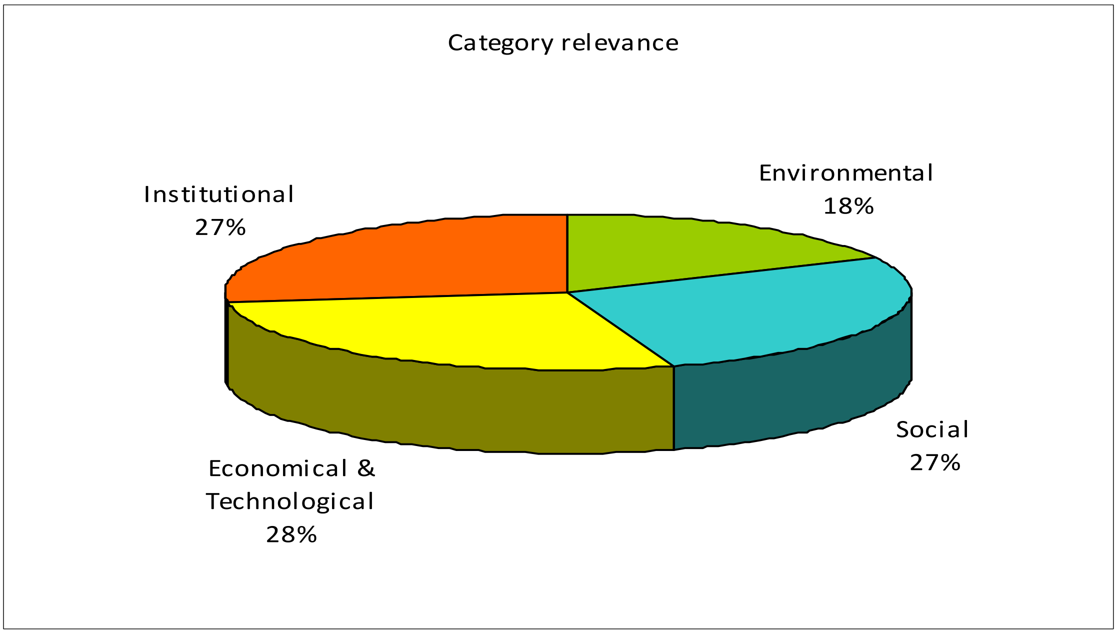

Figure 8.37 Case study UPC-4. $Cmap_2$: Category relevance index. 4 Categories

<u>Complexity Index</u>

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{184}{10 \times 19} = 0.97$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{15.6}$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.38 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. The very high values for *Environment* and *Stakeholders* categories from Cmap1 have been transformed into very high values for *Values* and *Technology*.

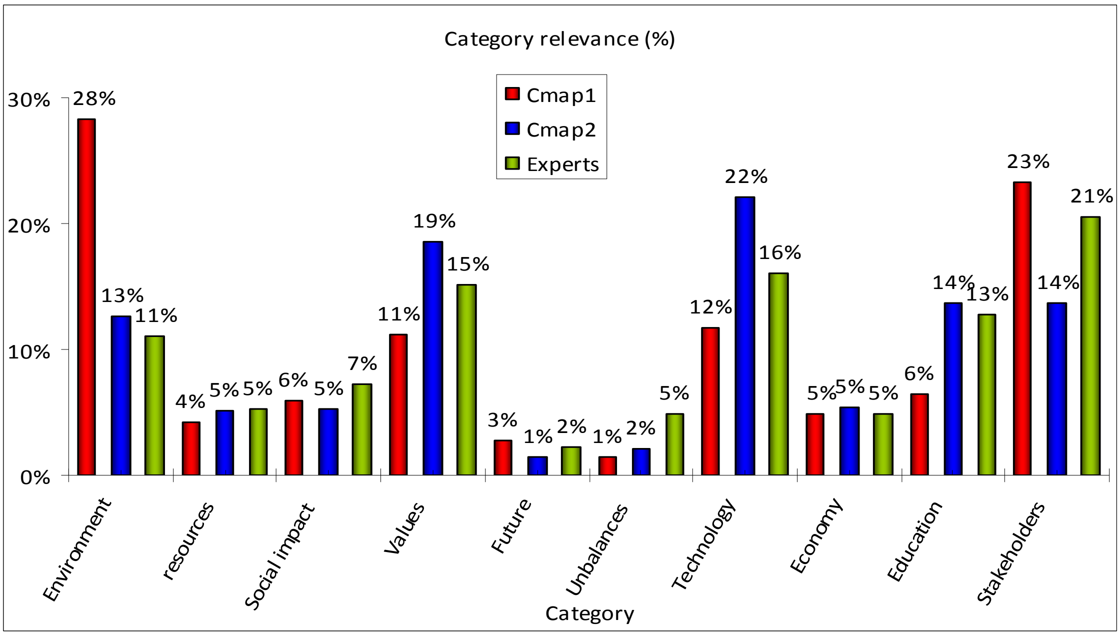

Figure 8.38 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

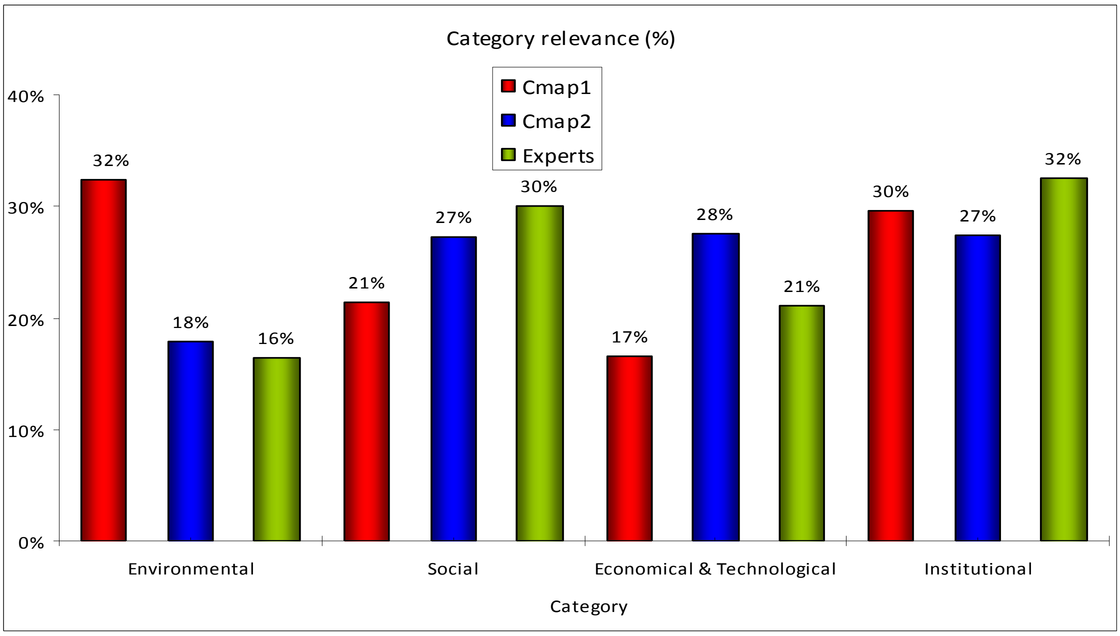

Figure 8.39 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, in figure 8.39, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Environmental* category and too little to the *Social* one. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one.

In relation to the complexity index the results obtained in the three studies table 8.25 shows that before taking the course the students saw sustainability as a complex subject (*CO*=20.35), but after finishing it they see sustainability as less systemic (*CO*=15.60). Nevertheless, when comparing students against the experts' values, their results are still far from the reference ones.

	Cmap1	Cmap2	Experts
Complexity index (CO)	20.35	15.60	24.8

Table 8.25 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.4 Case studies at Delft University of Technology

8.4.1 DUT Case study 1: Energy III

Case study Code: **DUT-1**			
University: **Delft University of Technology**			
Course name: **Energy III**		Cycle: **1st**	ECTS: 8.5 (0.7 on SD)
Web: **-**			
Pedagogy: **5% of lectures, 10% workshops, 5% direct feedback, 80% assignment and report writing.**			
Date of survey: **2006**	Type of course: **Compulsory**	Sample $Cmap_1$: **32**	Sample $Cmap_2$: **26**
Students speciality: **Mechanical engineering**			
Coordinator: **Gertjan de Werk**			
Objectives: - Examples of local, regional and global environmental problems in relation to sustainable development and the causes of these problems. - Examples of criteria requirements for energy technology. Establishing the criteria to maximize the sustainability of a product or process and show the reasons why certain criteria are not feasible. - To explain why from the perspective of sustainable development, it is important to study (adaptation of) the properties of an energy technology. - To analyze and explain the difference in durability of various energy systems. - Before, during and after the design process to be able also to identify whether there are other opportunities to meet the needs, and requirements established. And to be able to give advice on the commercial potential of other products, which fulfil the requirements in a different way.			
Program: The first part is about SD in relation to the energy system, where students are told about SD, the energy problem and have to define criteria for a sustainable heat pump or CHP-system. The second part is more specific about the criteria, how can the design be evaluated, how sustainable it is in the end.			

Table 8.26 Case study DUT-1. Energy III

The results of the students' Cmaps analysis are:

Cmap$_1$: Before taking the course

Variable		Values
Number of students	*NS*	32
Number total of concepts	NC_{S1}	235
Number total of links inter-categories	NL_{S2}	13
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	7.34

Table 8.27 Case study DUT-1. Cmap$_1$: Variables value

Therefore using the variables from the table 8.27 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	33	37	1	0	9	3	118	7	3	3
CD_i	14%	16%	0%	0%	4%	1%	50%	3%	1%	1%
NS_i	18	16	1	0	7	3	30	7	2	3
SC_i	56%	50%	3%	0%	22%	9%	94%	22%	6%	9%
CR_i	**11%**	**11%**	**0%**	**0%**	**1%**	**0%**	**68%**	**1%**	**0%**	**0%**

Table 8.28 Case study DUT-1. Cmap$_1$: Category relevance variables

Graphically:

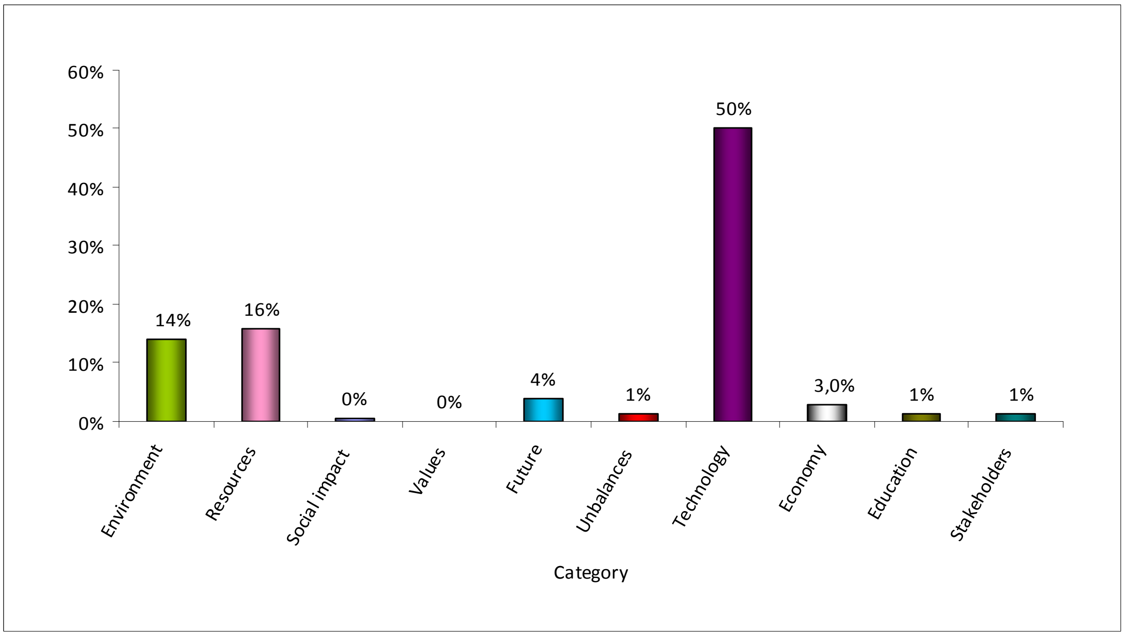

Figure 8.40 Case study DUT-1. Cmap$_1$: Concepts distribution

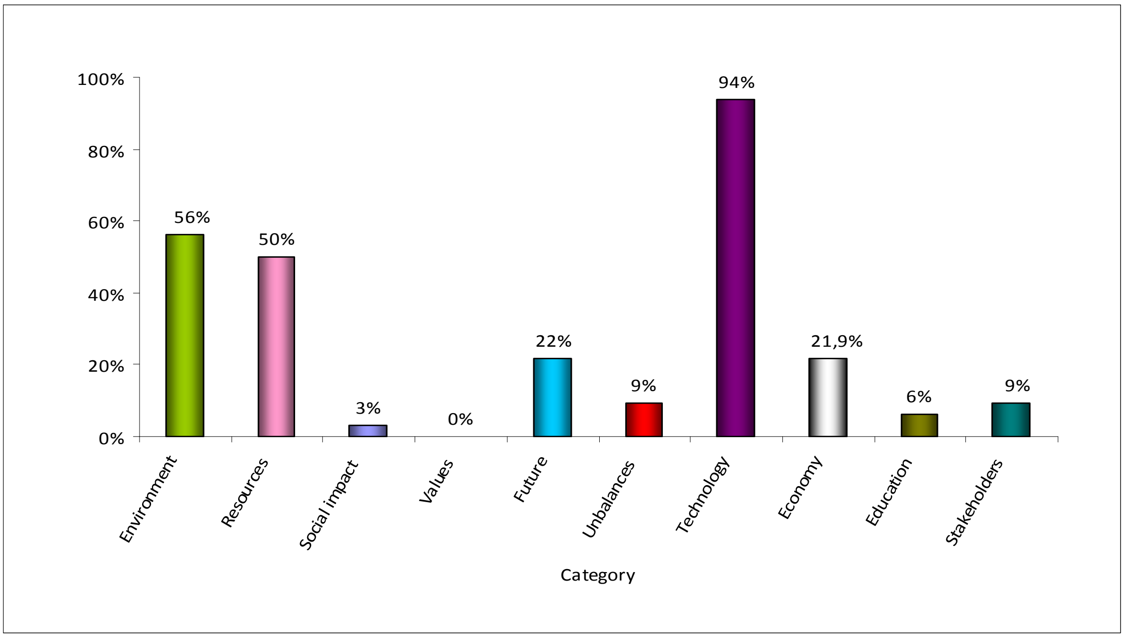

Figure 8.41 Case study DUT-1. $Cmap_1$: Percentage of experts per category distribution

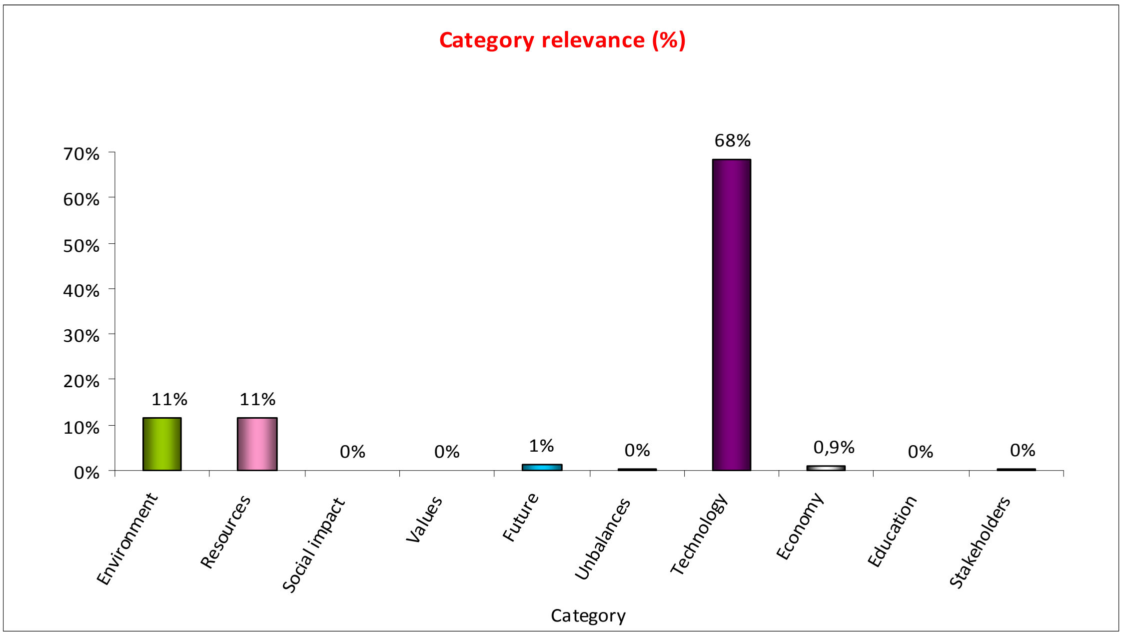

Figure 8.42 Case study DUT-1. $Cmap_1$: Category relevance index

From the category relevance index the *Technology* category is by far the most referenced (68%). *Environment* and *Resources* categories are also taken a bit into account to a limited extent with a *CR* of 11% each. The other categories are barely considered as related to sustainability.

Figure 8.43 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is by far taken as the most important category (69%) and *Environmental* has a share of 23%. *Social* and *Institutional* aspects are not given any value.

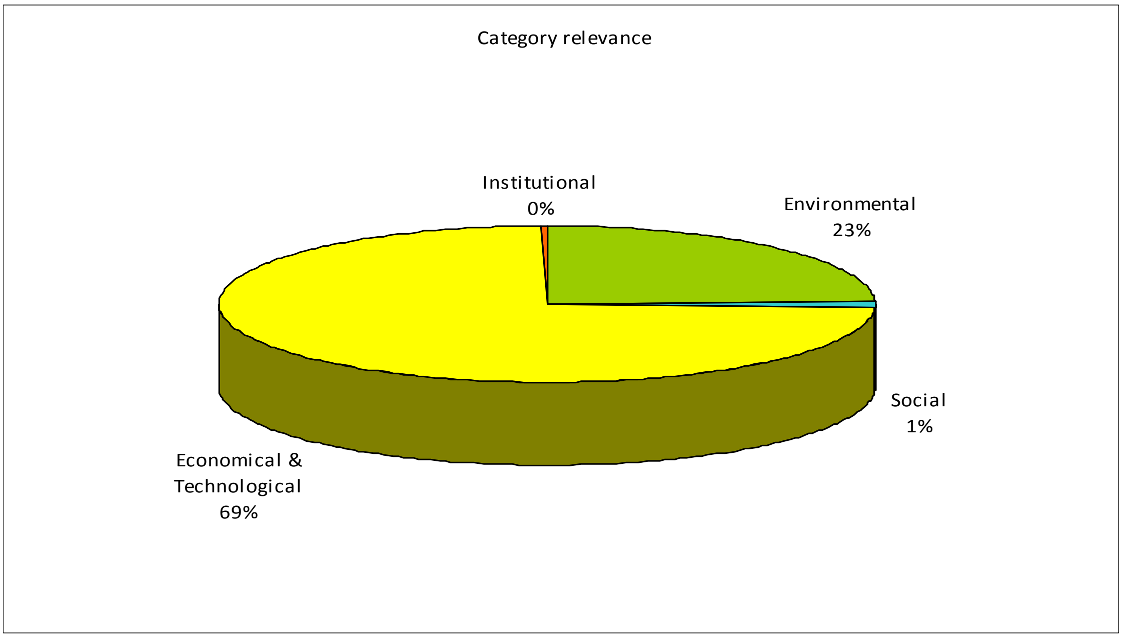

Figure 8.43 Case study DUT-1. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{13}{10 \times 32} = 0.04$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{0.29}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	26
Number total of concepts	NC_{S1}	256
Number total of links inter-categories	NL_{S2}	81
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9,85

Table 8.29 Case study DUT-1. $Cmap_2$: Variables value

Therefore using the variables from the table 8.29 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	44	35	23	2	5	1	63	20	16	23
CD_i	17%	14%	9%	1%	2%	0%	25%	8%	6%	9%
NS_i	19	14	19	1	3	1	23	13	11	16
SC_i	73%	54%	73%	4%	12%	4%	88%	50%	42%	62%
CR_i	**19%**	**11%**	**10%**	**0%**	**0%**	**0%**	**33%**	**6%**	**4%**	**8%**

Table 8.30 Case study DUT-1. $Cmap_2$: Category relevance variables

Graphically:

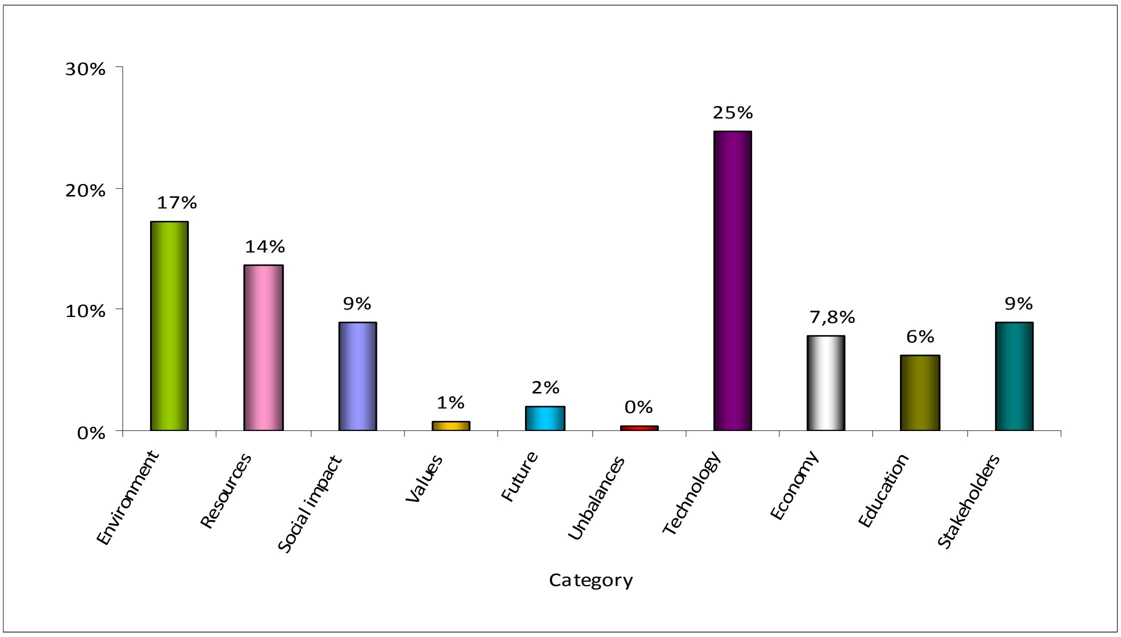

Figure 8.44 Case study DUT-1. $Cmap_2$: Concepts distribution

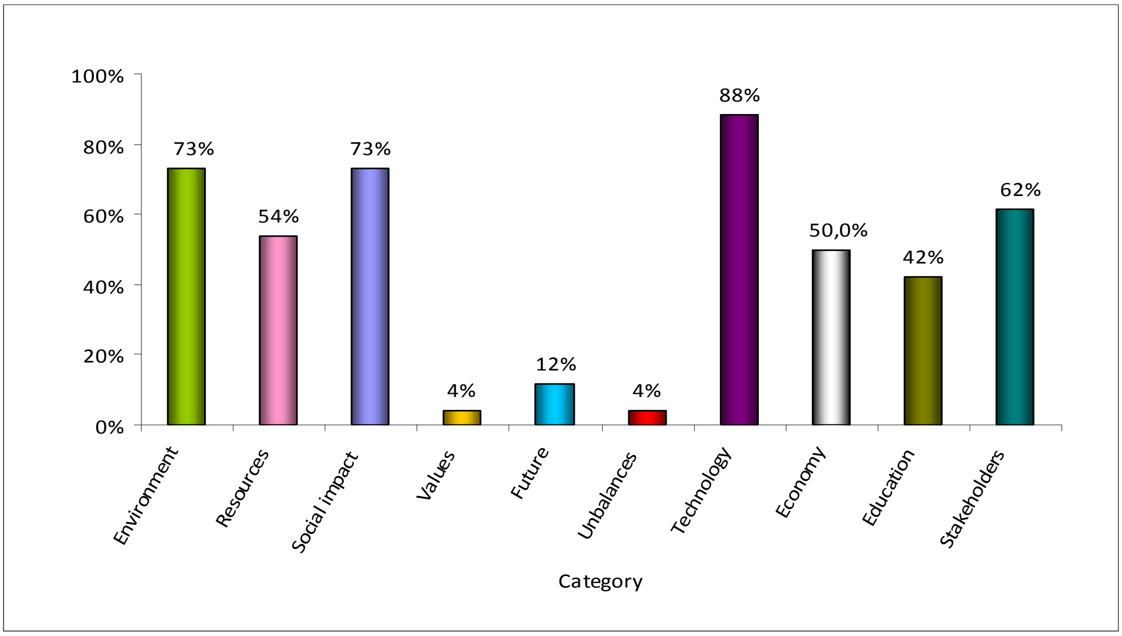

Figure 8.45 Case study DUT-1. $Cmap_2$: Percentage of experts per category distribution

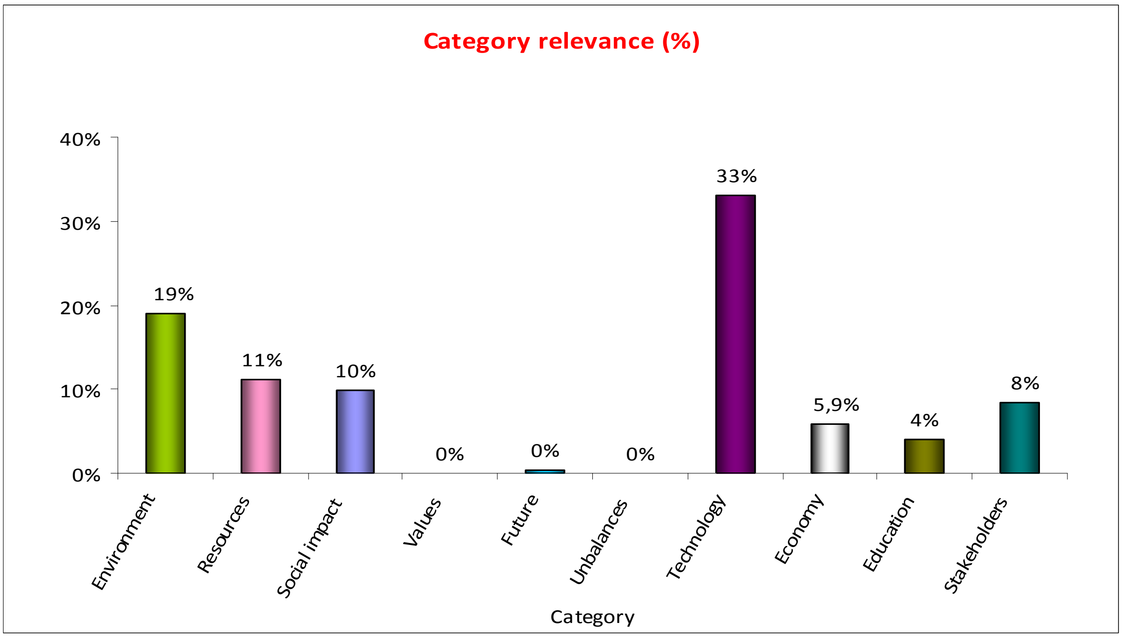

Figure 8.46 Case study DUT-1. $Cmap_2$: Category relevance index

From the category relevance index the *Technology* category is still the most referenced (33%). *Environment* is the next one with 19%. *Resources, Social impact* and *Stakeholders* have approximately the same relevance (≈ 10%). *Economy* and *Education* became more relevant, meanwhile *Values, Future* and *Unbalances* categories are still not taken into account by the students.

Figure 8.47 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* and *Environmental* are the most important categories for students. Nevertheless *Institutional* and *Social* ones have a value of 10%.

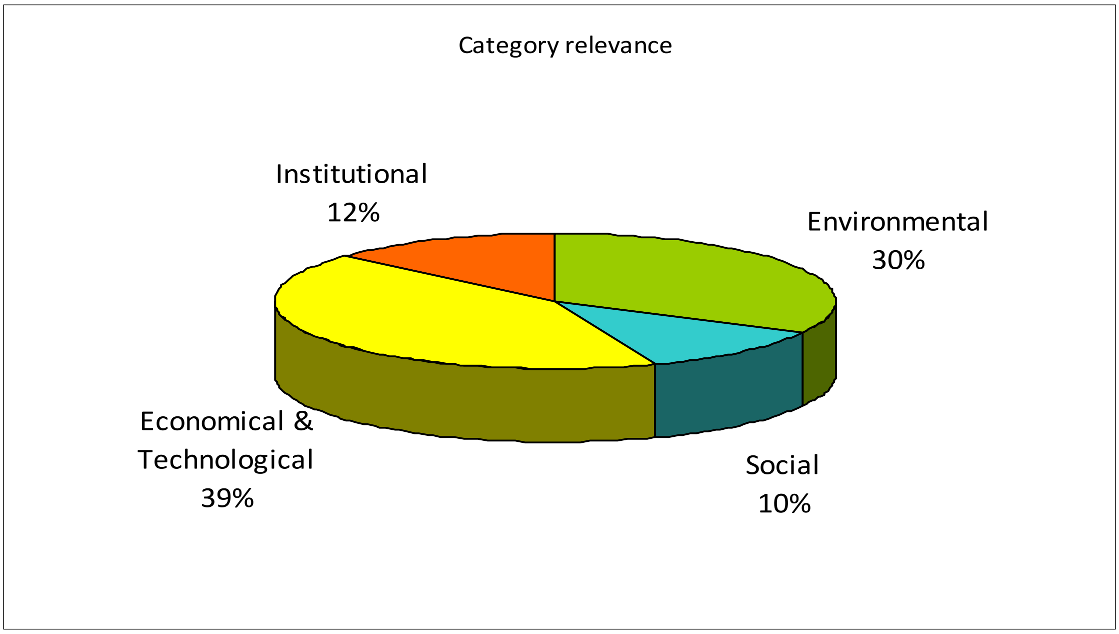

Figure 8.47 Case study DUT-1. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{81}{10 \times 26} = 0.31$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = 3.05$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.48 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. The very high value for *Technology* from Cmap1 has decreased significantly in $Cmap_2$. The initial lack of relevance for social related categories has only been partially modified.

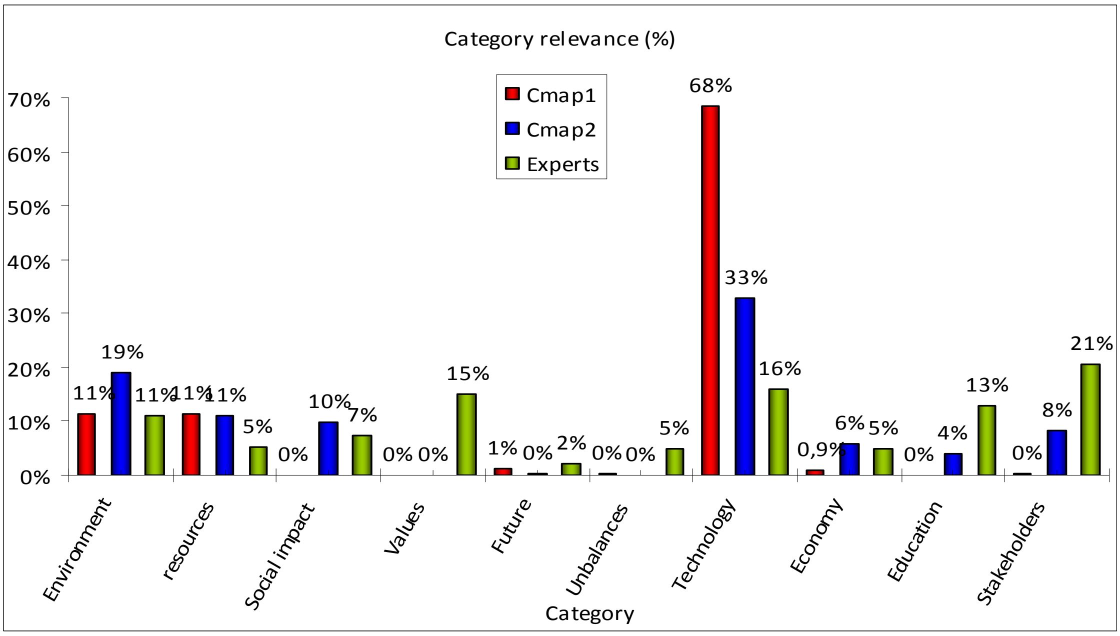

Figure 8.48 Case study DUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

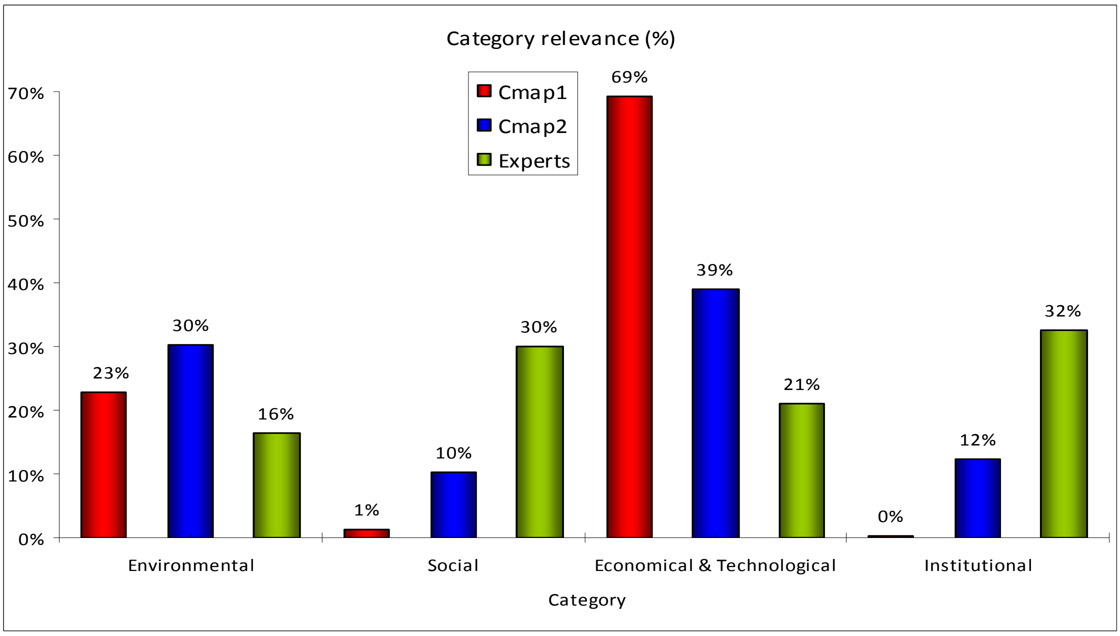

Figure 8.49 Case study DUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, figure 8.49, confirms the misunderstanding of engineering students, who before taking the course basically relate sustainability to *Technological/Economic* aspects. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one. Nevertheless there is considerable room for improvement.

In relation to the complexity index the results obtained in the three studies, table 8.31 shows that before taking the course the students saw sustainability as a not complex subject (*CO*=0,29).After finishing it they see sustainability a as bit more complex (*CO*=3.05) but their results are very far from the reference one (*CO*=24.8).

	Cmap1	Cmap2	Experts
Complexity index (CO)	0.29	3.05	24.8

Table 8.31 Case study DUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.4.2 DUT Case study 2: Societal aspects of information technology.

Case study Code: **DUT-2**			
University: **Delft University of Technology**			
Course name: **Societal aspects of information technology**		Cycle: **1st**	ECTS: **4**
Web: **http://studiegids.tudelft.nl/a101_displayCourse.do?course_id=8020**			
Pedagogy: **Face to face course. Lecturing (70%). Group work (30%).**			
Date of survey: **2006**	Type of course: **compulsory**	Sample Cmap$_1$: **68**	Sample Cmap$_2$: **3**
Students speciality: **Computer Science Engineering**			
Coordinator: **Karel Mulder**			
Objectives: Gain insight into the role of technology, especially information technology, in the process of sustainable development in relation to man and society, Gain understanding of the interplay between product, process and environment and the dynamics of technology development, Knowledge of the key concepts that apply to the use of technology from integrated environmental and economic objectives, Developing awareness of the responsibilities of the engineer in the process of sustainable development.			
Program: The development of information technology and society influence each other mutually. The technology analyzes how internal dynamic technological factors lead to innovation but also how social and economic factors such as globalization, standardization and market-regulating have an effect on technological innovation. To explain how technology in general and within the information and communication technology in particular, have increasingly seized environmental space. This environmental space is finite and therefore our production and consumption processes should be achieved within that space. In the lecture, a number of dilemmas are addressed and a number of strategies to achieve so-called transitions (changes in both technology and social organization of that technology) are discussed.			

Table 8.32 Case study DUT-2. Societal aspects of information technology.

The results of the students' Cmaps analysis are:

<u>Cmap$_1$: Before taking the course</u>

Variable		Values
Number of students	*NS*	68
Number total of concepts	NC_{S1}	679
Number total of links inter-categories	NL_{S2}	172
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.99

Table 8.33 Case study DUT-2. Cmap$_1$: Variables value

Therefore using the variables from table 8.33 the indexes' values are:

<u>Category relevance index</u>

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	107	91	47	8	30	5	237	25	58	35
CD_i	16%	13%	7%	1%	4%	1%	35%	4%	9%	5%
NS_i	47	39	33	6	23	3	64	21	30	24
SC_i	69%	57%	49%	9%	34%	4%	94%	31%	44%	35%
$\mathbf{CR_i}$	**17%**	**12%**	**5%**	**0%**	**2%**	**0%**	**51%**	**2%**	**6%**	**3%**

Table 8.34 Case study DUT-2. Cmap$_1$: Category relevance variables

Graphically:

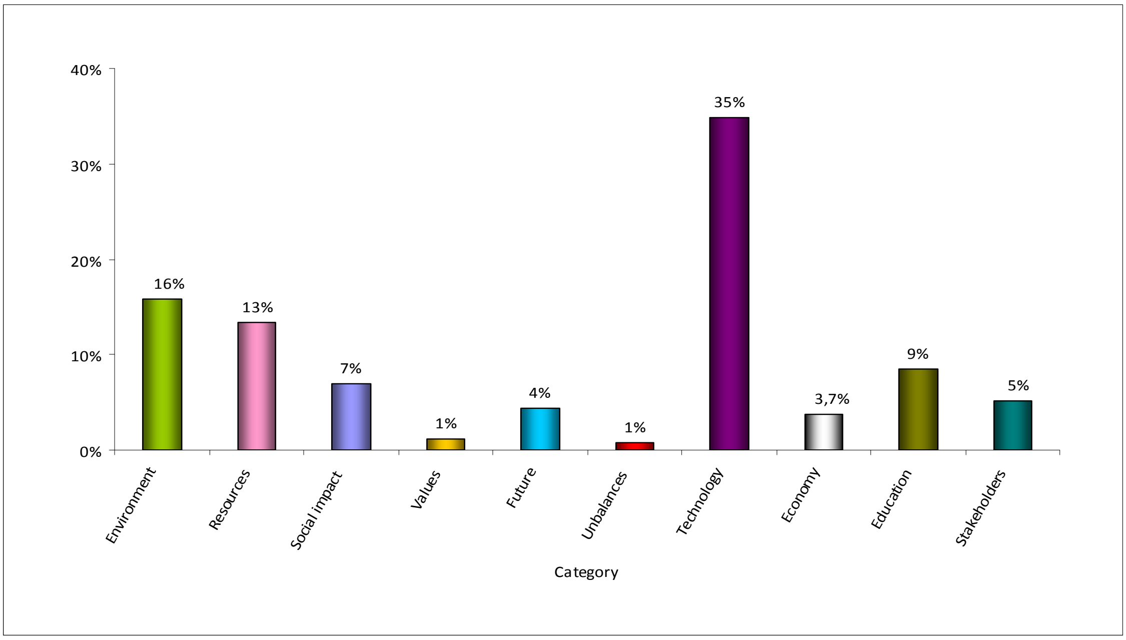

Figure 8.50 Case study DUT-2. $Cmap_1$: Concepts distribution

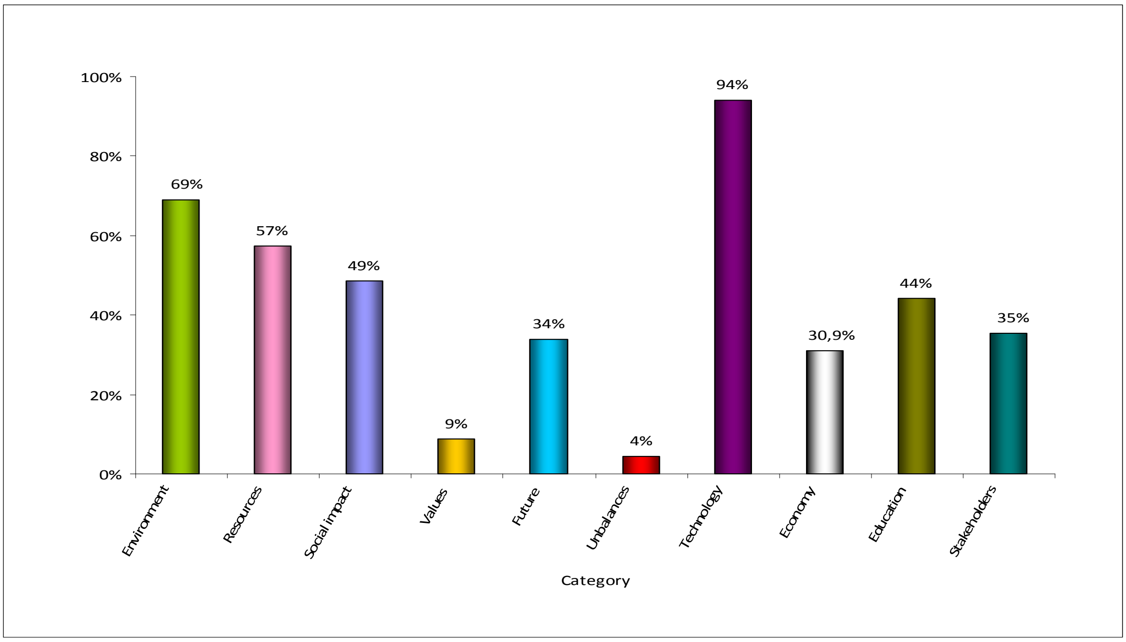

Figure 8.51 Case study DUT-2. $Cmap_1$: Percentage of experts per category distribution

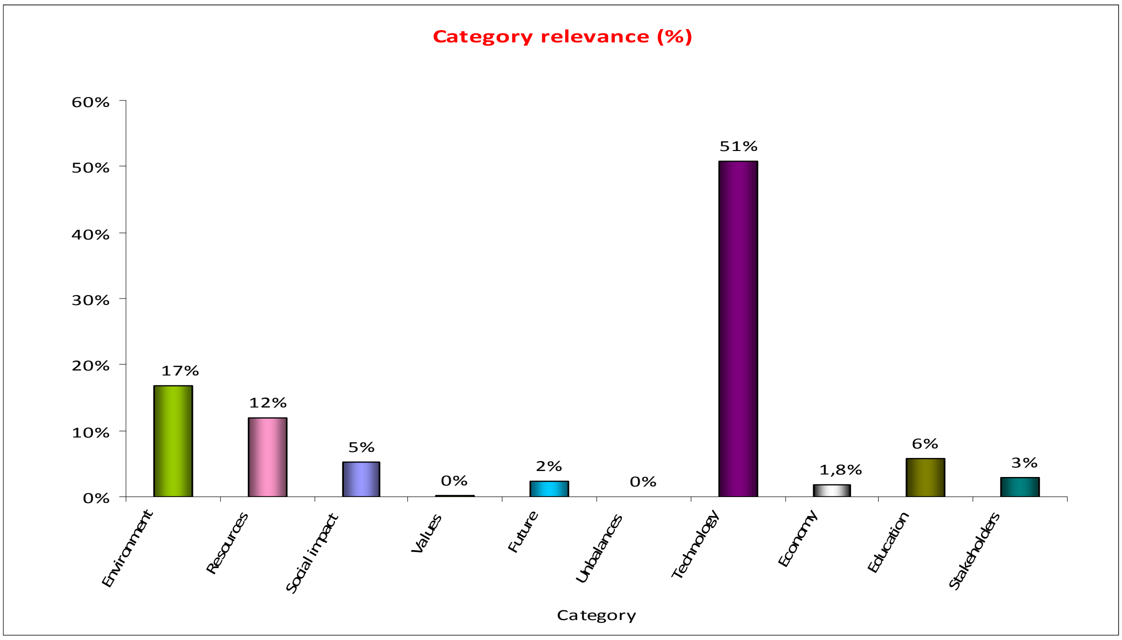

Figure 8.52 Case study DUT-2. $Cmap_1$: Category relevance index

From the category relevance index the *Technology* category is by far the most referenced (51%). *Environment* (17%) and *Resources (12%)* categories are the next categories to be considered important by students. The other categories are almost not considered as being related to sustainability.

Figure 8.53 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is taken by far as the most important category (52%) and *Environmental* has a share of 29%. *Social* and *Institutional* aspects are given little value.

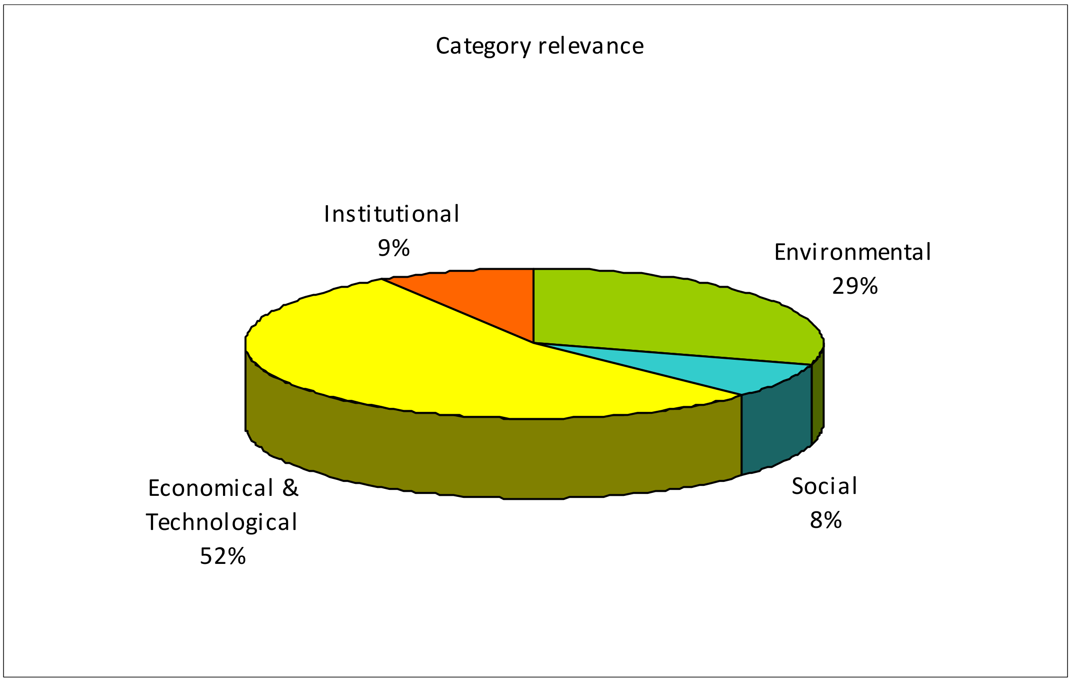

Figure 8.53 Case study DUT-2. $Cmap_1$: Category relevance index. 4 Categories

<u>Complexity Index</u>

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{172}{10 \times 68} = 0.25$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{2.50}$$

Cmap$_2$: After taking the course

Variable		Values
Number of students	*NS*	47
Number total of concepts	NC_{S1}	448
Number total of links inter-categories	NL_{S2}	169
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.53

Table 8.35 Case study DUT-2. Cmap$_2$: Variables value

Therefore using the variables from table 8.35 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	10	4	1	2	1	0	13	1	2	3
CD_i	26%	10%	3%	5%	3%	0%	33%	3%	5%	8%
NS_i	3	1	1	1	1	0	3	1	1	1
SC_i	100%	33%	33%	33%	33%	0%	100%	33%	33%	33%
CR_i	**35%**	**5%**	**1%**	**2%**	**1%**	**0%**	**46%**	**1%**	**2%**	**4%**

Table 8.36 Case study DUT-2. Cmap$_2$: Category relevance variables

Graphically:

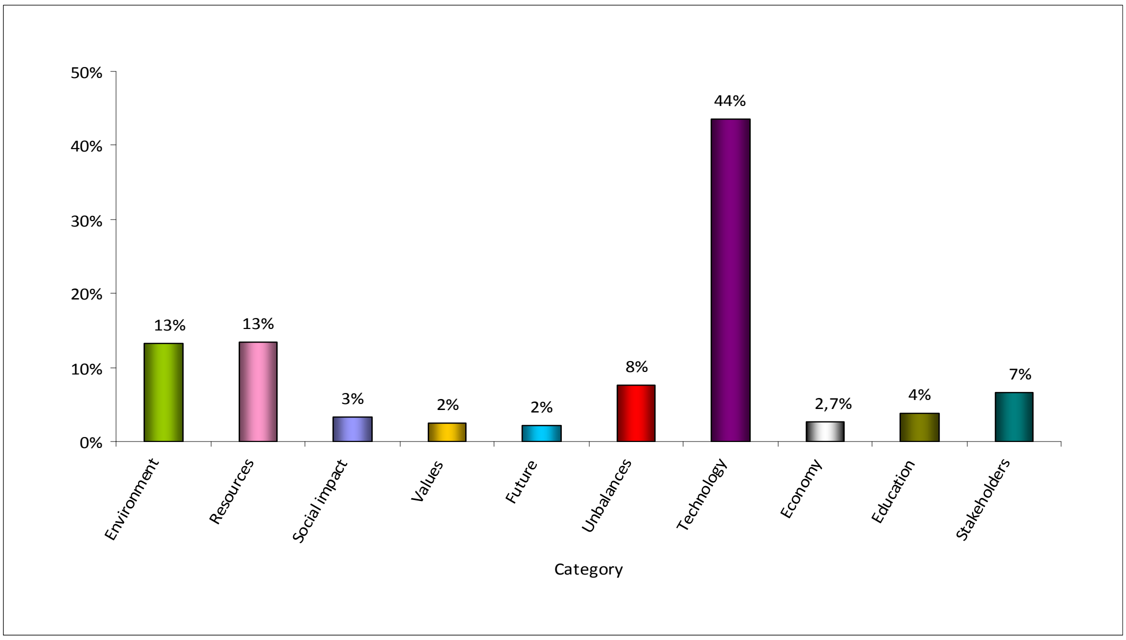

Figure 8.54 Case study DUT-2. Cmap$_2$: Concepts distribution

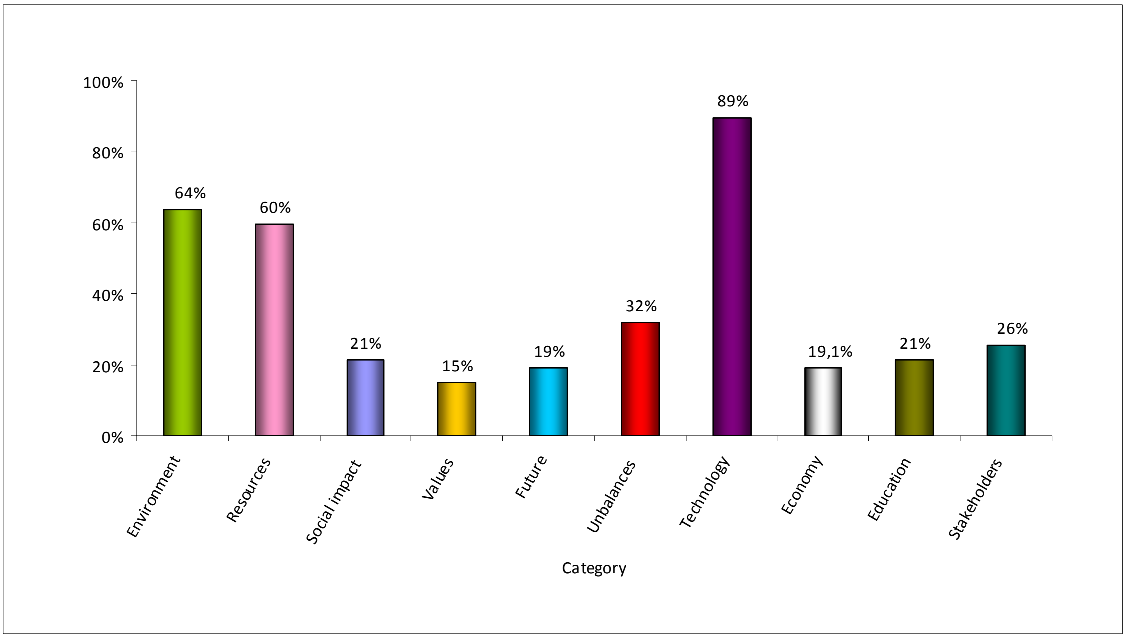

Figure 8.55 Case study DUT-2. Cmap$_2$: Percentage of experts per category distribution

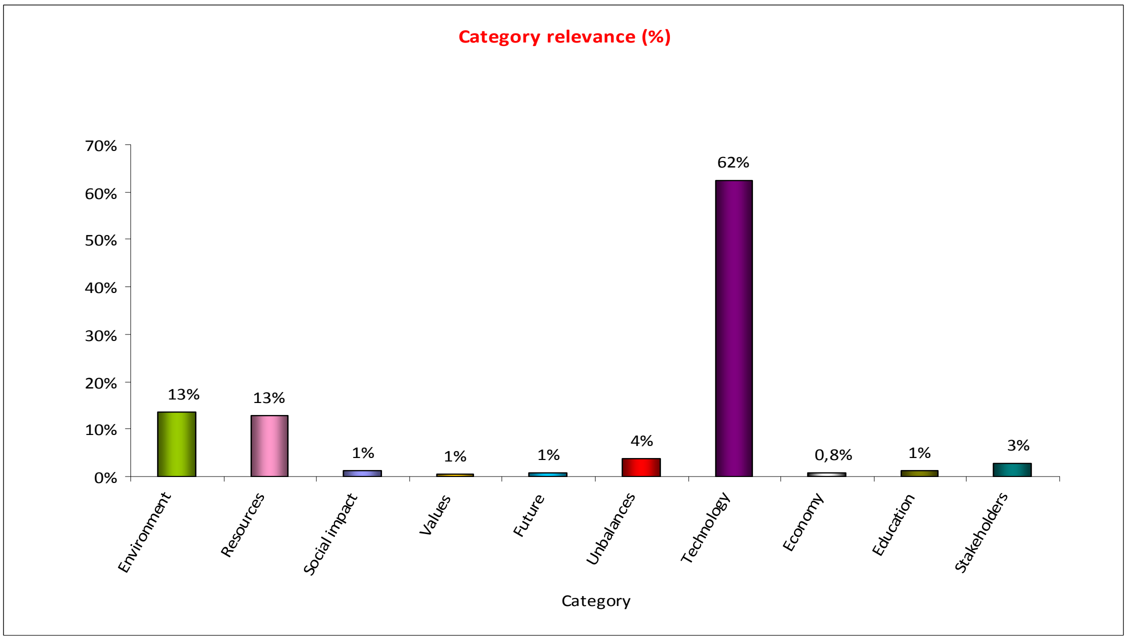

Figure 8.56 Case study DUT-2. Cmap$_2$: Category relevance index

From the category relevance index the *Technology* category is still the most referenced (62%) followed by *Environment* and *Resources* (13% each). The other categories are hardly taken into account by students.

Figure 8.57 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is by far taken as the most important category (63%) and *Environmental* has a share of 26%. *Social* and *Institutional* aspects are almost not given any value.

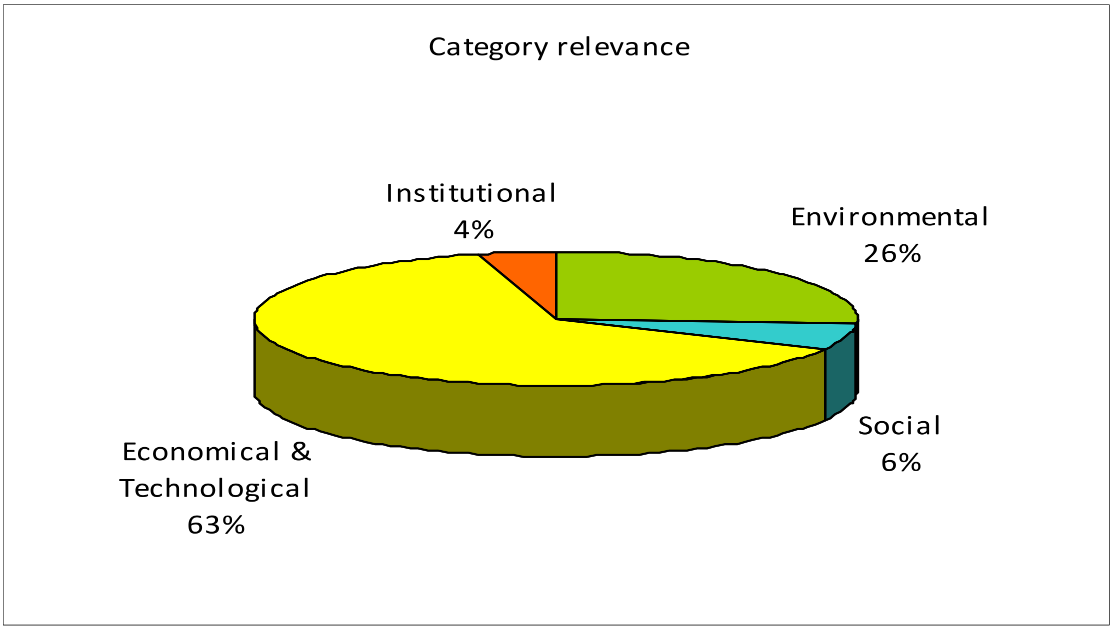

Figure 8.57 Case study DUT-2. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{169}{10 \times 47} = 0.36$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = 3.43$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.58 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. There are categories (*Environment*, *Values*, and *Unbalances*) where the results after having the course are closer to the experts' Cmaps than the results before taking it. In all the other categories the $Cmap_2$ results are more different to the experts' Cmaps than the $Cmap_1$ ones. The very high value for *Technology* from Cmap1 has even increased significantly in $Cmap_2$. The initial lack of relevance for social related categories is maintained when not increased.

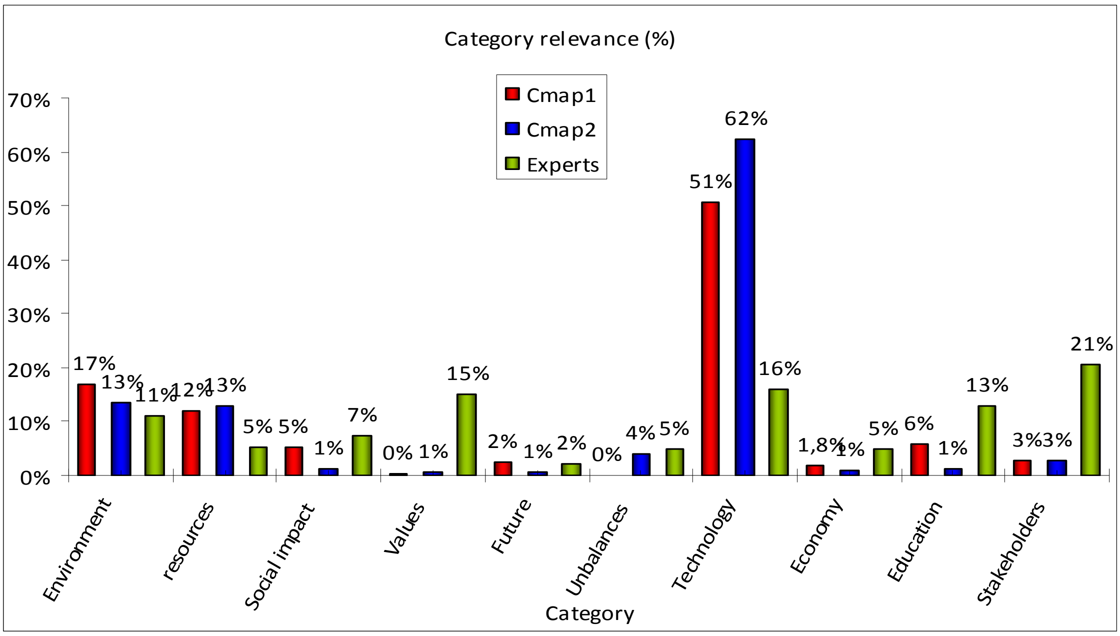

Figure 8.58 Case study DUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

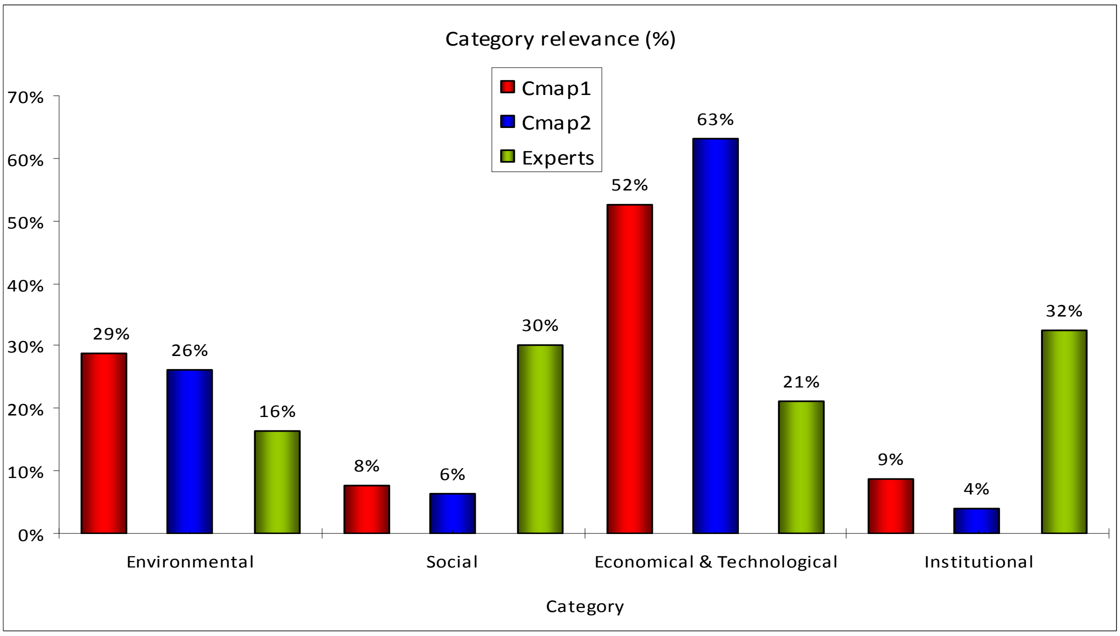

Figure 8.59 Case study DUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, figure 8.59, confirms the misunderstanding of engineering students, who before taking the course basically relate sustainability to *Technological/Economic* aspects. After taking the course this mistake is only rectified for the *Environmental* category. The other three categories get worse results after taking the course.

In relation to the complexity index the results obtained in the three studies, table 8.37 shows that before taking the course the students saw sustainability as a not complex subject (*CO*=2.50). After finishing it they see sustainability as a bit more complex (*CO*=3.43) but their results are very far from the reference one (*CO*=24.8).

	Cmap1	Cmap2	Experts
Complexity index (CO)	2.50	3.43	24.8

Table 8.37 Case study DUT-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.5 Case studies at Chalmers University of Technology

8.5.1 Chalmers Case study 1: Global Chemical Sustainability

Case study Code: **CUT-1**			
University: **Chalmers University of Technology**			
Course name: **Global Chemical Sustainability**		Cycle: **2nd**	ECTS: **7.5**
Web: **http://www.student.chalmers.se/sp/course?course_id=10353**			
Pedagogy: **Lectures. Guest lectures. Exercises. Role play. Seminars and Project Based Learning.**			
Date of survey: **2008**	Type of course: **Compulsory**	Sample $Cmap_1$: **51**	Sample $Cmap_2$: **53**
Students speciality: **Chemical (Innovative and Sustainable Chemical Technology)**			
Coordinator: **Magdalena Svanström**			
Objectives: The course deals with the environmental incentives for sustainable development in the chemical and chemical engineering industry and with tools and strategies to achieve it. The course describes how the different compartments of the environment function, how efforts are made to solve these problems in an international arena and the major sustainability challenges in industry and tools and methods to facilitate a move in the right direction. The course is broad but has a particular focus on process industry related issues, on chemistry and chemicals, on international and global concerns and efforts, and on the environmental dimension of sustainable development.			
Program: The course deals with incentives for sustainable development in chemical and chemical engineering industry and with tools and strategies to achieve it. The course describes how the different compartments of the environment function and the connections to the social and economic dimensions, how efforts are made to solve these problems in an international arena and the major sustainability challenges in industry and tools and methods to facilitate a move in the right direction. The course is broad but has a particular focus on process industry related issues, on chemistry and chemicals, on international and global concerns and efforts, and on the environmental dimension of sustainable development.			

Table 8.38 Case study CUT-1. Global Chemical Sustainability

The results of the students' Cmaps analysis are:

$Cmap_1$: Before taking the course

Variable		Values
Number of students	*NS*	51
Number total of concepts	NC_{S1}	737
Number total of links inter-categories	NL_{S2}	421
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	14.45

Table 8.39 Case study CUT-1. $Cmap_1$: Variables value

Therefore using the variables from table 8.39 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	192	69	59	15	19	6	265	28	21	46
CD_i	26%	9%	8%	2%	3%	1%	36%	4%	3%	6%
NS_i	49	29	31	10	16	5	45	22	16	23
SC_i	96%	57%	61%	20%	31%	10%	88%	43%	31%	45%
CR_i	**34%**	**7%**	**7%**	**1%**	**1%**	**0%**	**43%**	**2%**	**1%**	**4%**

Table 8.40 Case study CUT-1. Cmap$_1$: Category relevance variables

Graphically:

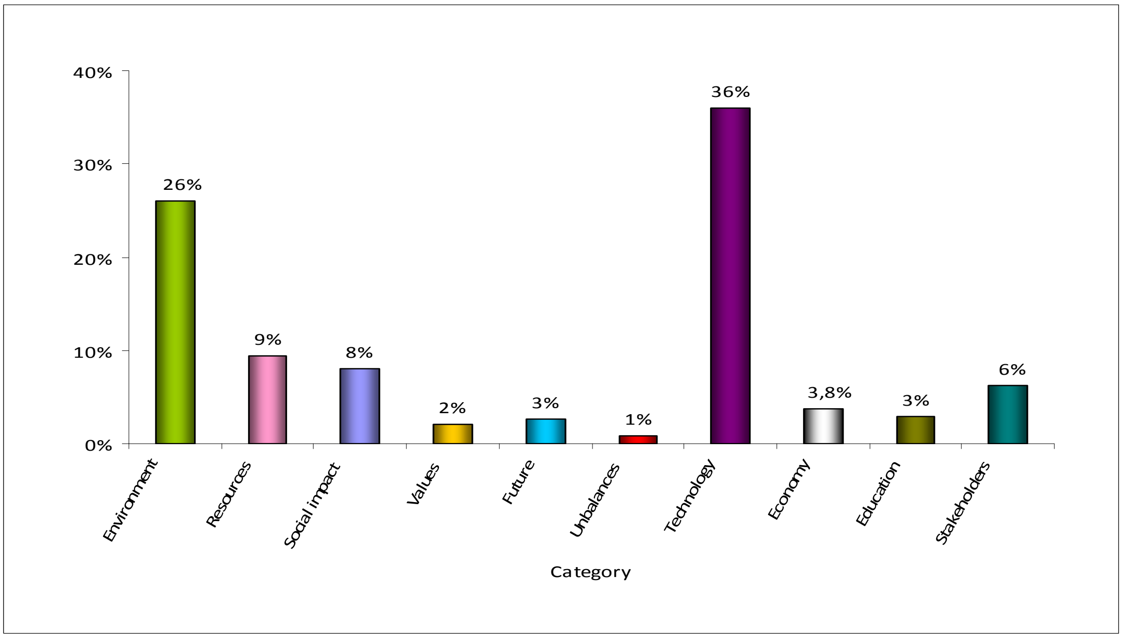

Figure 8.60 Case study CUT-1. Cmap$_1$: Concepts distribution

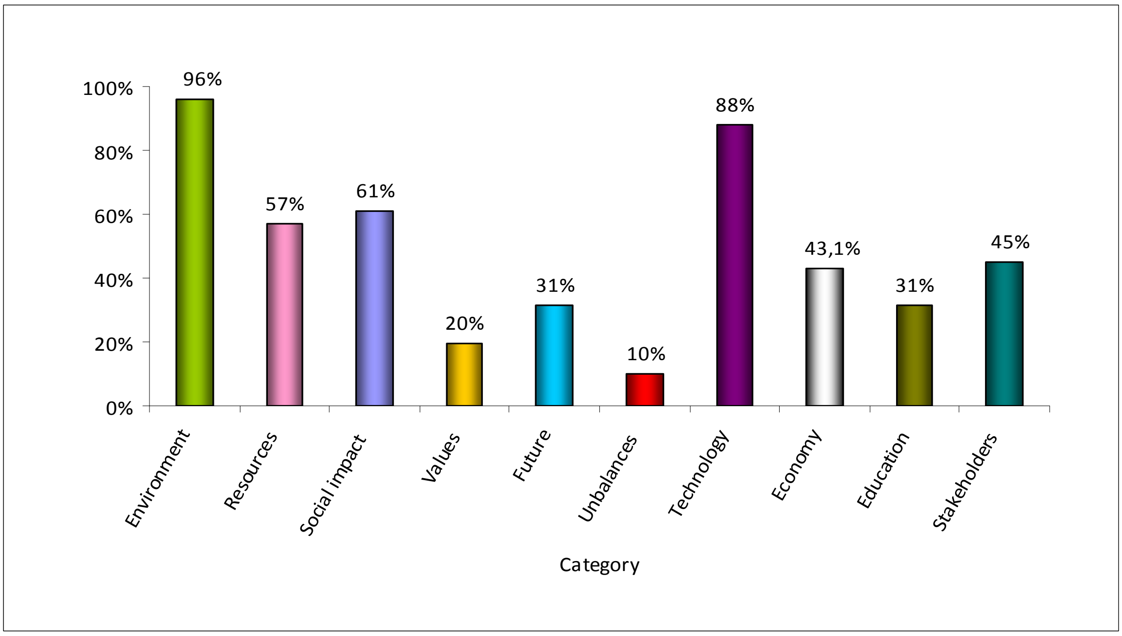

Figure 8.61 Case study CUT-1. Cmap$_1$: Percentage of experts per category distribution

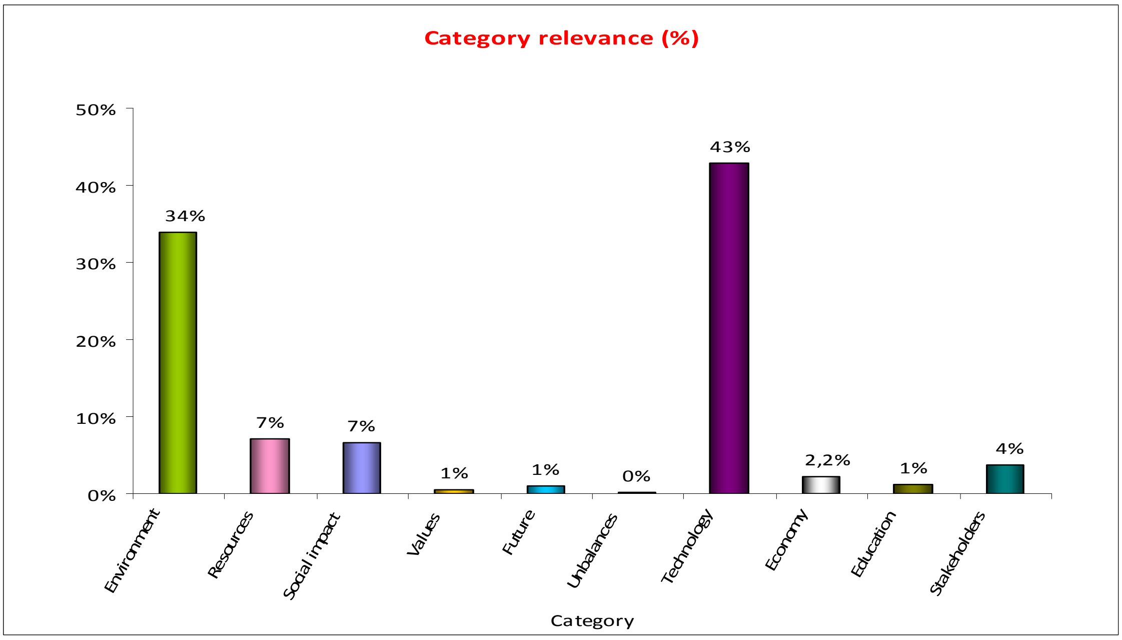

Figure 8.62 Case study CUT-1. $Cmap_1$: Category relevance index

From the category relevance index the *Technology* and *Environment* categories are the most referenced (43% + 34% = 77%). The next category relevance values are *Resources* and *Social Impact* (7% each). Finally the other categories have little relevance, except *Stakeholders* (4%).

Figure 8.63 shows the Category distribution under the four categories taxonomy. It shows that *Environmental* and *Technological/Economic* categories are (86%) seen as the most related to sustainability by the students before taking the course.

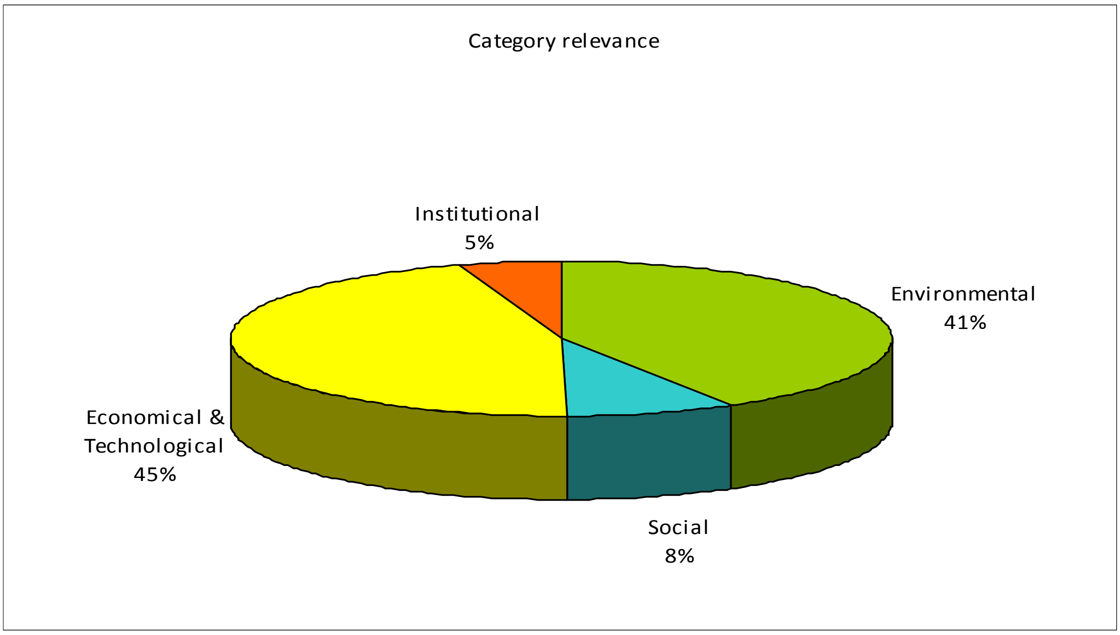

Figure 8.63 Case study CUT-1. $Cmap_1$: Category relevance index. 4 Categories

<u>Complexity Index</u>

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{421}{10 \times 51} = 0.83$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{11.92}$$

Cmap$_2$: After taking the course

Variable		Values
Number of students	*NS*	53
Number total of concepts	NC_{S1}	825
Number total of links inter-categories	NL_{S2}	585
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	15.57

Table 8.41 Case study CUT-1. Cmap$_2$: Variables value

Therefore using the variables from table 8.41 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	190	100	58	38	19	61	213	61	65	99
CD_i	21%	11%	6%	4%	2%	7%	23%	7%	7%	11%
NS_i	27	24	18	15	11	19	28	17	20	21
SC_i	51%	45%	34%	28%	21%	36%	53%	32%	38%	40%
CR_i	**24%**	**11%**	**5%**	**3%**	**1%**	**6%**	**28%**	**5%**	**6%**	**10%**

Table 8.42 Case study CUT-1. Cmap$_2$: Category relevance variables

Graphically:

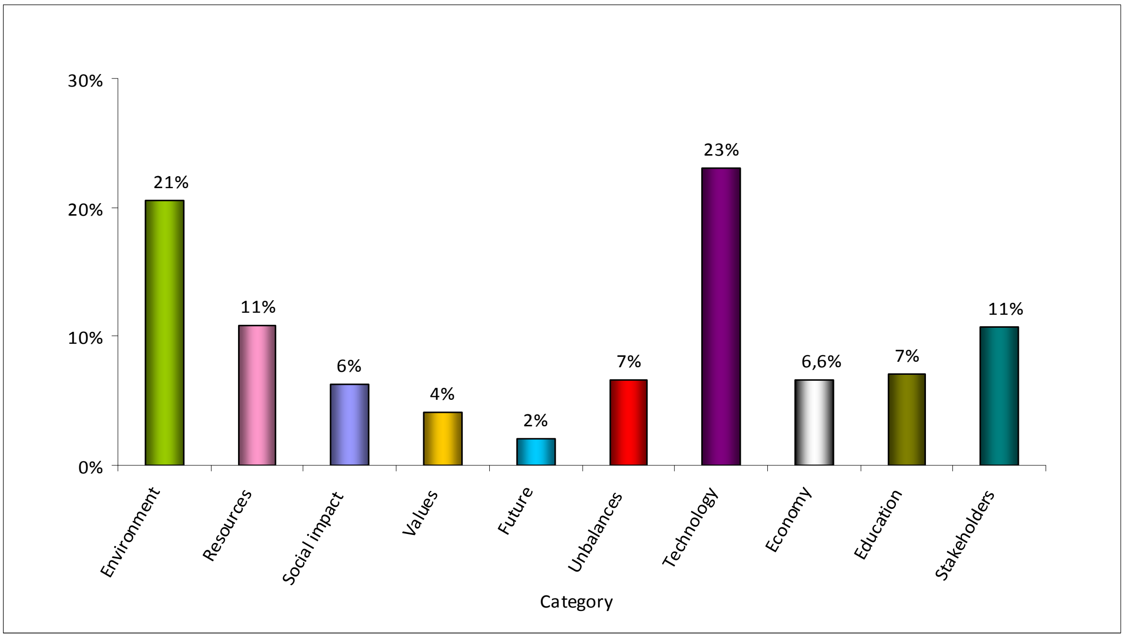

Figure 8.64 Case study CUT-1. Cmap$_2$: Concepts distribution

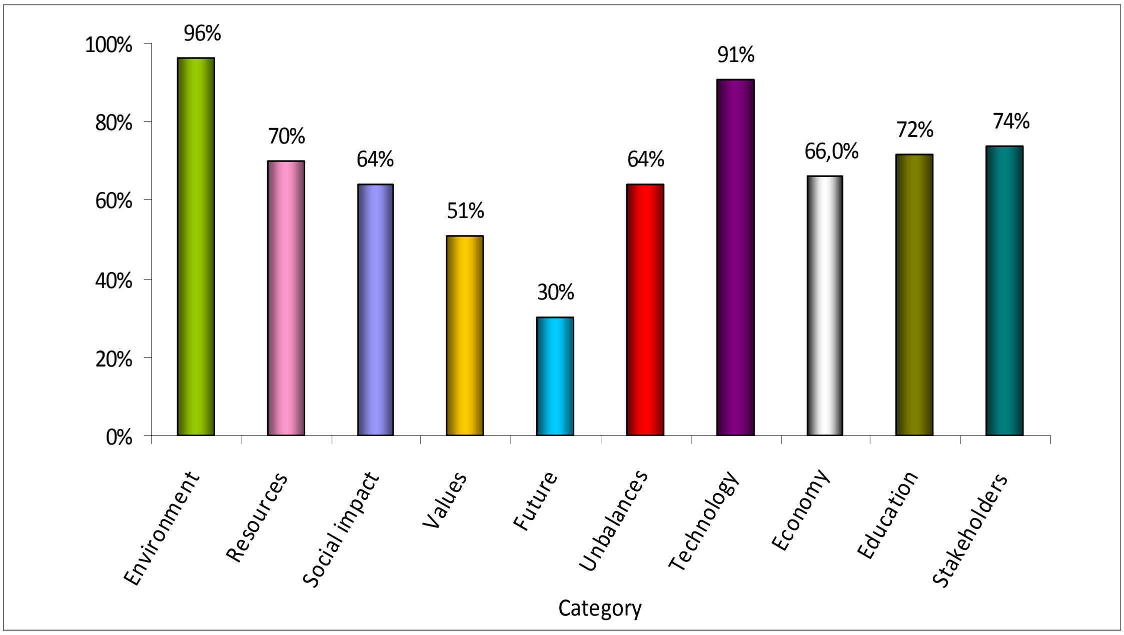

Figure 8.65 Case study CUT-1. $Cmap_2$: Percentage of experts per category distribution

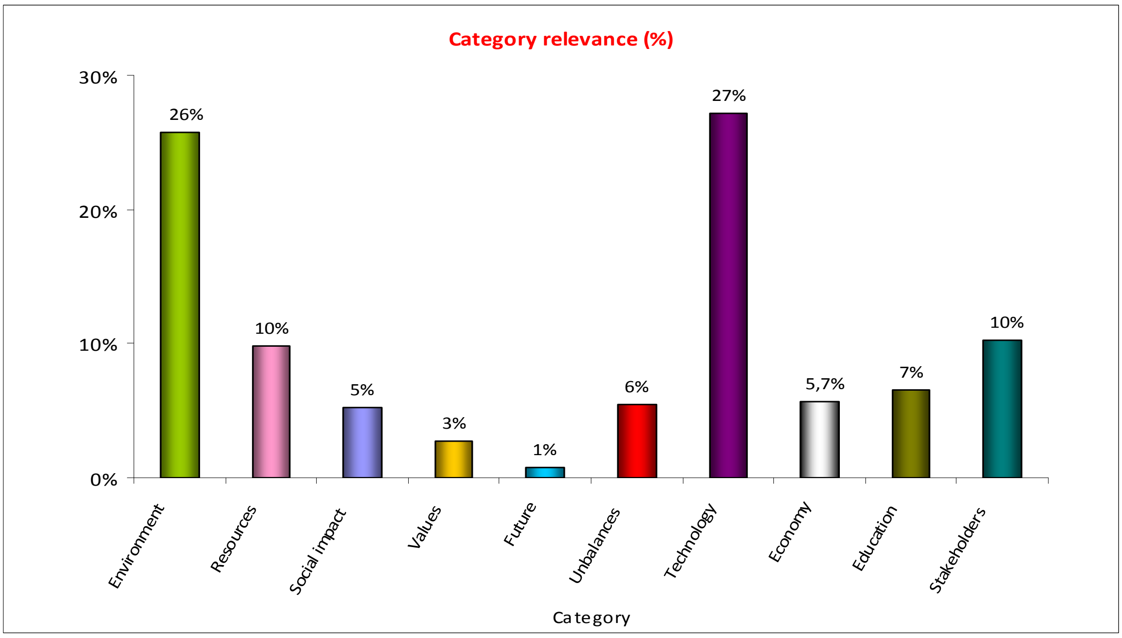

Figure 8.66 Case study CUT-1. $Cmap_2$: Category relevance index

From the category relevance index the *Technology* and *Environment* categories are the most referenced (27% + 26% = 53%). The next category relevance values are *Resources* and *Stakeholders* (10% each). Finally the other categories have little relevance, especially the *Future* category (1%), although it is important to highlight that all categories are more or less considered.

Figure 8.67 shows the Category distribution under the four categories taxonomy. It shows that *Environmental* and *Technological/Economic* categories are (69%) seen as the most related to sustainability by the students before taking the course.

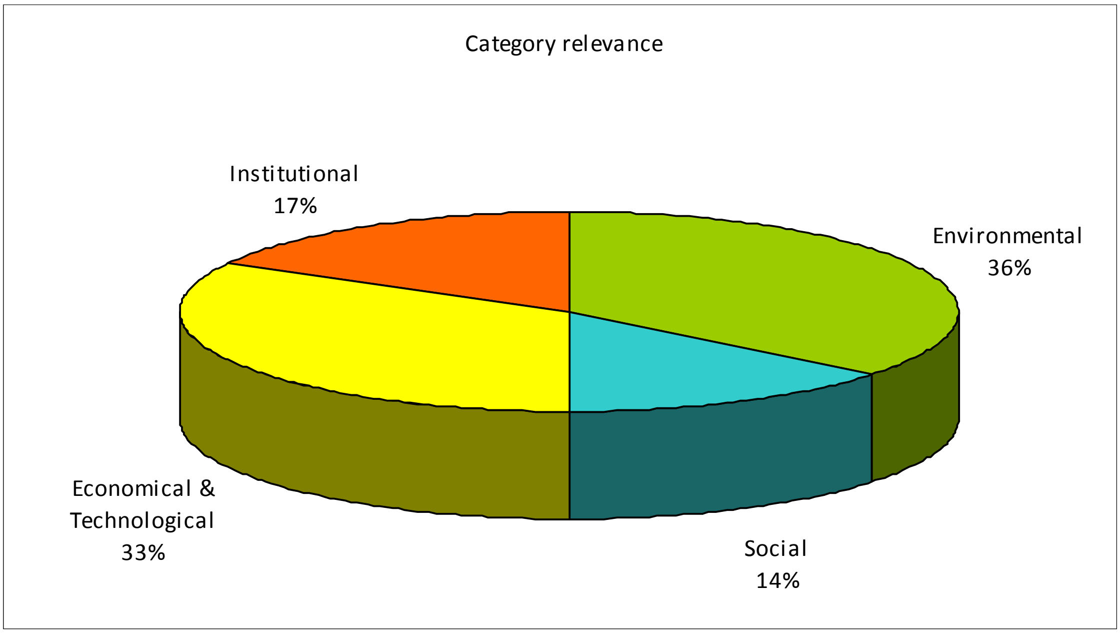

Figure 8.67 Case study CUT-1. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{585}{10 \times 53} = 1{,}10$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = 17.13$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.68 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. The very high values for *Environment* and *Stakeholders* categories from Cmap1 should have decrease further and that the *Values* category is the one which should have increased the most.

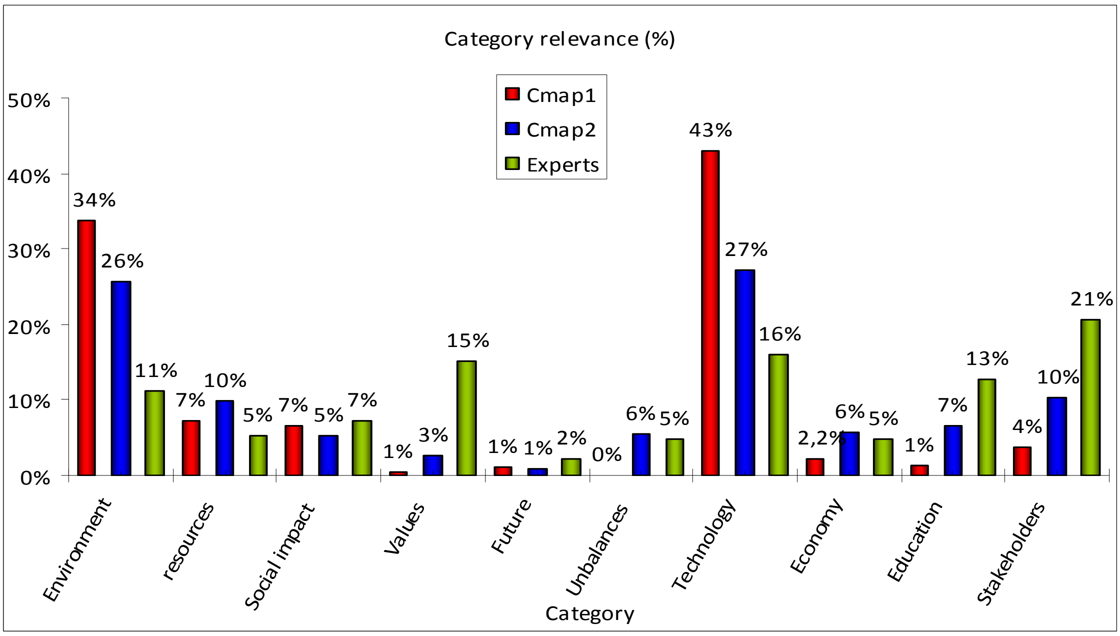

Figure 8.68 Case study CUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

The analysis of the category relevance index under the four categories taxonomy, in figure 8.68, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* categories and too little to the *Social* and *Institutional* ones. After taking the course this mistake is partially rectified and the distribution is more similar to the experts' one.

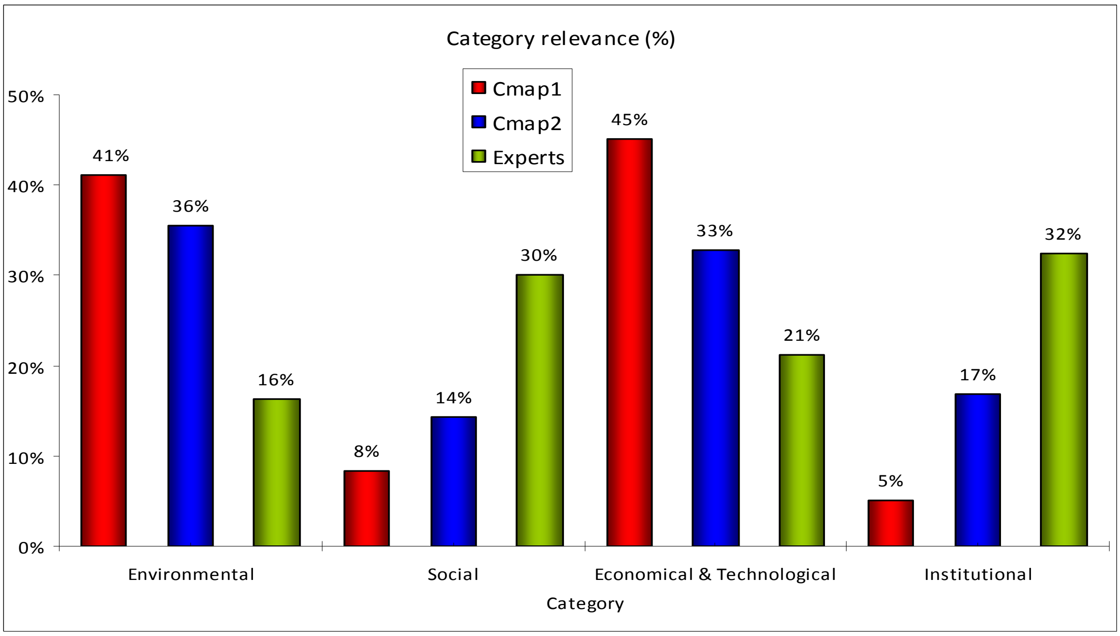

Figure 8.69 Case study DUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

In relation to the complexity index the results obtained in the three studies table 8.43 shows that before taking the course the students saw sustainability as a quite a complex subject (*CO*=12.43), and after finishing it they see sustainability as even more systemic (*CO*=17.13), a result which is getting closer to the experts.

	Cmap1	Cmap2	Experts
Complexity index (CO)	12,43	17.13	24.8

Table 8.43 Case study CUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.6 Case studies at Kiev Polytechnic Institute

8.6.1 KPI Case study 1: Sustainability and Technology

<table>
<tr><td>Case study Code: KPI-1</td><td colspan="3"></td></tr>
<tr><td colspan="4">University: Kiev Polytechnic Institute</td></tr>
<tr><td colspan="2">Course name: Sustainable Development</td><td>Cycle: 2nd</td><td>ECTS: 3</td></tr>
<tr><td colspan="4">Web: http://ssa.ntu-kpi.kiev.ua/sd/</td></tr>
<tr><td colspan="4">Pedagogy: Lectures (25%). Role Play. Project Based Learning. Film watching & debate. Workshops. Students’ presentations.</td></tr>
<tr><td>Date of survey: 2007</td><td>Type of course: Elective</td><td>Sample $Cmap_1$: 23</td><td>Sample $Cmap_2$: 17</td></tr>
<tr><td colspan="4">Students speciality: Electronics, Chemical, System analysis, Management</td></tr>
<tr><td colspan="4">Coordinator: Ronald Wennersten</td></tr>
<tr><td colspan="4">Objectives:
The course is designed so that the participants should reflect on the concept of sustainable development starting from practical case studies in the Ukraine. The course also introduces Industrial Ecology as a platform for research in Sustainable development.</td></tr>
<tr><td colspan="4">Program:
- The concept of Sustainable Development
- Global perspective on Sustainable Development
- Global perspective on Energy
- The Ukrainian Energy System
- Introduction to Industrial Ecology
- Interrelation Technology/Society
- Introduction of Social Technical Maps
- Technology and Sustainable Development
- Sustainability Indexes
- Indexes for Sustainability Assessment
- Scenario methods and Backcasting tools in Sustainability Research
- Sustainability in Business perspective
- Sustainable Consumption</td></tr>
</table>

Table 8.44 Case study KPI-1. Technology and Sustainability

The results of the students' Cmaps analysis are:

Cmap$_1$: Before taking the course

Variable		Values
Number of students	*NS*	23
Number total of concepts	NC_{S1}	303
Number total of links inter-categories	NL_{S2}	81
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	13.17

Table 8.45 Case study KPI-1. Cmap$_1$: Variables value

Therefore using the variables from table 8.45 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	42	13	44	2	2	7	70	33	38	25
CD_i	14%	4%	15%	1%	1%	2%	23%	11%	13%	8%
NS_i	15	6	16	2	1	5	19	15	14	7
SC_i	65%	26%	70%	9%	4%	22%	83%	65%	61%	30%
CR_i	**15%**	**2%**	**17%**	**0%**	**0%**	**1%**	**31%**	**12%**	**13%**	**4%**

Table 8.46 Case study KPI-1. Cmap$_1$: Category relevance variables

Graphically:

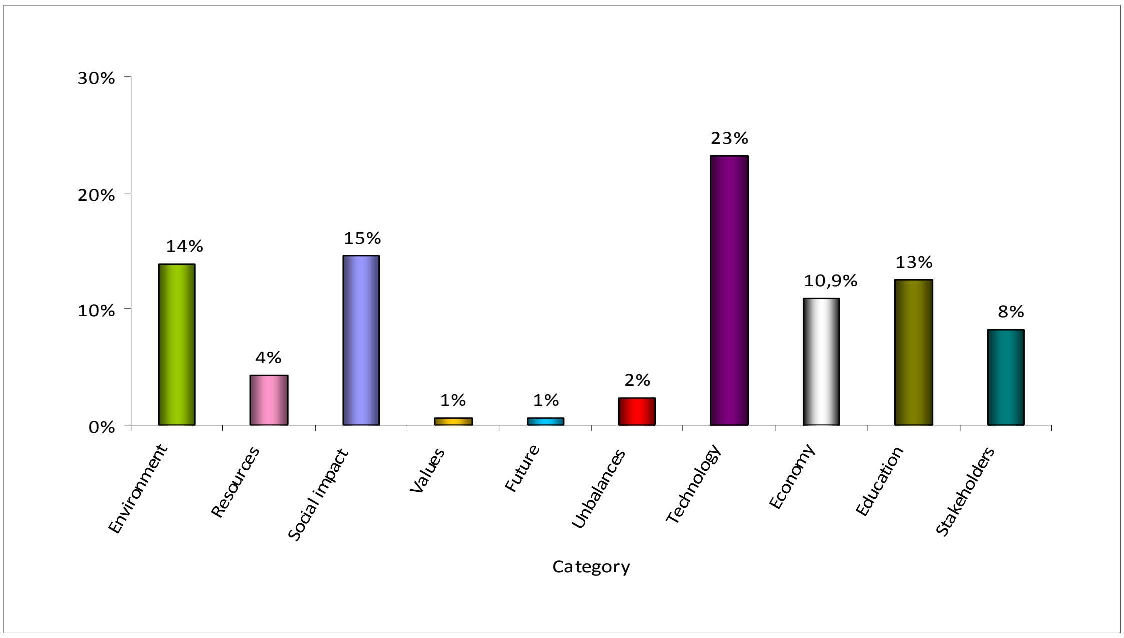

Figure 8.70 Case study KPI-1. Cmap$_1$: Concepts distribution

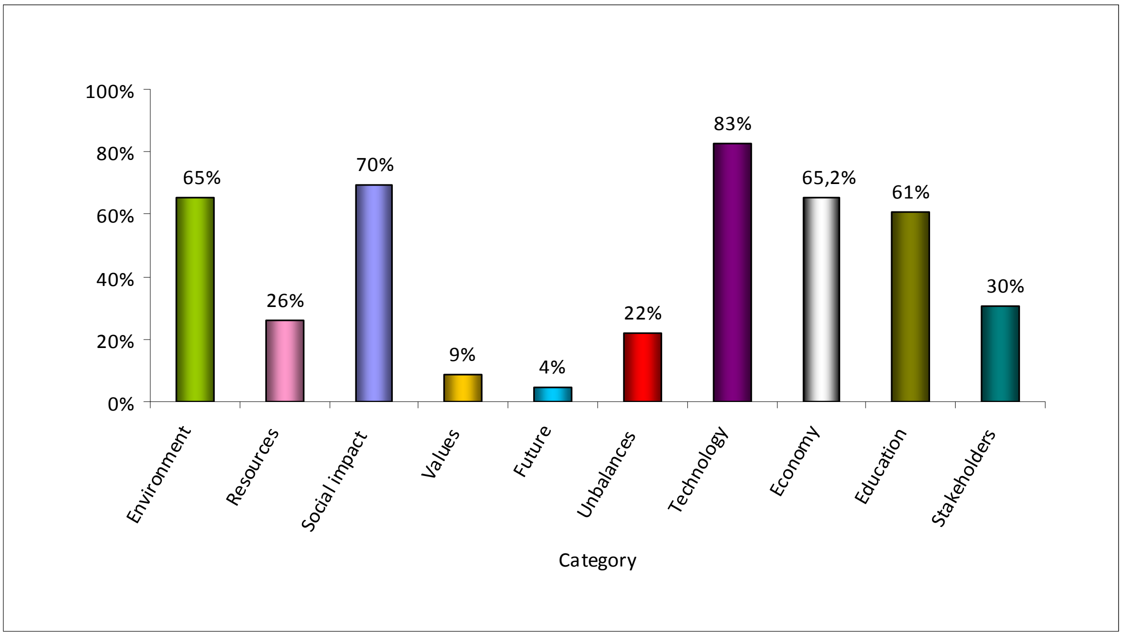

Figure 8.71 Case study KPI-1. Cmap$_1$: Percentage of experts per category distribution

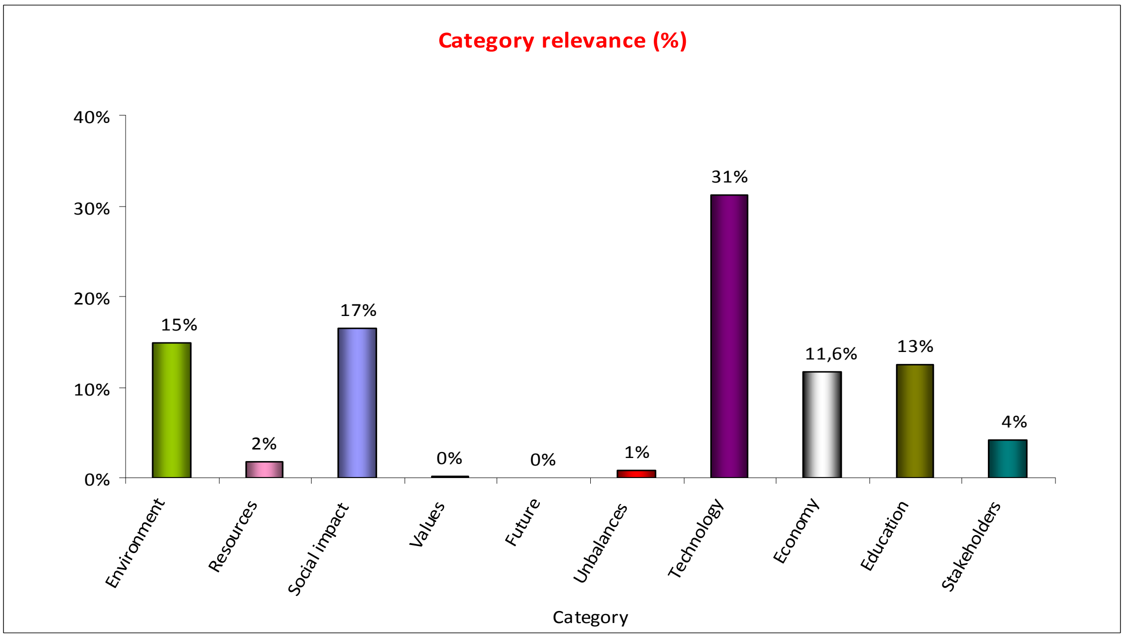

Figure 8.72 Case study KPI-1. Cmap$_1$: Category relevance index

From the category relevance index the *Technology* category is the most referenced (31%), followed by *Social impact* (17%), *Environment* (15%), *Education* (13%) and *Economy (11)*. Finally the other categories are given little relevance.

Figure 8.73 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is by far taken as the most important category (43%). The other three categories share the category relevance percentage left equally.

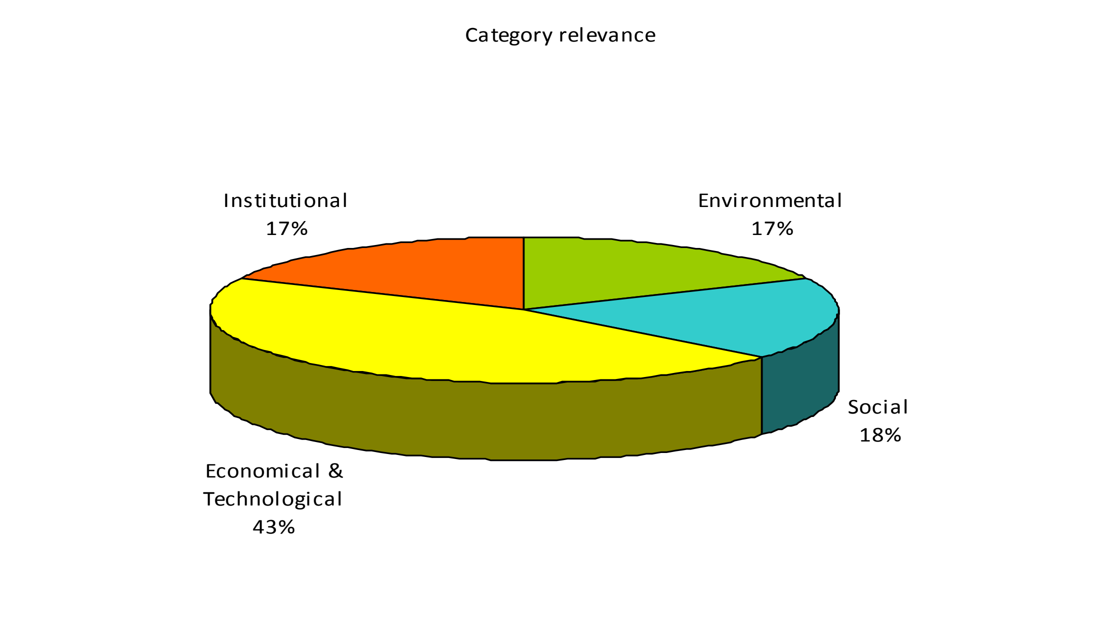

Figure 8.73 Case study KPI-1. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{81}{10 \times 23} = 0.35$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{4.61}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	17
Number total of concepts	NC_{S1}	377
Number total of links inter-categories	NL_{S2}	205
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	22.18

Table 8.47 Case study KPI-1. $Cmap_2$: Variables value

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	56	16	36	7	4	3	124	35	35	44
CD_i	15%	4%	10%	2%	1%	1%	33%	9%	9%	12%
NS_i	16	7	16	6	3	2	17	15	15	12
SC_i	94%	41%	94%	35%	18%	12%	100%	88%	88%	71%
CR_i	**16%**	**2%**	**11%**	**1%**	**0%**	**0%**	**39%**	**10%**	**10%**	**10%**

Table 8.48 Case study KPI-1. $Cmap_2$: Category relevance variables

Graphically:

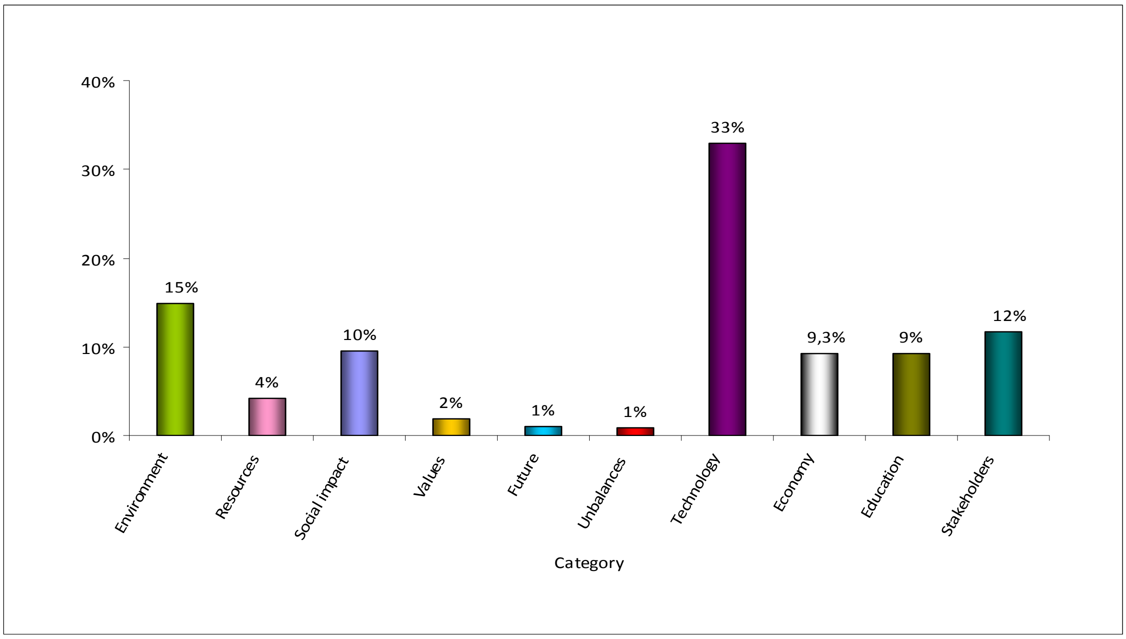

Figure 8.74 Case study KPI-1. Cmap$_2$: Concepts distribution

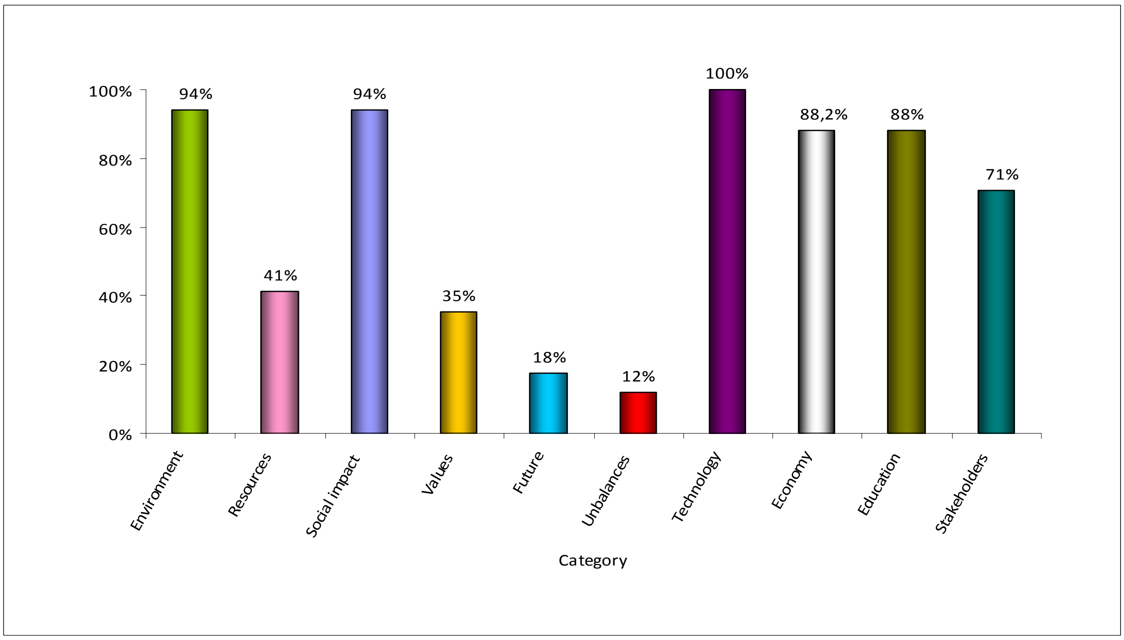

Figure 8.75 Case study KPI-1. Cmap$_2$: Percentage of experts per category distribution

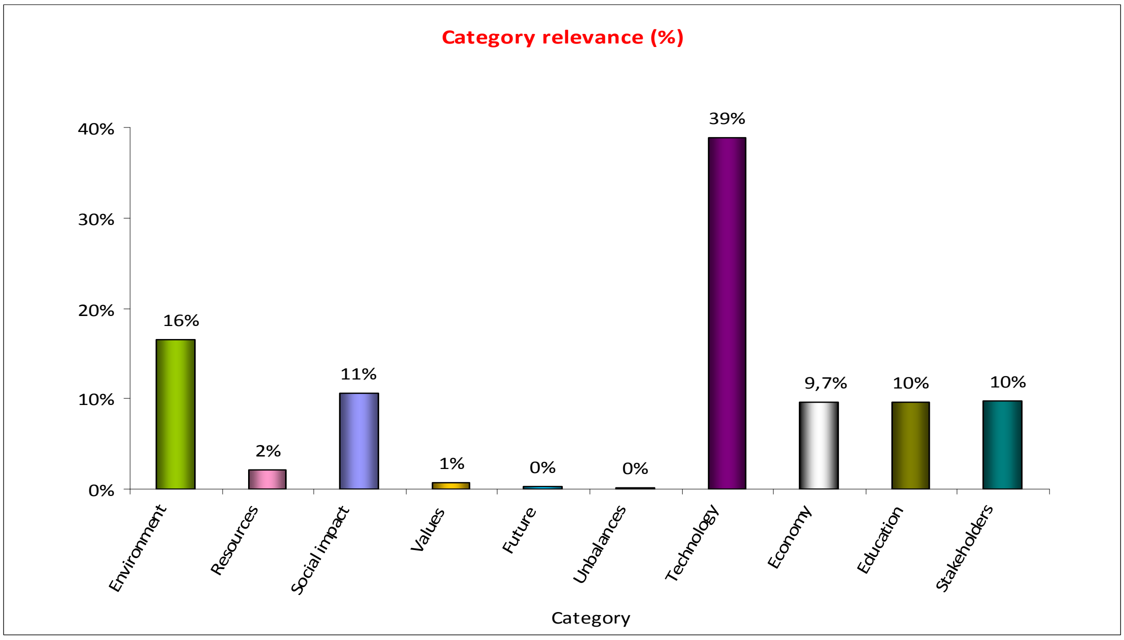

Figure 8.76 Case study KPI-1. $Cmap_2$: Category relevance index

From the category relevance index *Technology* (39%) is by far the most considered. Then *Environment* (16%), *Social impact* (11%), *Education* (10%), *Stakeholders* (10%) and *Economy* (9,7%) which are given a relative importance. Finally, the other categories have almost no relevance at all.

Figure 8.77 shows the Category distribution under the four categories taxonomy. It illustrates that the *Technological/Economic* category is given the most relevance. *Environmental* and *Institutional* categories have both 19% and the least considered one is *Social* (12%).

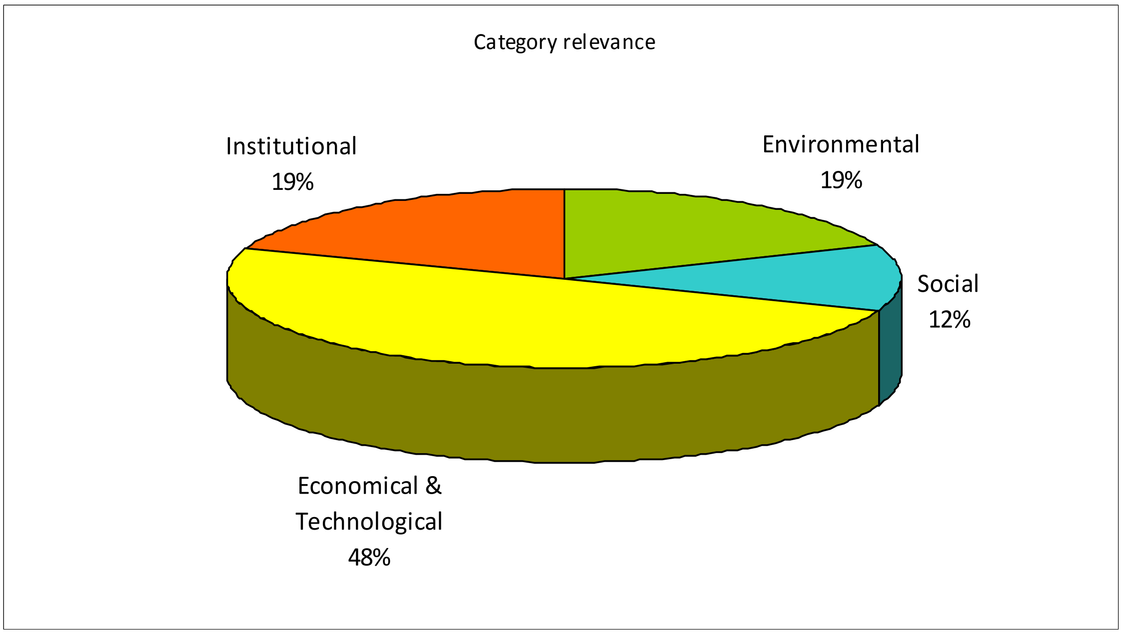

Figure 8.77 Case study KPI-1. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{205}{10 \times 17} = 1.21$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{26.84}$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.78 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taken the course are closer to the experts' Cmaps than the results before taking it. Although the high value that *Environment* and *Technology* categories get in $Cmap_1$ is even higher in $Cmap_2$.

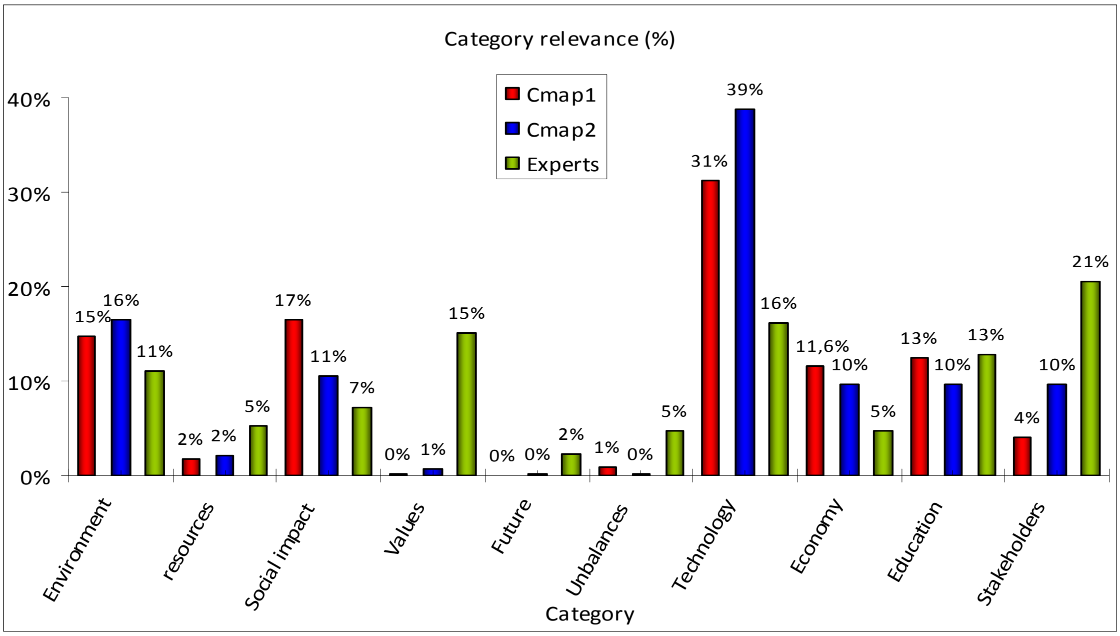

Figure 8.78 Case study KPI-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

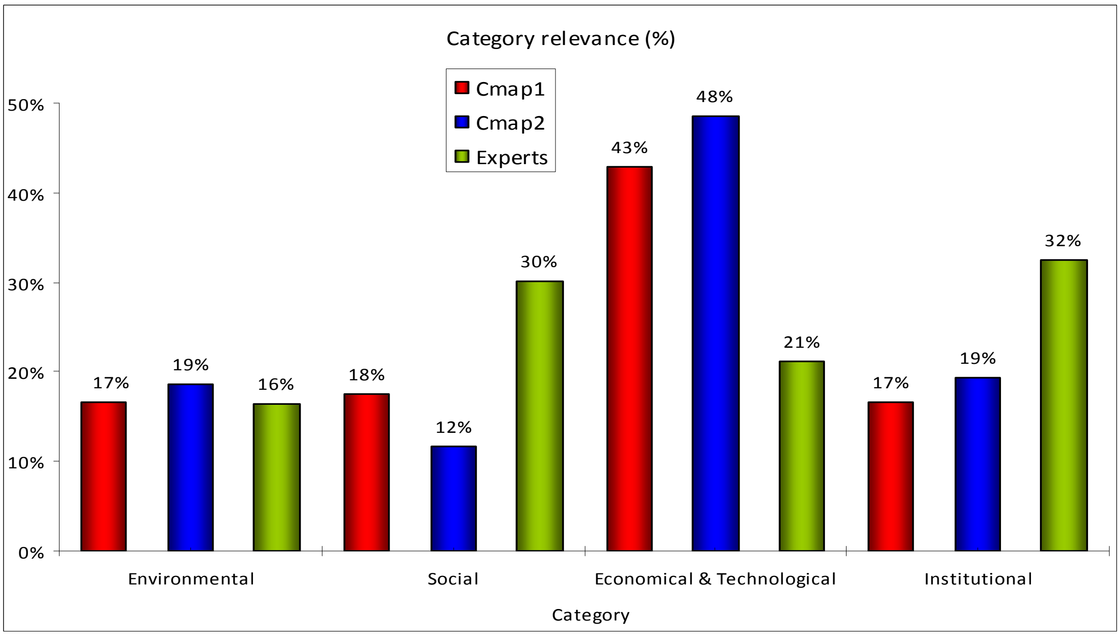

Figure 8.79 Case study KPI-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, figure 8.79, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Technological* category and too little to the *Social* and *Institutional* ones. It is surprising that after taking the course only the *Institutional* category got values closer to the experts' one, while the other three categories got worse results than before taking the course.

In relation to the complexity index the results obtained in the three studies table 6.49 shows that before taking the course the students saw sustainability as a not complex subject (*CO*=4.61), but after finishing it they see sustainability as more systemic (*CO*=26.48), even more so than the results of the experts.

	Cmap1	Cmap2	Experts
Complexity index (CO)	4.61	26.84	24.8

Table 8.49 Case study KPI-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.7 Case studies at Eindhoven University of Technology

8.7.1 EUT Case study 1: Technology and Sustainability

Case study Code: **EUT-1**			
University: **Eindhoven University of Technology**			
Course name: **Technology and Sustainability**		Cycle: **1st**	ECTS: **3**
Web: https://venus.tue.nl/owinfo-cgi/owi_0695.opl?vakcode=7Z100			
Pedagogy: **Distance learning course. Contents in CD. Exercises.**			
Date of survey: **2006**	Type of course: **compulsory**	Sample $Cmap_1$: **10**	Sample $Cmap_2$: **28**
Students speciality: **Architecture and Building**			
Coordinator: **Arjan Kirkels**			
Objectives: Students should learn how to deal with environmental aspects during the whole design process and how to evaluate these aspects in relation to the technical and social aspect. Students should acquire the required knowledge on the basis of case studies and the standard work.			
Program: I Points of departure: 1 - Sustainable development: history and analysis of an idea 2 - Technology and sustainable development II Environmental themes 3 – Introduction to environmental themes 4 – Climate change 5 – Ozone layer depletion 6 – Acidification 7 – Eutrophication 8 – Soil contamination 9 – Smog and fine particulate matter 10 – Spread of hazardous substances 11 – Removal of solid waste materials 12 – Depletion of natural resources III Social framework 13 – Actors: their roles and perspectives 14 – Government policies 15 – Consumer behaviour 16 – Trade and Industry IV Analysis methods 17 – Introduction to analysis methods 18 – Flow charts and mass flows 19 – Energy and exergy analysis 20 – Life Cycle Assessment 21 – Financial feasibility analysis 22 – Multi-criteria analysis V Technological solutions 23 – Design for environment 24 – Extraction stage 25 – Production stage 26 – Use stage 27 – Waste stage 28 – Recycling stage 29 - Energy			

Table 8.50 Case study EUT-1. Technology and Sustainability

The results of the students' Cmaps analysis are:

$Cmap_1$: Before taking the course

Variable		Values
Number of students	*NS*	10
Number total of concepts	NC_{S1}	96
Number total of links inter-categories	NL_{S2}	19
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.6

Table 8.51 Case study EUT-1. $Cmap_1$: Variables value

Therefore using the variables from table 8.51 the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	13	11	4	0	9	0	40	3	5	9
CD_i	14%	11%	4%	0%	9%	0%	42%	3%	5%	9%
NS_i	7	4	3	0	5	0	9	2	2	3
SC_i	70%	40%	30%	0%	50%	0%	90%	20%	20%	30%
CR_i	**15%**	**7%**	**2%**	**0%**	**8%**	**0%**	**60%**	**1%**	**2%**	**5%**

Table 8.52 Case study EUT-1. $Cmap_1$: Category relevance variables

Graphically:

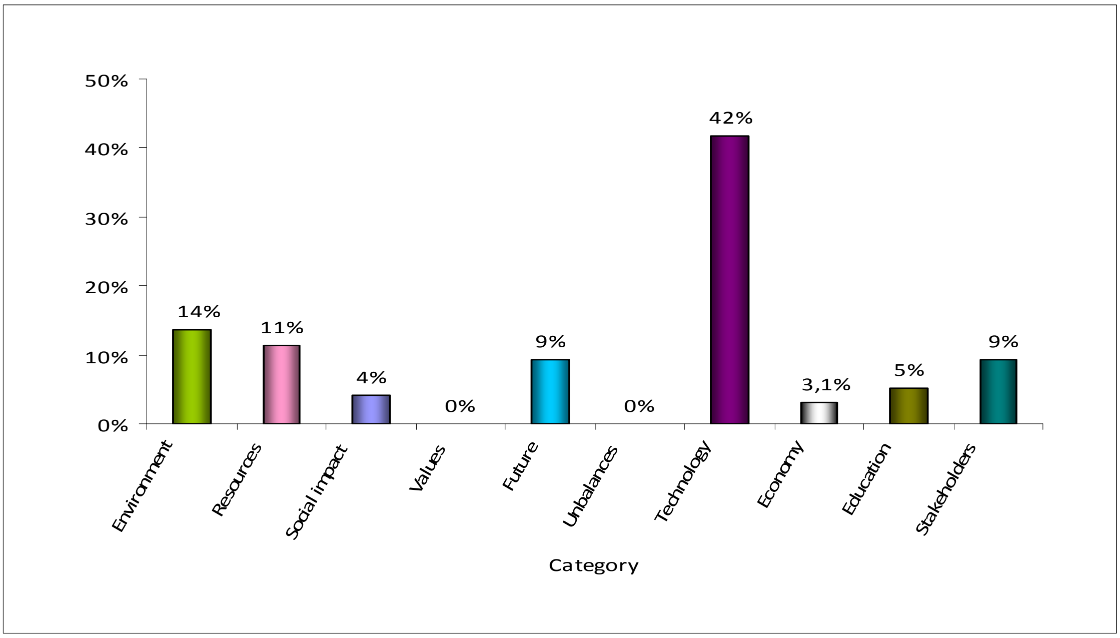

Figure 8.80 Case study EUT-1. $Cmap_1$: Concepts distribution

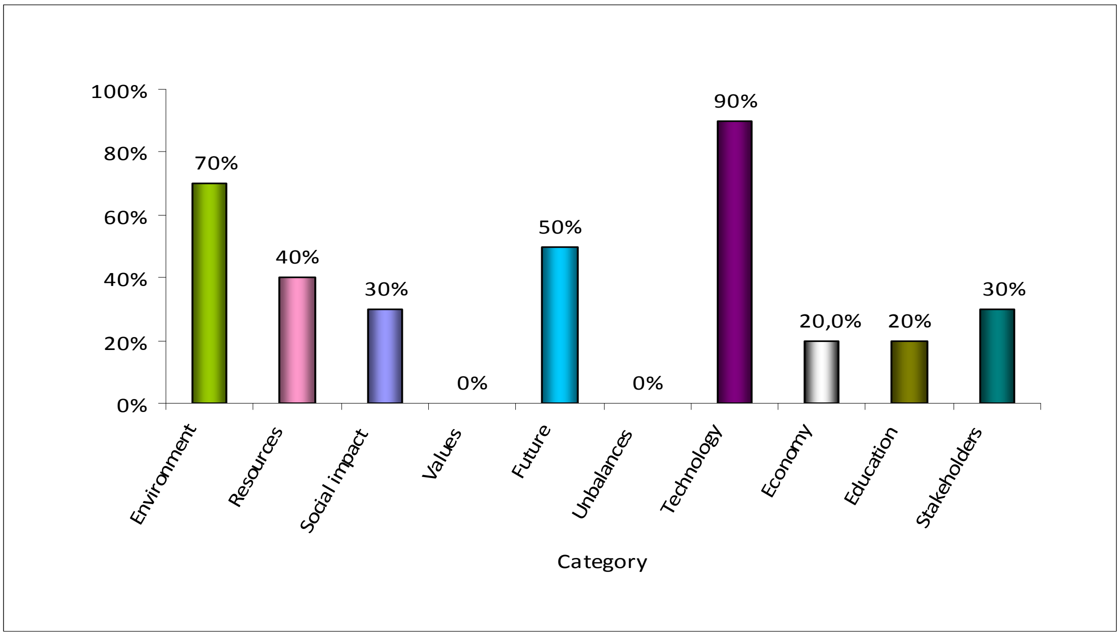

Figure 8.81 Case study EUT-1. $Cmap_1$: Percentage of experts per category distribution

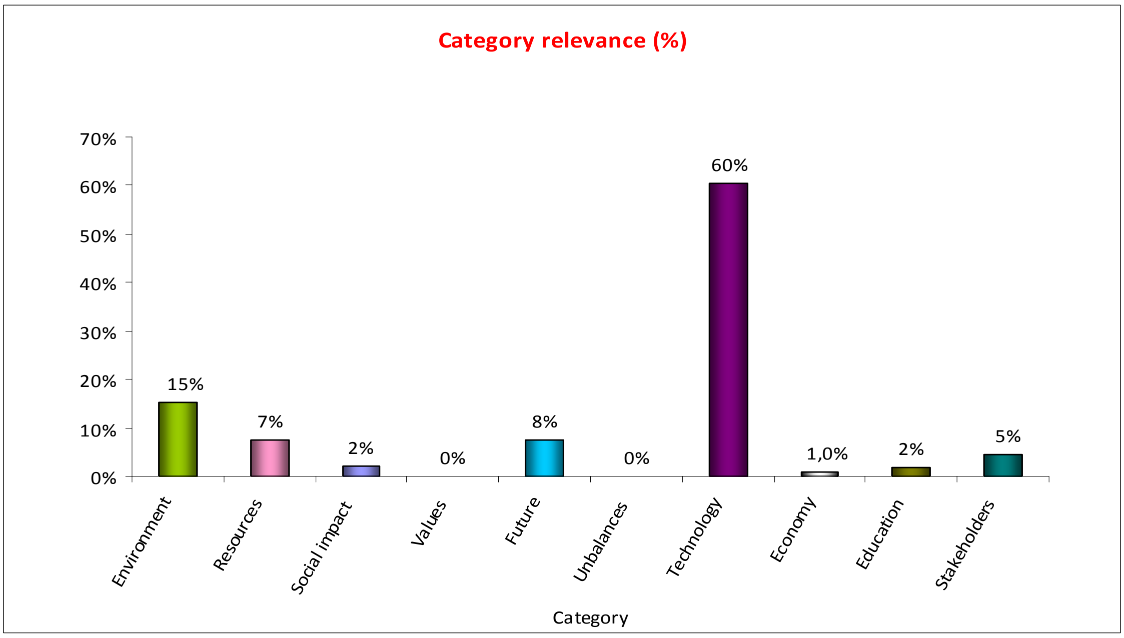

Figure 8.82 Case study EUT-1. $Cmap_1$: Category relevance index

From the category relevance index the *Technology* category is the most referenced (60%). Followed by *Environment* (15%), *Future* (8%) and *Resources (7%)*. Finally the other categories are given little relevance. Actually the *Values* category has no concept.

Figure 8.83 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is taken by far as the most important category (61%). The next most mportant category is *Environment* (23%) followed by *Social* and *Institutional*.

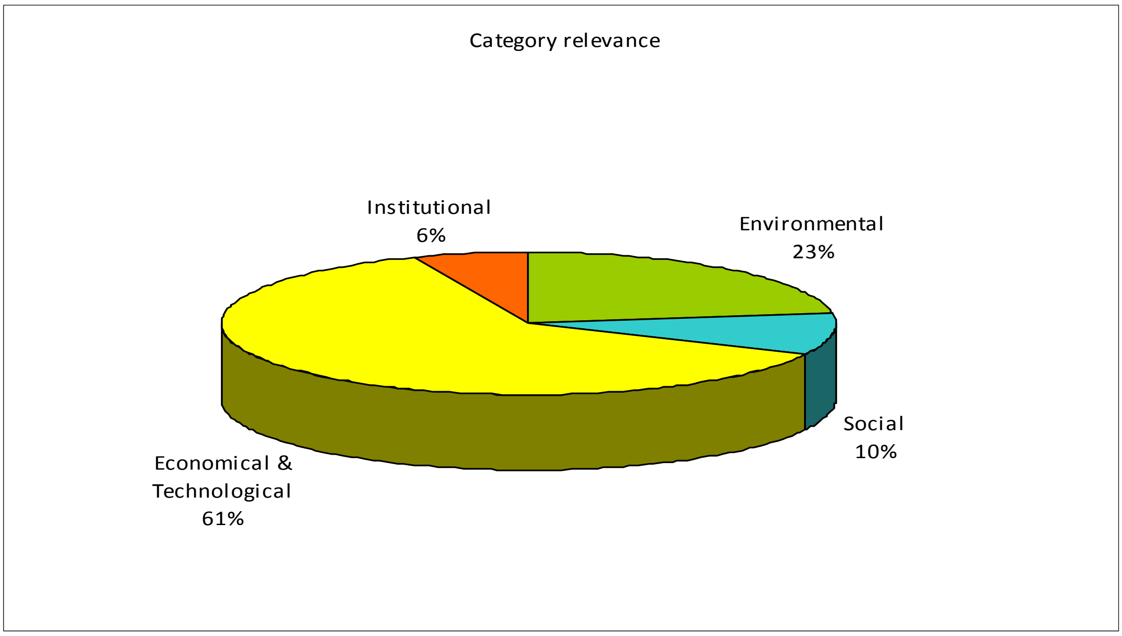

Figure 8.83 Case study EUT-1. Cmap$_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{19}{10 \times 10} = 0.19$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{1.82}$$

Cmap$_2$: After taking the course

Variable		Values
Number of students	*NS*	28
Number total of concepts	NC_{S1}	250
Number total of links inter-categories	NL_{S2}	52
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	8.93

Table 8.53 Case study EUT-1. Cmap$_2$: Variables value

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	33	27	5	10	10	0	115	12	9	28
CD_i	13%	11%	2%	4%	4%	0%	46%	5%	4%	11%
NS_i	15	14	5	8	6	0	23	8	6	11
SC_i	54%	50%	18%	29%	21%	0%	82%	29%	21%	39%
CR_i	12%	9%	1%	2%	1%	0%	64%	2%	1%	7%

Table 8.54 Case study EUT-1. Cmap$_2$: Category relevance variables

Graphically:

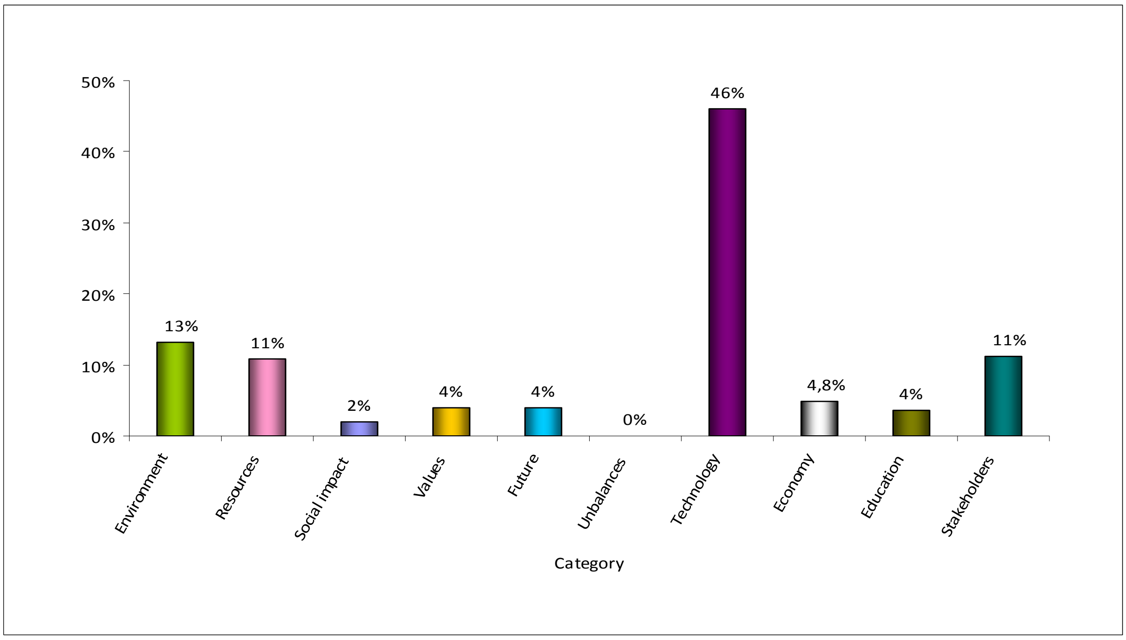

Figure 8.84 Case study EUT-1. $Cmap_2$: Concepts distribution

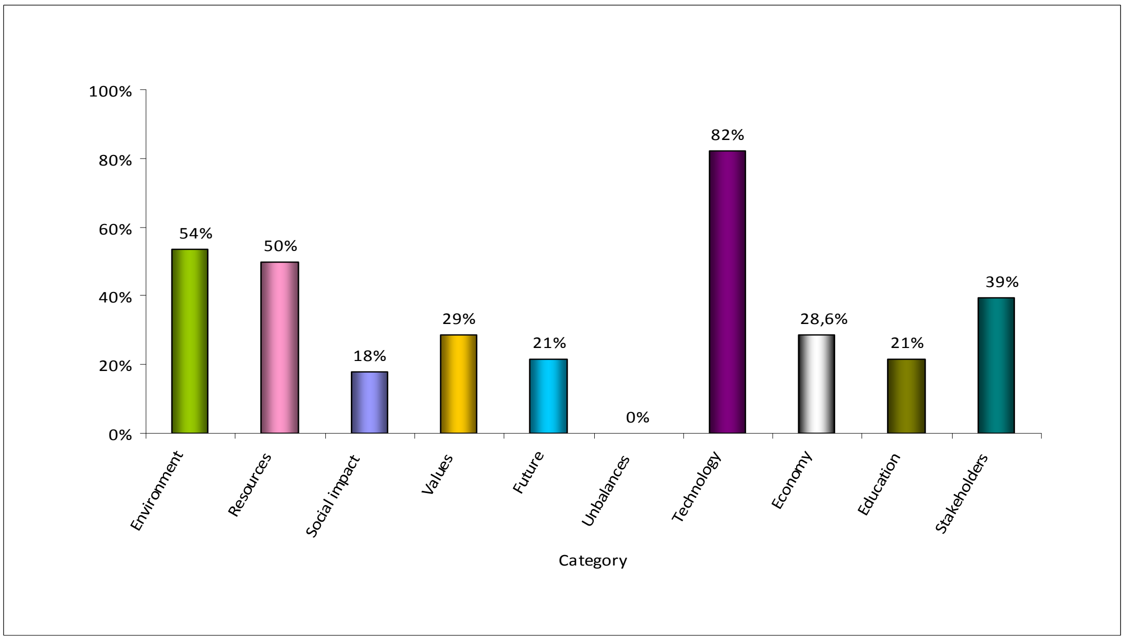

Figure 8.85 Case study EUT-1. $Cmap_2$: Percentage of experts per category distribution

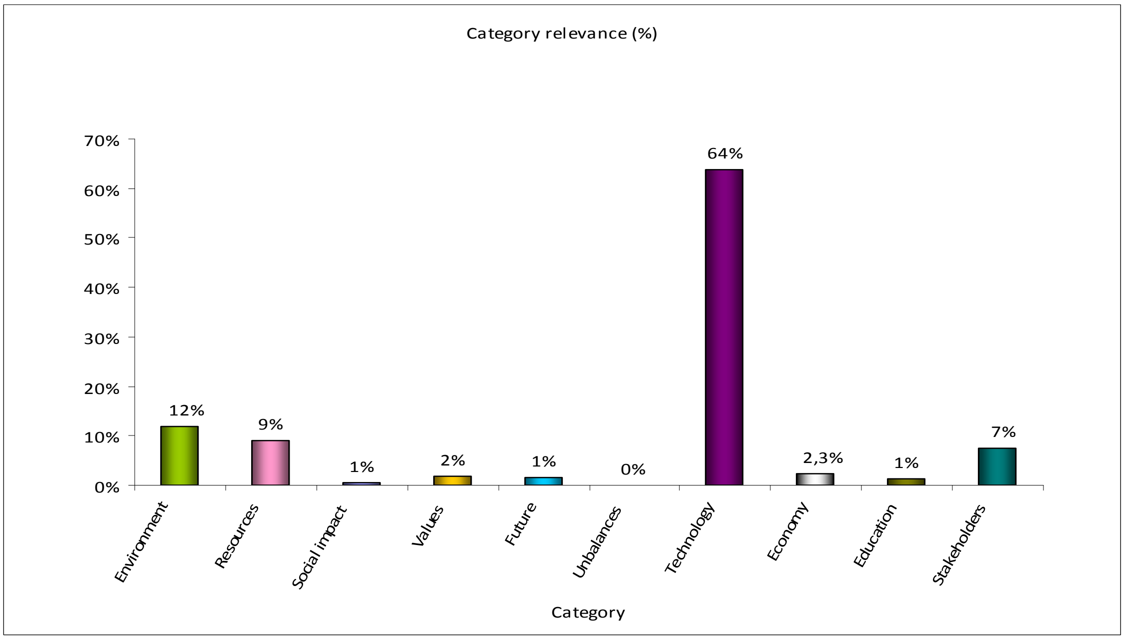

Figure 8.86 Case study EUT-1. $Cmap_2$: Category relevance index

From the category relevance index *Technology* (64%) is by far the most considered. *Environment* (12%), *Resources* (9%) and *Stakeholders* (7%) and *Economy* (9,7%) are given little importance. Finally the other categories have almost no relevance at all.

Figure 8.87 shows the Category distribution under the four categories taxonomy. It illustrates that the *Technological/Economic* category is given the most relevance. The *Environmental* (21%) and *Institutional* (9%) categories are given little relevance and the least valuated category is *Social* (4%).

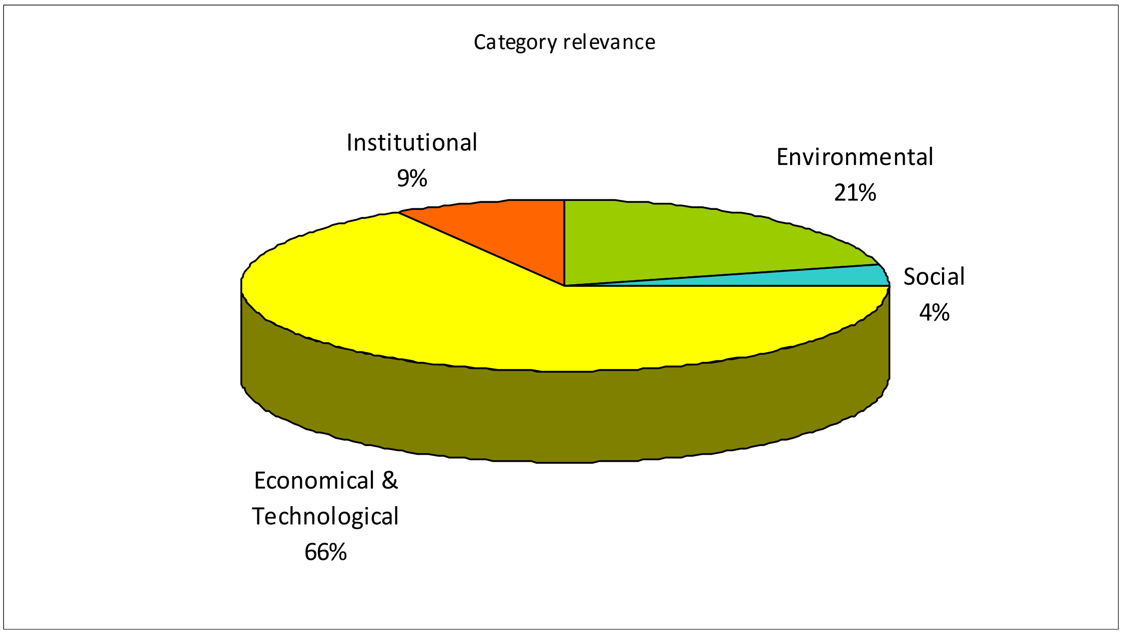

Figure 8.87 Case study EUT-1. $Cmap_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{52}{10 \times 28} = 0.19$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{1.70}$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.88 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. Although the high value that *Technology* category got in $Cmap_1$ is even higher in $Cmap_2$.

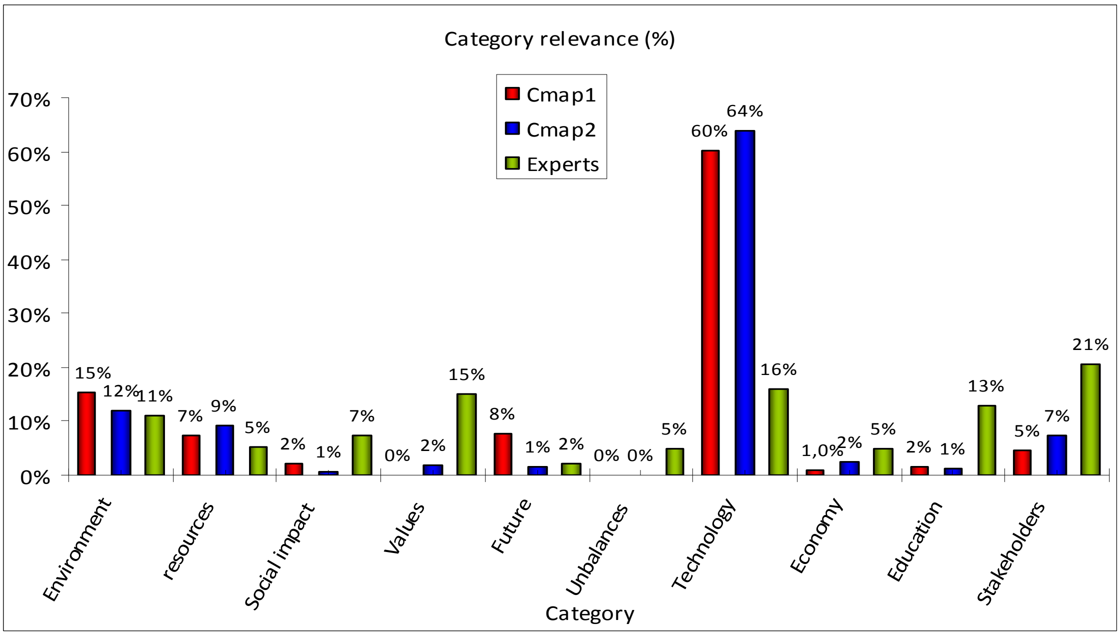

Figure 8.88 Case study EUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

The analysis of the category relevance index under the four categories taxonomy, next figure, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Technological* category and too little to the *Social* and *Institutional* ones. It is surprising that after taking the course only the *Institutional* and *Environmental* categories got values closer to the experts' ones, while the *Technological/Economic* and *Social* categories got worse results than before taking the course.

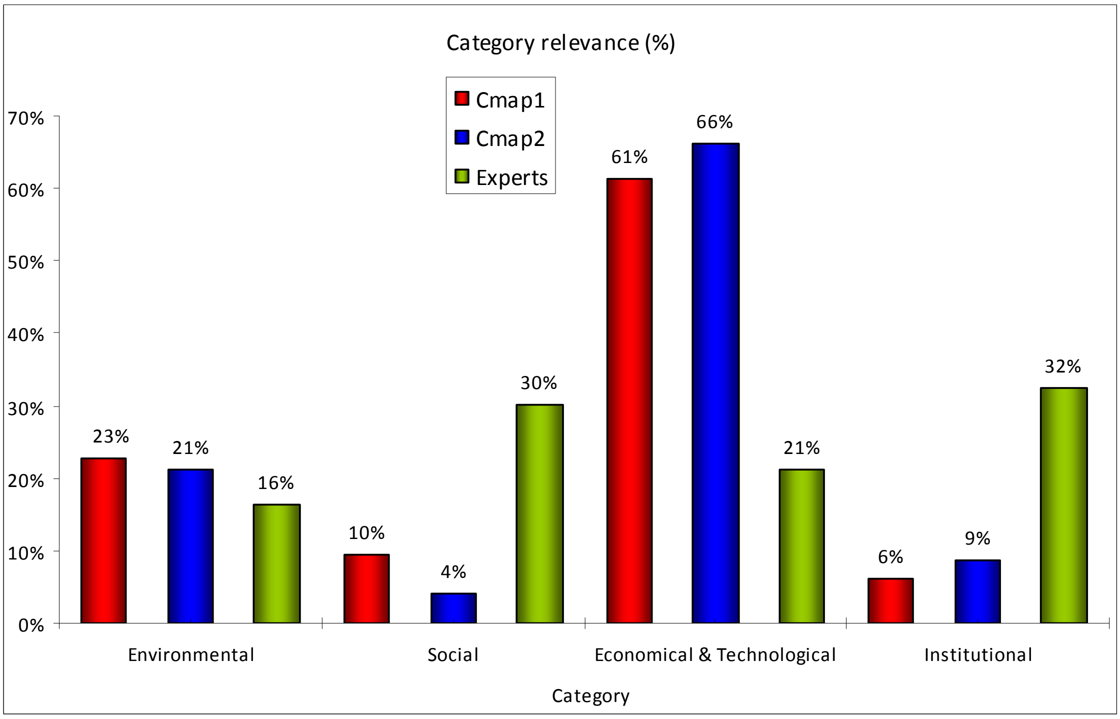

Figure 8.89 Case study EUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

In relation to the complexity index the results obtained in the three studies table 8.55 shows that before taking the course the students saw sustainability as a not complex subject (*CO*=1.82), moreover after finishing it they see sustainability as even less complex (*CO*=1.70), which is very far from the experts' results.

	Cmap1	Cmap2	Experts
Complexity index (CO)	1.82	1.70	24.8

Table 8.55 Case study EUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.7.2 EUT Case study 2: Technology and Sustainability II

Case study Code: **EUT-2**			
University: **Eindhoven University of Technology**			
Course name: **Technology and Sustainability**		Cycle: **1st**	ECTS: **3**
Web: **https://venus.tue.nl/owinfo-cgi/owi_0695.opl**			
Pedagogy: **Distance learning course. Context in CD. 6 Lectures of 2 hours.**			
Date of survey: **2005**	Type of course: **Elective**	Sample $Cmap_1$: **60**	Sample $Cmap_2$: **18**
Students speciality: **Mechanical Engineering**			
Coordinator: **Arjan Kirkels**			
Objectives: Students should learn how to deal with environmental aspects during the whole design process and how to evaluate these aspects in relation to technical and social aspects. Students should acquire the required knowledge on the basis of case studies and the standard work.			
Program: I Points of departure: 1 - Sustainable development: history and analysis of an idea 2 - Technology and sustainable development II Environmental themes 3 – Introduction to environmental themes 4 – Climate change 5 – Ozone layer depletion 6 – Acidification 7 – Eutrophication 8 – Soil contamination 9 – Smog and fine particulate matter 10 – Spread of hazardous substances 11 – Removal of solid waste materials 12 – Depletion of natural resources III Social framework 13 – Actors: their roles and perspectives 14 – Government policies 15 – Consumer behaviour 16 – Trade and Industry IV Analysis methods 17 – Introduction to analysis methods 18 – Flow charts and mass flows 19 – Energy and exergy analysis 20 – Life Cycle Assessment 21 – Financial feasibility analysis 22 – Multi-criteria analysis V Technological solutions 23 – Design for environment 24 – Extraction stage 25 – Production stage 26 – Use stage 27 – Waste stage 28 – Recycling stage 29 - Energy			

Table 8.56 Case study EUT-2. Technology and Sustainability

The results of the students' Cmaps analysis are:

$Cmap_1$: Before taking the course

Variable		Values
Number of students	*NS*	60
Number total of concepts	NC_{S1}	283
Number total of links inter-categories	NL_{S2}	44
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	6.4

Table 8.57 Case study EUT-2. $Cmap_1$: Variables value

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	48	56	3	5	8	1	212	4	4	32
CD_i	13%	15%	1%	1%	2%	0%	55%	1%	1%	8%
NS_i	27	21	3	3	7	1	51	4	2	17
SC_i	45%	35%	5%	5%	12%	2%	85%	7%	3%	28%
CR_i	11%	5%	0%	0%	0%	0%	78%	0%	0%	4%

Table 8.58 Case study EUT-2. $Cmap_1$: Category relevance variables

Graphically:

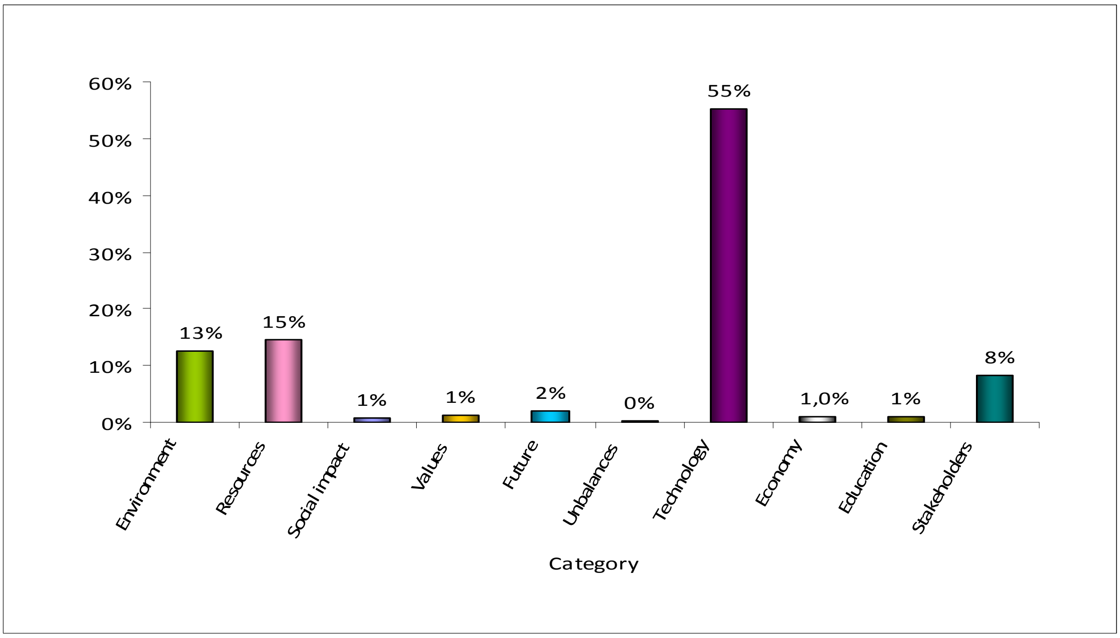

Figure 8.90 Case study EUT-2. $Cmap_1$: Concepts distribution

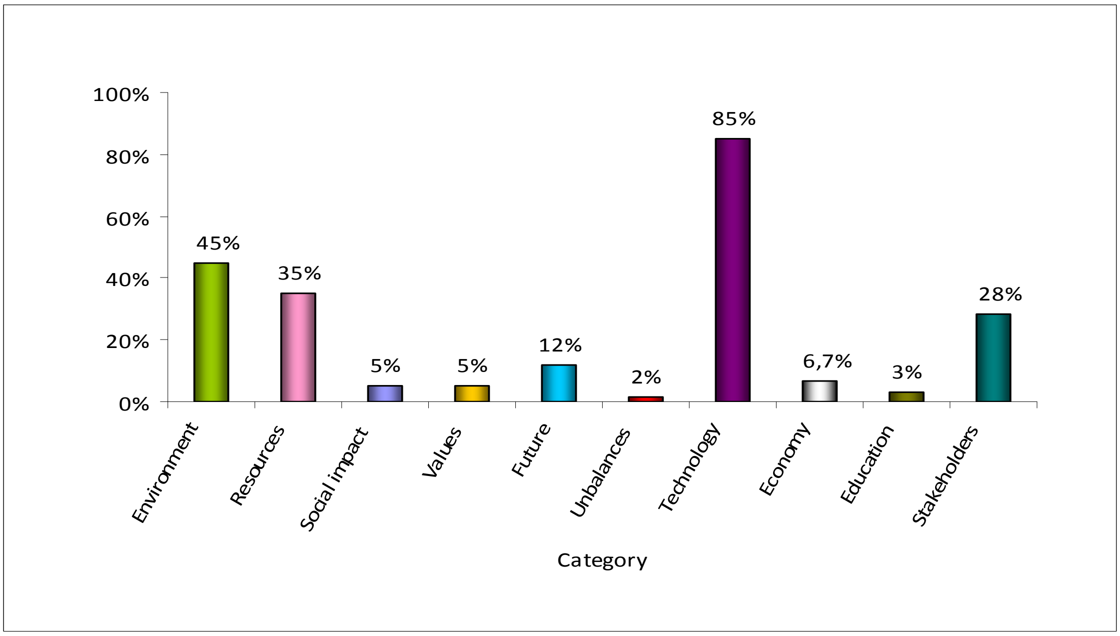

Figure 8.91 Case study EUT-2. $Cmap_1$: Percentage of experts per category distribution

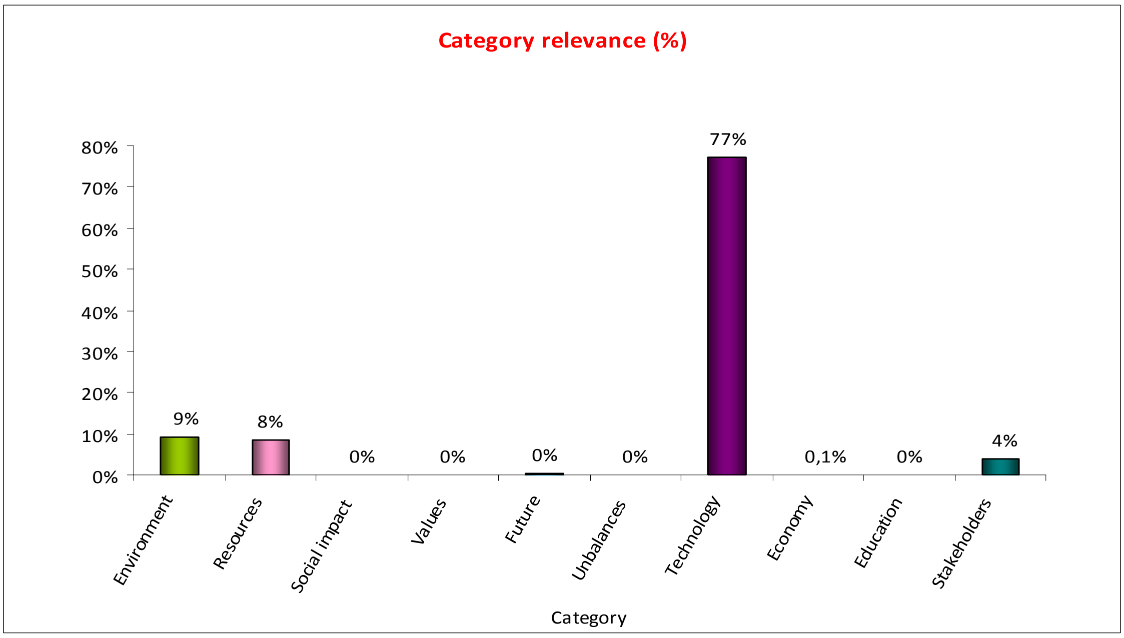

Figure 8.92 Case study EUT-2. $Cmap_1$: Category relevance index

From the category relevance index the *Technology* category is by far the most referenced (677%), followed by *Environment* (9%), *Resources (8%)* and *Stakeholders* (4%). Finally the other categories are given no relevance.

Figure 8.93 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is by far the most important category (77%). The next most important category is *Environment* (18%) while *Institutional* and *Social* ones have almost no relevance.

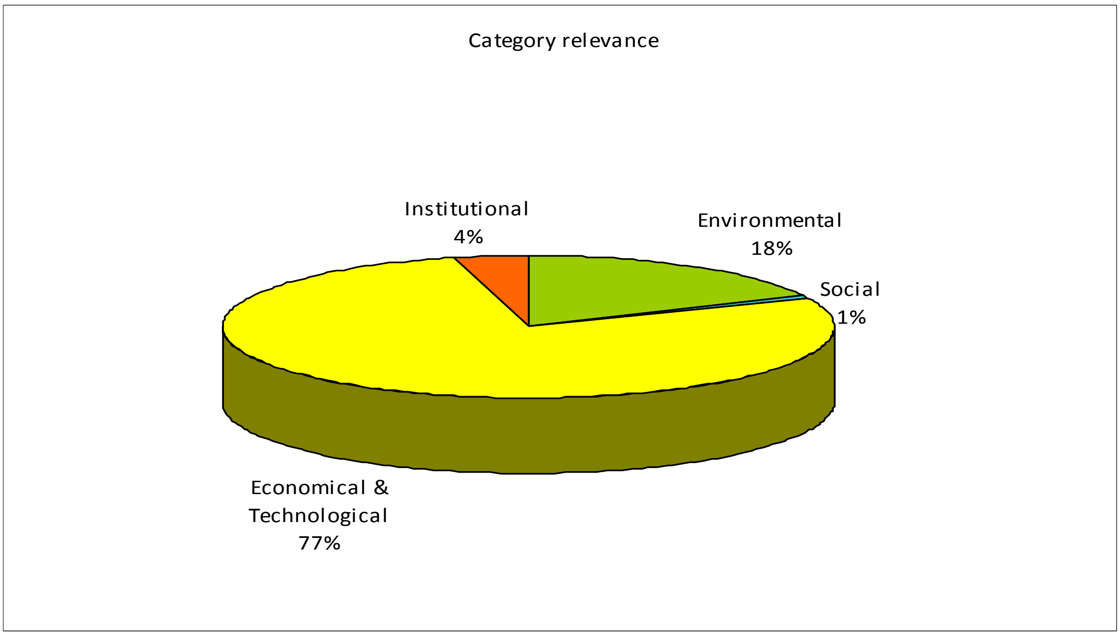

Figure 8.93 Case study EUT-2. $Cmap_1$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{44}{10 \times 60} = 0.07$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{0.47}$$

$Cmap_2$: After taking the course

Variable		Values
Number of students	*NS*	18
Number total of concepts	NC_{S1}	221
Number total of links inter-categories	NL_{S2}	52
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	12.28

Table 8.59 Case study EUT-2. $Cmap_2$: Variables value

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NC_i	38	27	3	3	15	2	76	7	4	27
CD_i	17%	12%	1%	1%	7%	1%	34%	3%	2%	12%
NS_i	14	10	3	2	8	1	16	5	2	9
SC_i	78%	56%	17%	11%	44%	6%	89%	28%	11%	50%
CR_i	20%	10%	0%	0%	5%	0%	47%	1%	0%	9%

Table 8.60 Case study EUT-2. $Cmap_2$: Category relevance variables

Graphically:

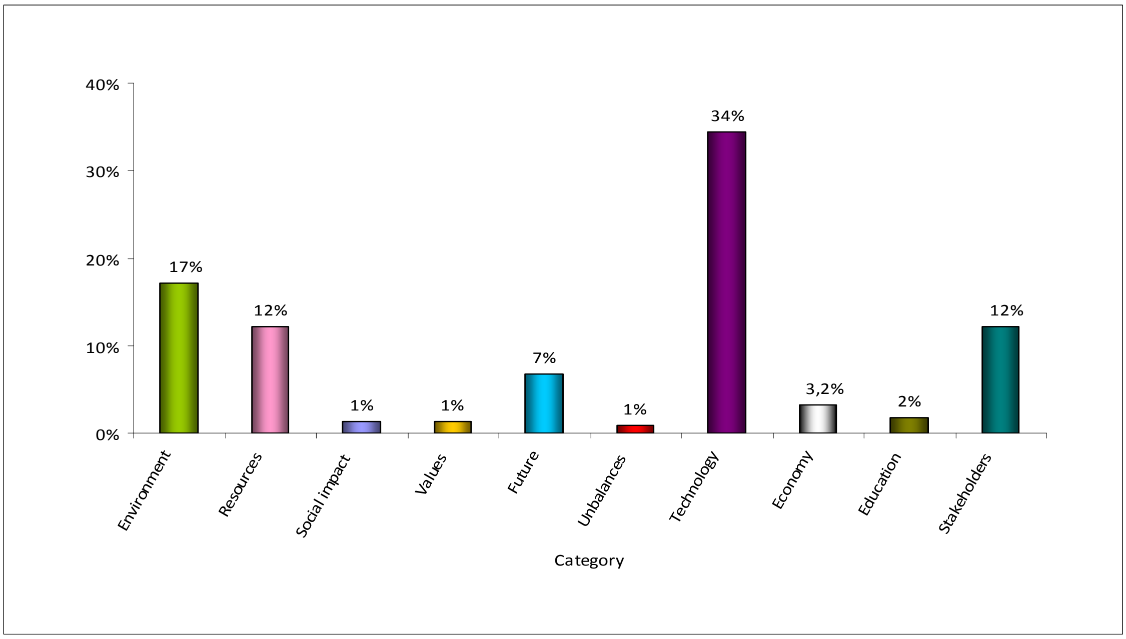

Figure 8.94 Case study EUT-2. $Cmap_2$: Concepts distribution

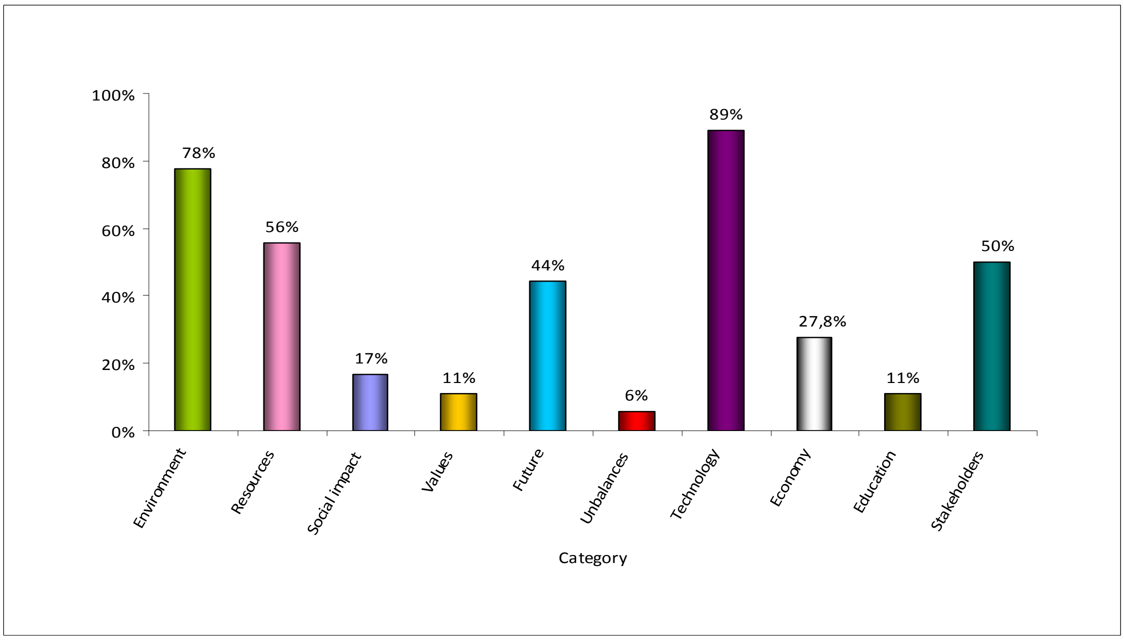

Figure 8.95 Case study EUT-2. $Cmap_2$: Percentage of experts per category distribution

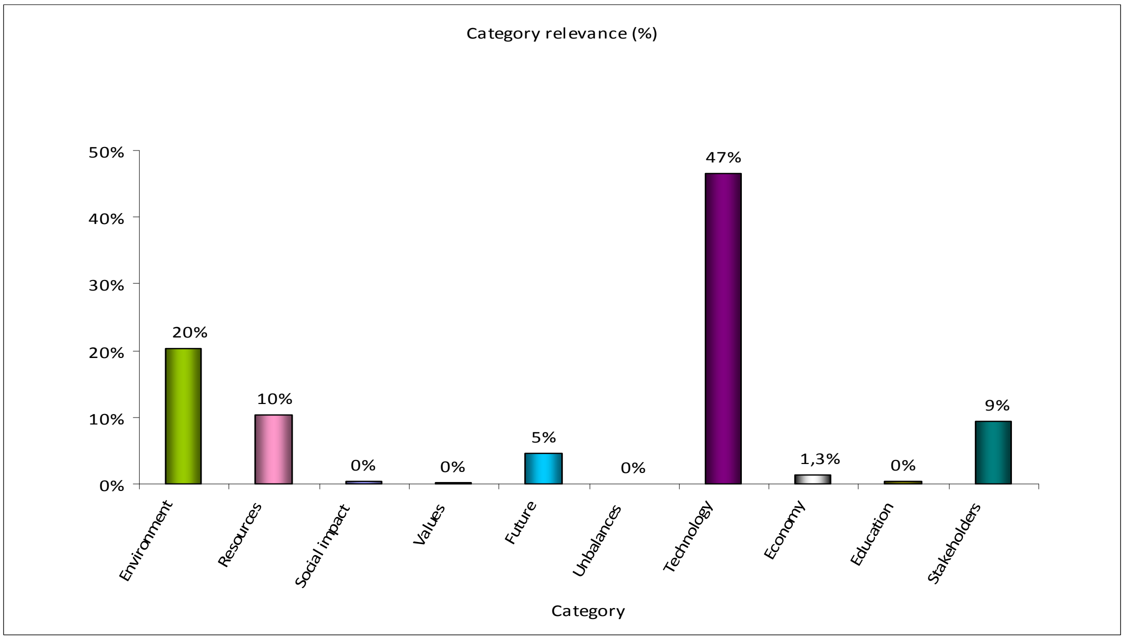

Figure 8.96 Case study EUT-2. Cmap$_2$: Category relevance index

From the category relevance index the *Technology* category is still the most referenced (47%), followed by *Environment* (120%), *Resources* (10%) *and Stakeholders* (9%). Finally the other categories are given no relevance except *Future* with al value of 5%.

Figure 8.97 shows the Category distribution under the four categories taxonomy. It illustrates that *Technological/Economic* is still seen as the most important category (48%). The next most important category is *Environment* (31%) followed by *Institutional* and *Social*.

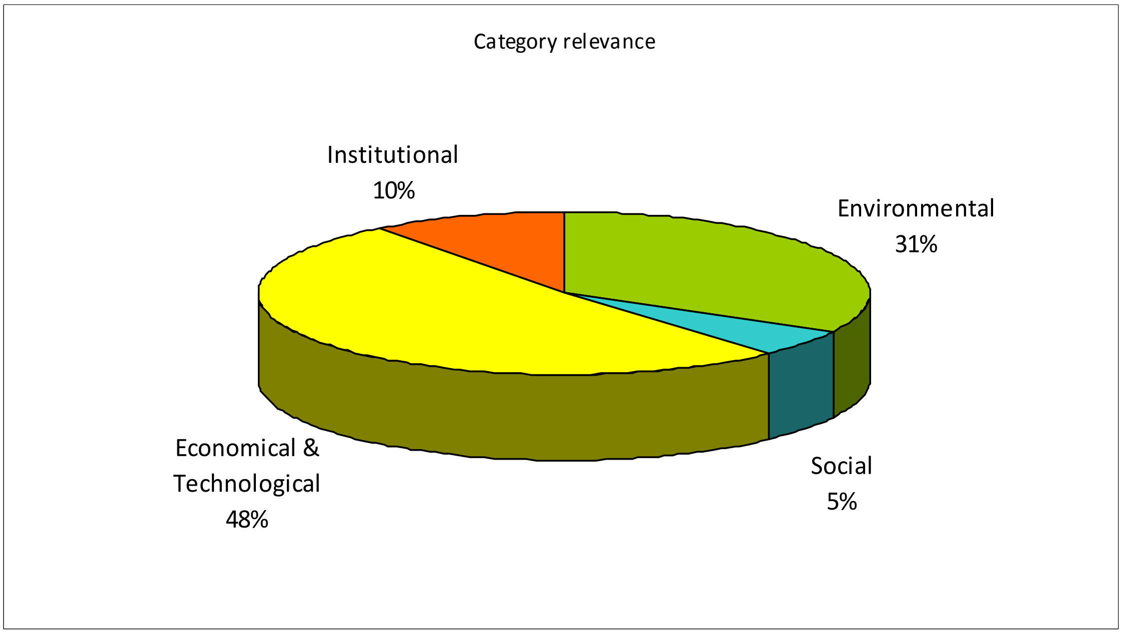

Figure 8.97 Case study EUT-2. Cmap$_2$: Category relevance index. 4 Categories

Complexity Index

Relative inter-category links (Eq. 7.6):

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} = \frac{52}{10 \times 18} = 0.29$$

Applying equation 7.5 the result is:

$$CO = \overline{NC} \times L_{Ca} = \mathbf{3.55}$$

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.98 shows the category relevance index for the three studies: Cmap before taking the course (Cmap1), Cmap after taking the course (Cmap2) and the reference experts' Cmap. In most categories the results after taking the course are closer to the experts' Cmaps than the results before taking it. Although the high value that *Resources* category has in $Cmap_1$ is even higher in $Cmap_2$. The very little relevance to the social categories does not change after finishing the course.

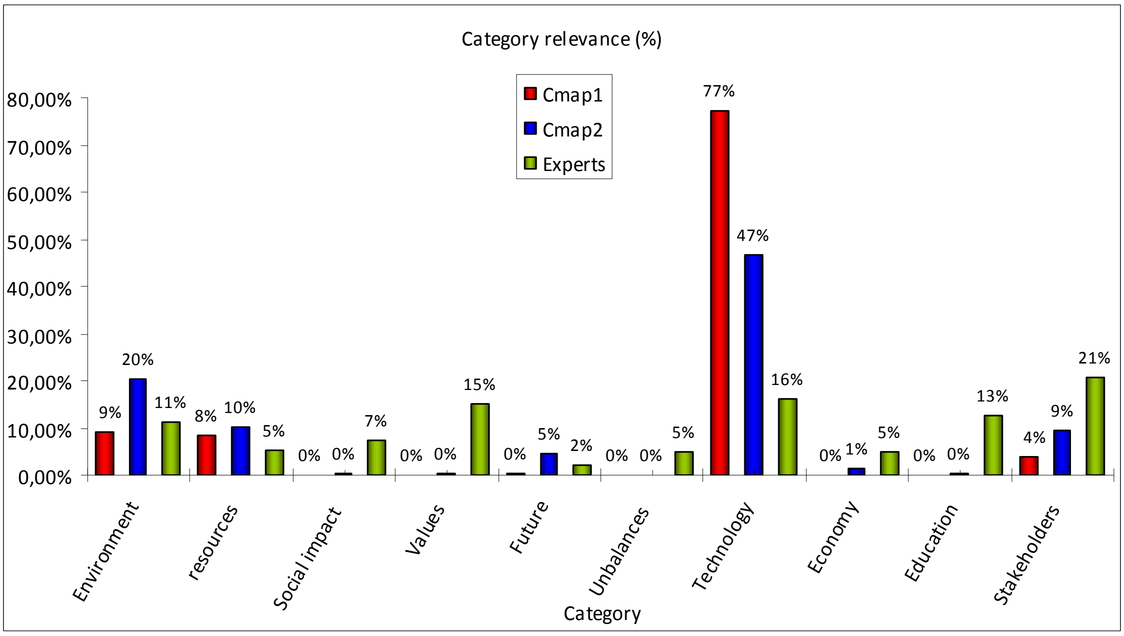

Figure 8.98 Case study EUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap

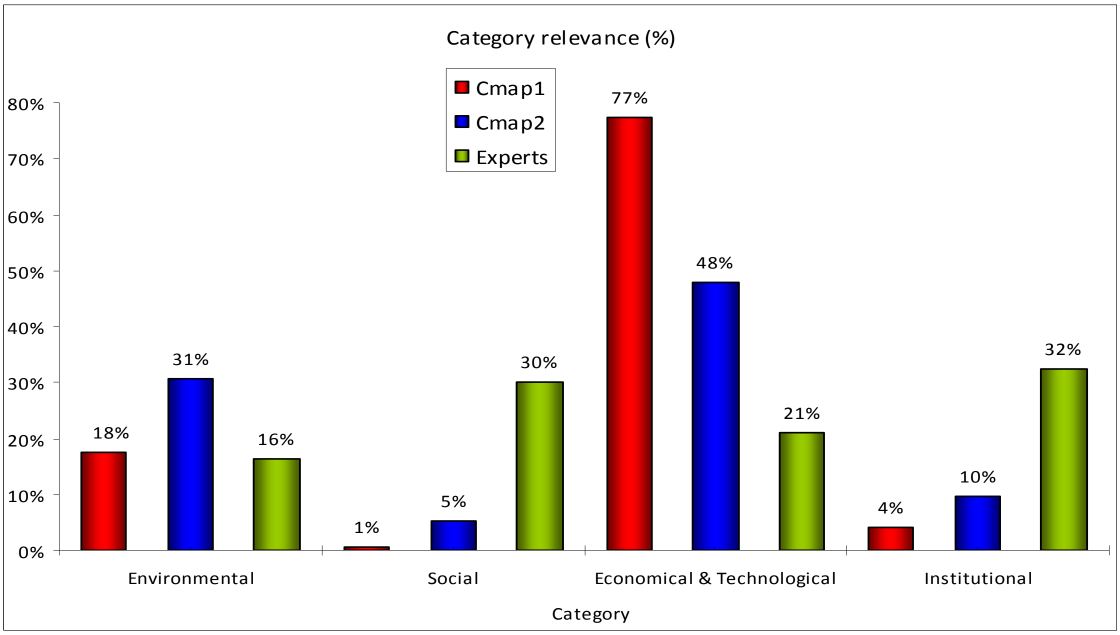

Figure 8.99 Case study EUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories

The analysis of the category relevance index under the four categories taxonomy, figure 8.99, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Technological/Economic* category and too little to *Social* and *Institutional* ones. The value decrease in the *Technological/Economic* category goes to the *Environmental* one, giving this too much relevance. The *Social* and *Institutional* categories only increase their values slightly.

In relation to the complexity index the results obtained in the three studies in table 8.61 show that before taking the course the students saw sustainability as almost a non complex subject (*CO*=0.47), but after finishing it they see sustainability as only a bit complex (*CO*=3.55), very far from the experts' results.

	Cmap1	Cmap2	Experts
Complexity index (CO)	0.47	3.55	24.8

Table 8.61 Case study EUT-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap

8.8 Students country analysis

From all the case studies, there are only two in which there are a significant number of students from different countries: Case study CUT-1 and UPC-4.

In this study two kinds of nationalities are considered.

- Students from OECD[1] countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States of America.
- Students from non OECD countries: All the other countries

The results of the two case studies are described in the followingt sections.

8.8.1 Country analysis: Case study CUT-1

Cmap$_1$: Before taking the course

Variable		OECD students	Non OECD students
Number of students	*NS*	28	23
Number total of concepts	NC_{S1}	441	296
Number total of links inter-categories	NL_{S2}	260	161
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	15.8	12.9

Table 8.62 Case study CUT-1. Cmap$_1$: Variables value. Country analysis

Therefore using the variables from table 8.62 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
OECD	CR_i	29%	11%	5%	0%	1%	0%	47%	2%	1%	3%
Non OECD	CR_i	39%	3%	10%	1%	2%	0%	36%	3%	2%	5%

Table 8.63 Case study CUT-1. Cmap$_1$: Category relevance variables. Country analysis

Graphically:

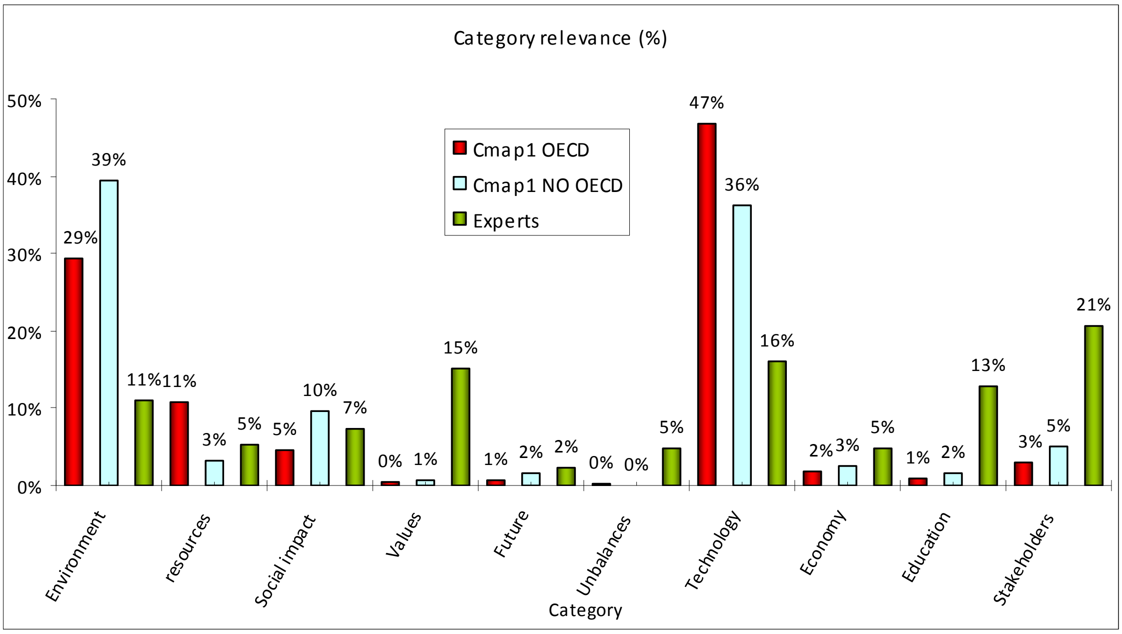

Figure 8.100 Case study CUT-1. Cmap$_1$: Category relevance index. Country analysis

The greatest differences are in *Environment* (where Non OECD students have a higher value) and in *Technology* (where OECD students have 11 more points) categories. In the other "soft" categories, they have slightly higher values from Non OECD students.

Figure 8.101 shows the Category distribution under the four categories taxonomy. It illustrates that Non OECD clearly give more relevance to *Social* and *Institutional* categories, and that OECD students see *Technological/Economic* more related to sustainability than Non OECD.

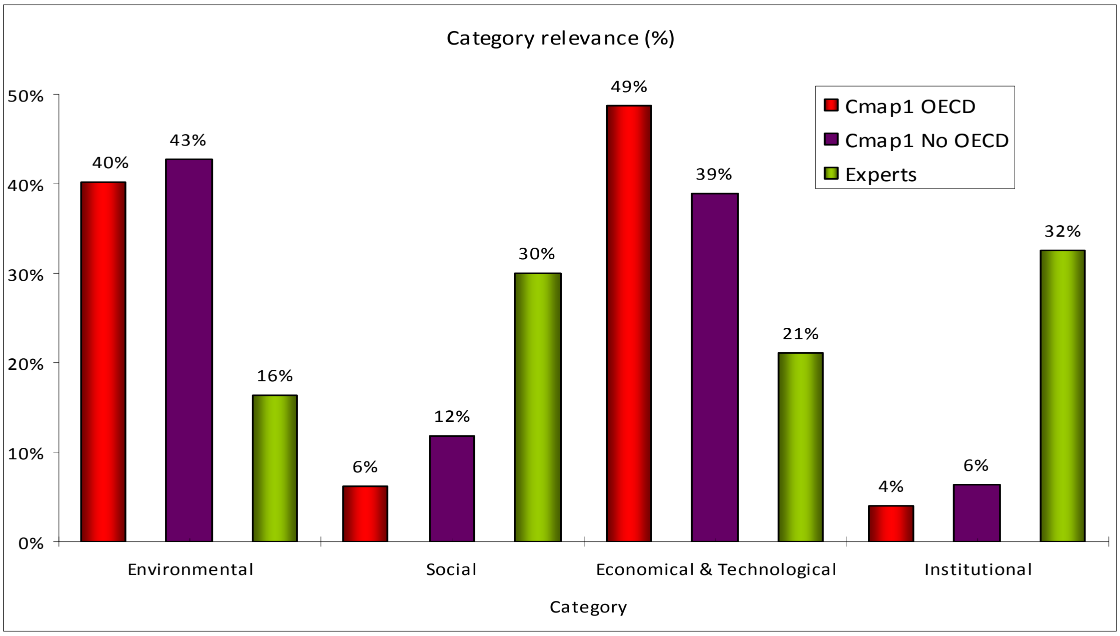

Figure 8.101 Case study CUT-1. $Cmap_1$: Category relevance index. 4 Categories. Country analysis

Complexity Index

	OECD	Non OECD
Complexity index (CO)	14.6	9.0

Table 8.64 Case study CUT-1. $Cmap_1$: Complexity index. Country analysis

$Cmap_2$: After taking the course

Variable		OECD students	Non OECD students
Number of students	*NS*	32	18
Number total of concepts	NC_{S1}	597	251
Number total of links inter-categories	NL_{S2}	381	165
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	18.66	13.94

Table 8.65 Case study CUT-1. $Cmap_2$: Variables value. Country analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
OECD	CR_i	20%	13%	5%	2%	1%	5%	33%	4%	6%	11%
Non OECD	CR_i	38%	4%	5%	3%	1%	8%	16%	8%	6%	9%

Table 8.66 Case study CUT-1. $Cmap_2$: Category relevance variables. Country analysis

Graphically:

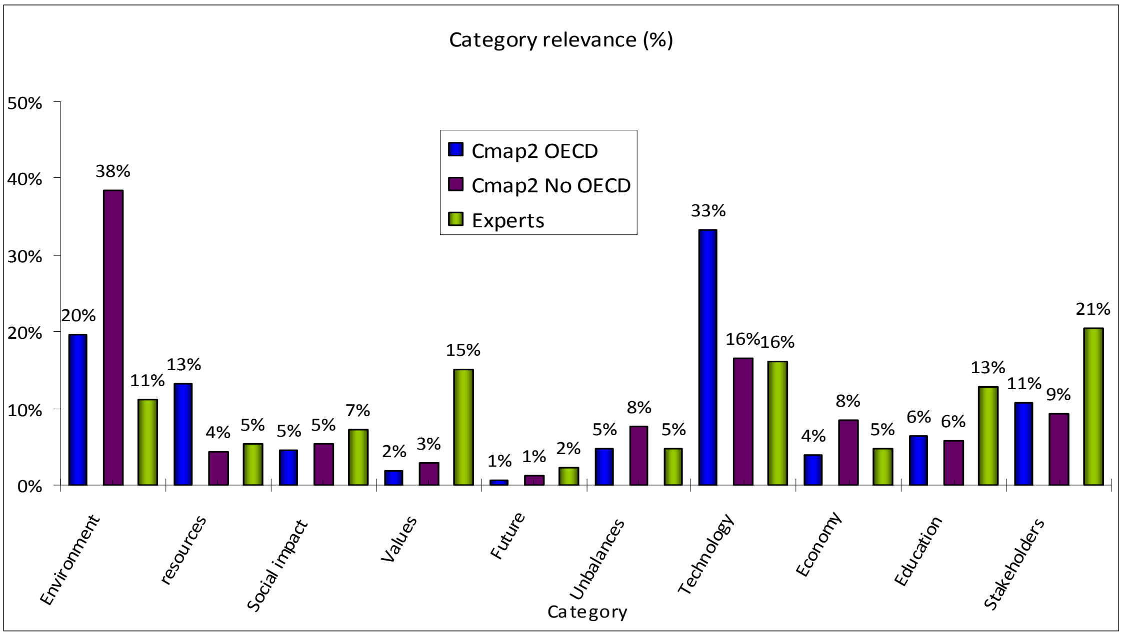

Figure 8.102 Case study CUT-1. $Cmap_2$: Category relevance index. Country analysis

The patterns shown in Cmap1 are still valid after taking the course, being the greatest differences in *Environment* (where Non OECD students have a higher value -18 points-) and in the *Technology* and *Resources* categories. In the other "soft" categories, they have slightly higher values from Non OECD students.

Figure 8.103 shows the Category distribution under the four categories taxonomy. It illustrates that Non OECD give clearly more relevance to *Social* and *Environmental* categories, and that OECD students see *Technological/Economic* more related to sustainability than Non OECD.

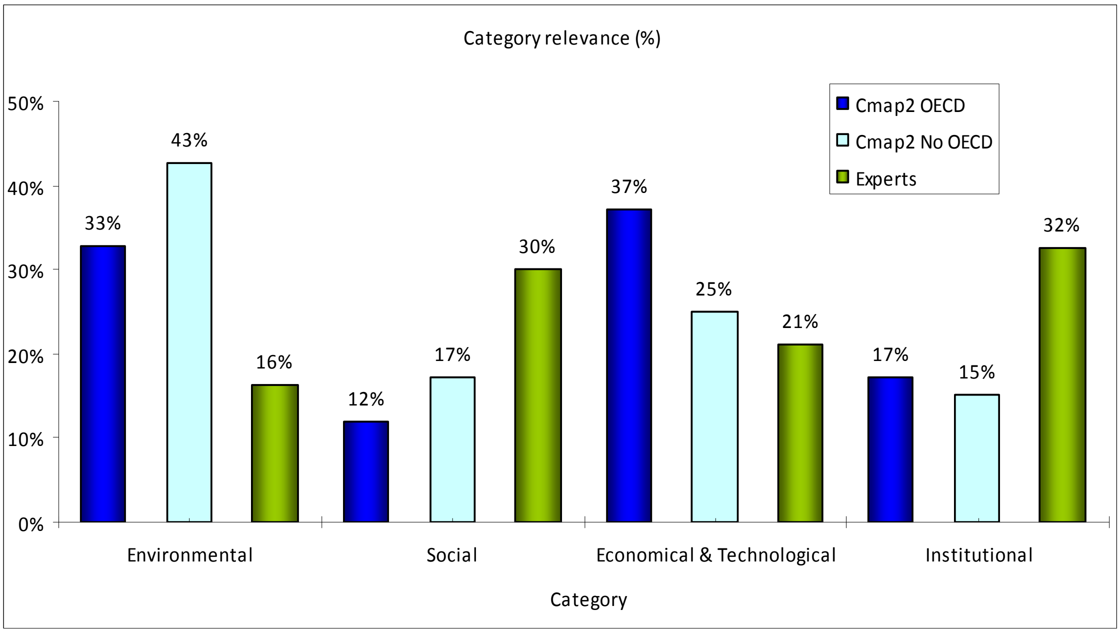

Figure 8.103 Case study CUT-1. $Cmap_2$: Category relevance index. 4 Categories. Country analysis

Complexity Index

	OECD	Non OECD
Complexity index (CO)	22.2	12.8

Table 8.67 Case study CUT-1. $Cmap_2$: Complexity index. Country analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.104 shows that there's has been an improvement since the initial conceptual map; the results after taking the course closer to the experts' ones. Nevertheless, in both cases there's a lack of relevance for the *Values*, *Education* and *Stakeholders* categories. The much higher values for *Technology* category are only reduced significantly in Non OECD students.

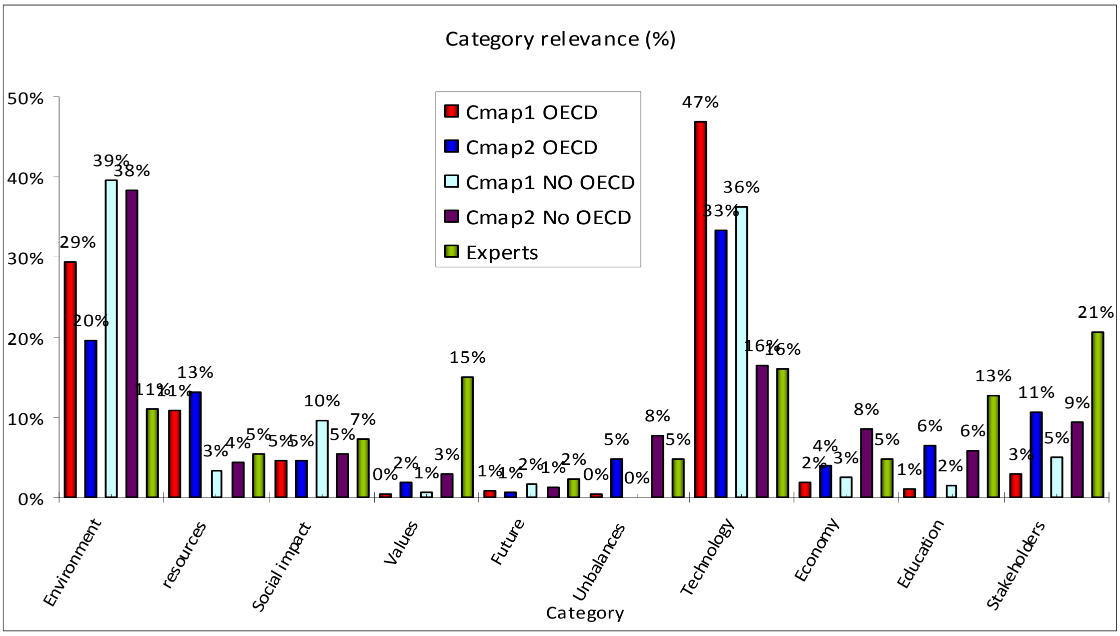

Figure 8.104 Case study CUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Country analysis

Both groups of students keep giving too much relevance to the *Environmental* and *Technological* categories. In all cases the course signifies that the results are closer to the experts' ones. The main difference is that OCDE students give much more relevance to the *Technological* category and much less to *Social* and *Environmental* one.

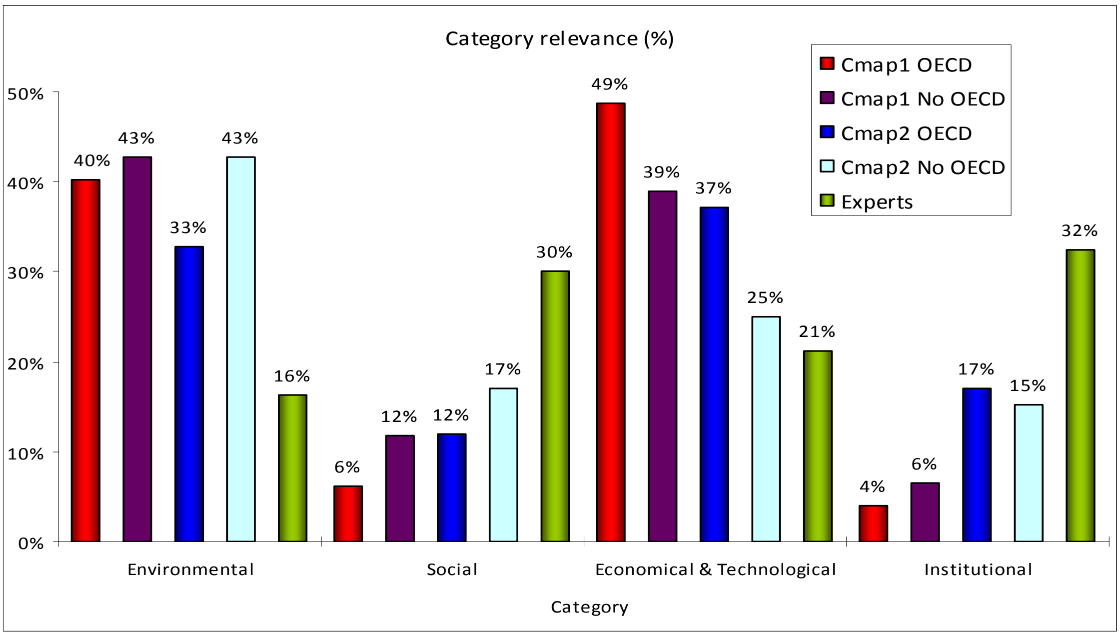

Figure 8.105 Case study CUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Country analysis

In relation to the complexity index the results obtained show that the course causes an increase in complexity. Nevertheless OECD students see Sustainability much more complex than Non OECD ones.

	OECD		Non OECD		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	14.6	22.2	9.0	12.8	24.8

Table 8.68 Case study CUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Country analysis

8.8.2 Country analysis: Case study UPC-4

$Cmap_1$: Before taking the course

Variable		OECD students	Non OECD students
Number of students	*NS*	13	6
Number total of concepts	NC_{S1}	304	68
Number total of links inter-categories	NL_{S2}	157	40
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	23.4	11.3

Table 8.69 Case study UPC-4. $Cmap_1$: Variables value. Country analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
OECD	CR_i	27%	4%	5%	13%	2%	1%	14%	5%	5%	23%
Non OECD	CR_i	25%	7%	8%	7%	7%	5%	5%	3%	11%	24%

Table 8.70 Case study UPC-4. $Cmap_1$: Category relevance variables. Country analysis

Graphically:

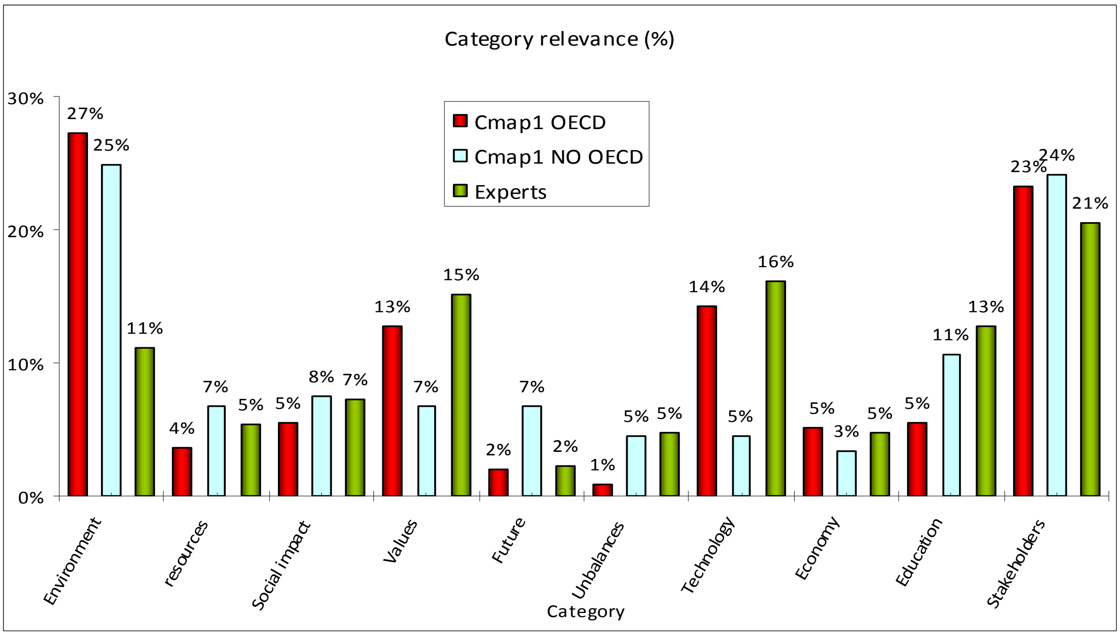

Figure 8.106 Case study UPC-4. $Cmap_1$: Category relevance index. Country analysis

The greatest differences are in *Future and Unbalances* (where Non OECD students give a higher value) and in *Technology* and *Values* (where OECD students give higher values) categories. In the other categories, they have slightly higher values from Non OECD students.

Figure 8.107 shows the Category distribution under the four categories taxonomy. It illustrates that Non OECD give clearly more relevance to *Social* and *Institutional* categories, and that OECD students see *Technological/Economic* as being more related to sustainability than Non OECD. (This follows the same pattern as case study CUT-1)

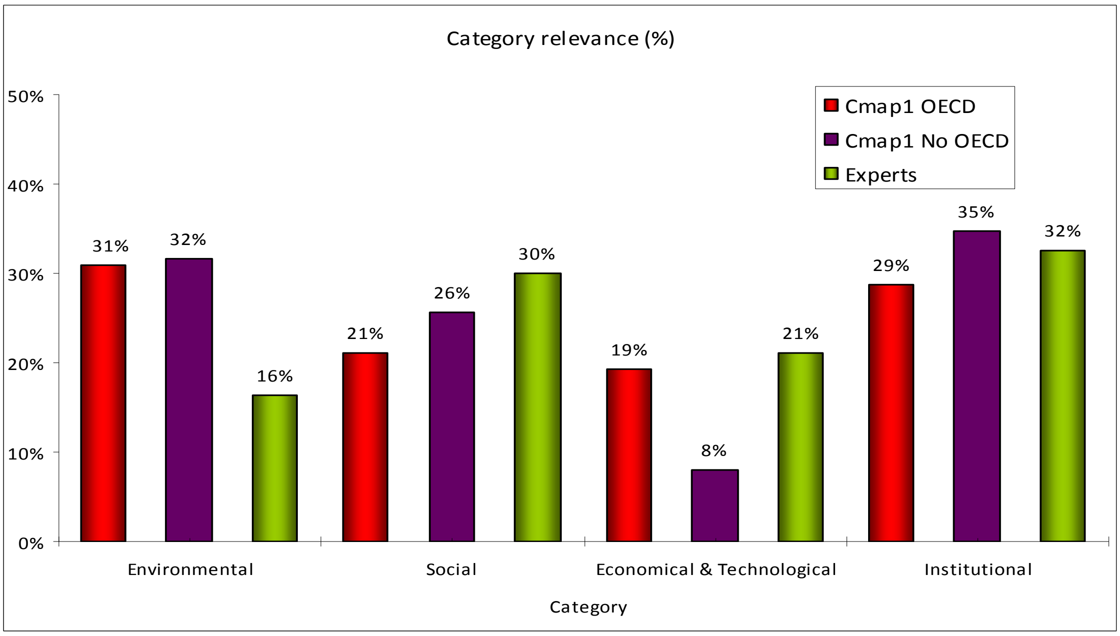

Figure 8.107 Case study UPC-4. $Cmap_1$: Category relevance index. 4 Categories. Country analysis

Complexity Index

	OECD	Non OECD
Complexity index (CO)	28.2	7.6

Table 8.71 Case study UPC-4. $Cmap_1$: Complexity index. Country analysis

$Cmap_2$: After taking the course

Variable		OECD students	Non OECD students
Number of students	*NS*	9	5
Number total of concepts	NC_{S1}	194	56
Number total of links inter-categories	NL_{S2}	106	42
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	21.56	11.20

Table 8.72 Case study UPC-4. $Cmap_2$: Variables value. Country analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
OECD	CR_i	12%	3%	5%	20%	1%	2%	22%	3%	15%	17%
Non OECD	CR_i	4%	7%	15%	7%	3%	1%	25%	16%	11%	11%

Table 8.73 Case study UPC-4. $Cmap_2$: Category relevance variables. Country analysis

Graphically:

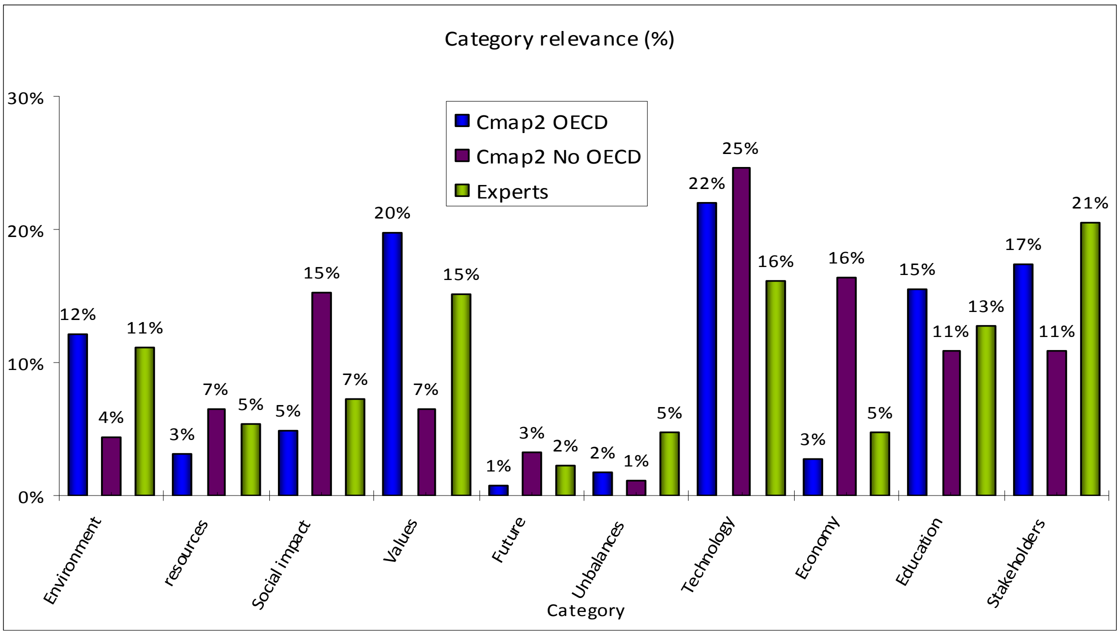

Figure 8.108 Case study UPC-4. $Cmap_2$: Category relevance index. Country analysis

The greatest differences are in *Social impact and Economy* (where Non OECD students give a higher value) and in *Environment, Values, Education* and *Stakeholders* (where OECD students give higher values) categories. In the other categories, there is not a clear pattern.

Figure 8.109 shows the Category distribution under the four categories taxonomy. It illustrates that Non OECD give clearly more relevance to the *Technological* category, and that OECD students see *Institutional* as being more related to sustainability than Non OECD.

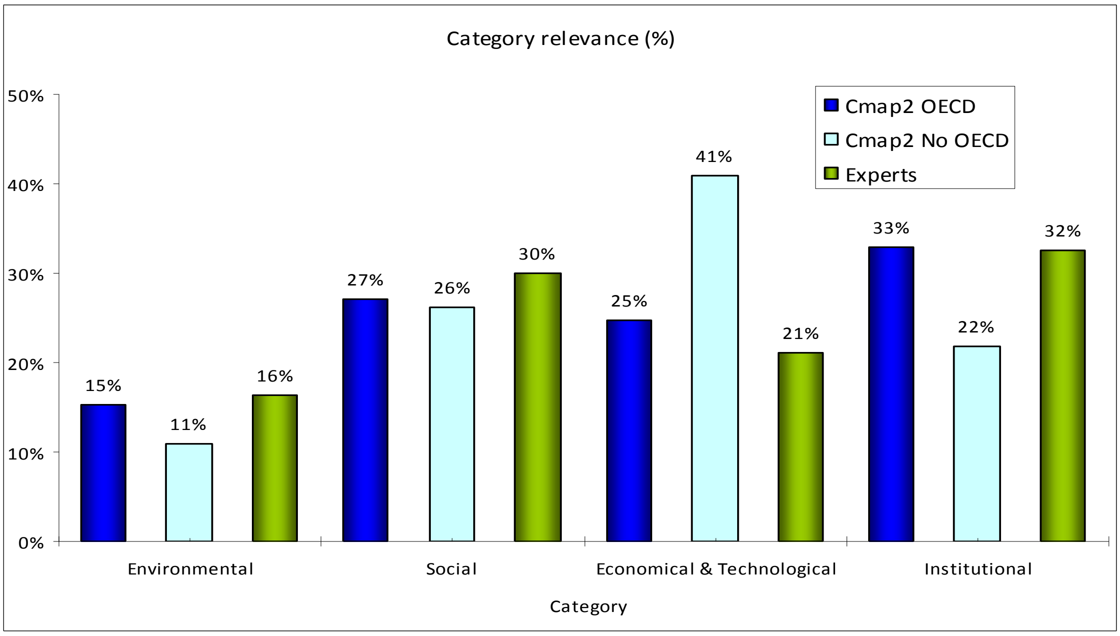

Figure 8.109 Case study UPC-4. $Cmap_2$: Category relevance index. 4 Categories. Country analysis

Complexity Index

	OECD	Non OECD
Complexity index (CO)	25.4	9.4

Table 8.74 Case study UPC-4. $Cmap_2$: Complexity index. Country analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.110 shows that there's has been an improvement since the initial conceptual map; the results after taking the course are closer to the experts' ones. For Non OECD students the biggest increase is in the *Technology* and *Economy* categories. In both student groups, the environment category is the one which decreases the most.

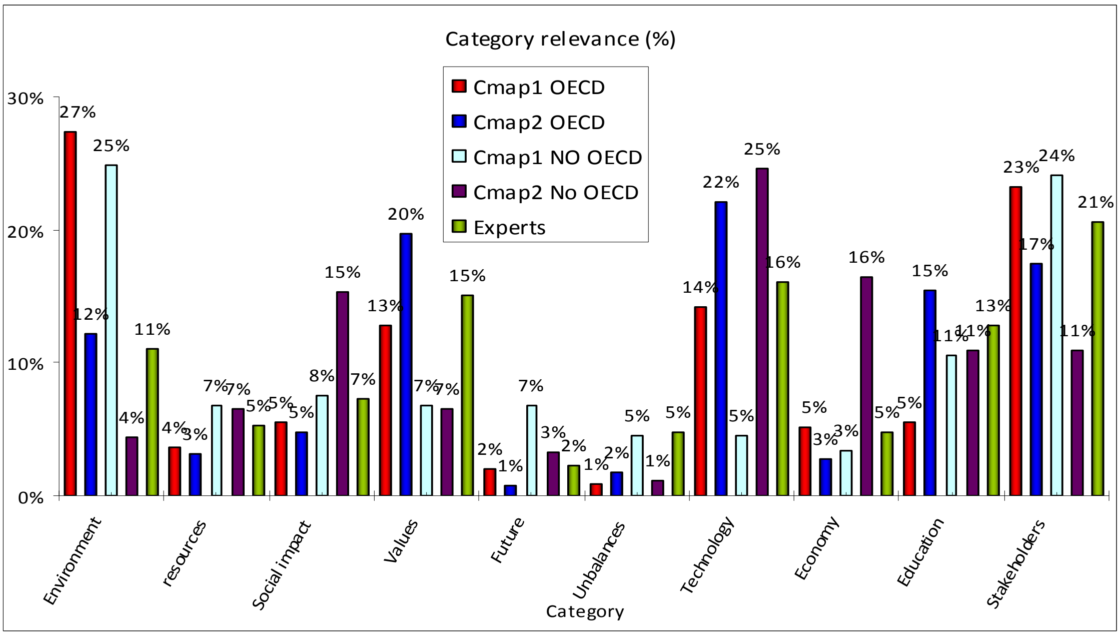

Figure 8.110 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Country analysis

The analysis of the category relevance index under the four categories taxonomy, figure 8.111, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Environmental* category. After taking the course, the OECD students have a distribution which is quite similar to the experts' one, but the Non OECD students transform the *Environment* relevance (Cmap1) to the *Technological* one (Cmap2), giving too much important to this one after taking the course.

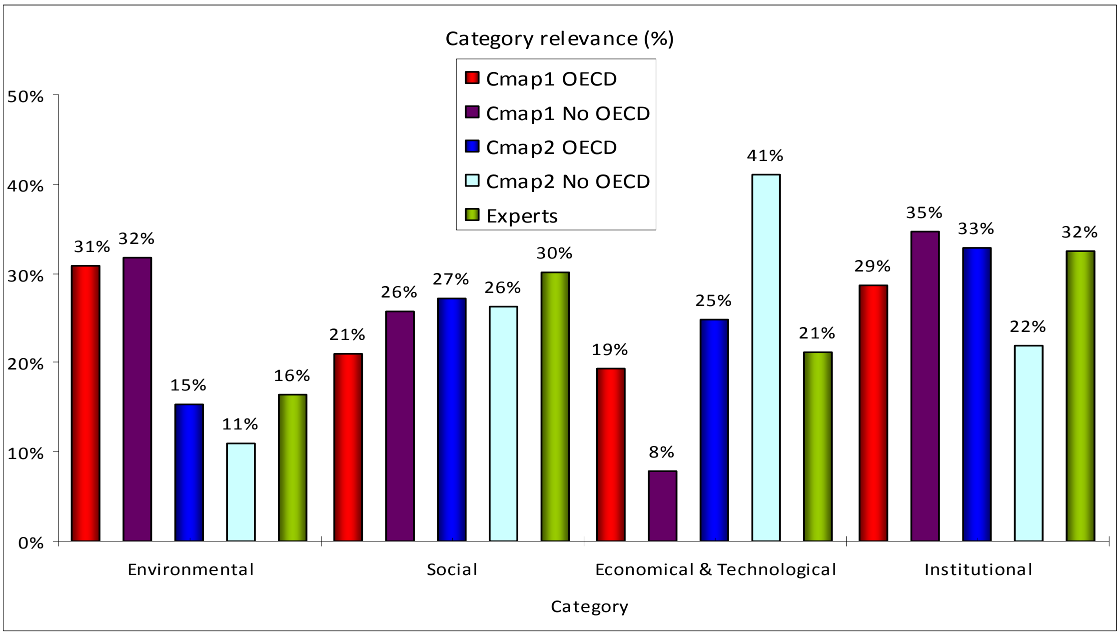

Figure 8.111 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Country analysis

In relation to the complexity index the results obtained show that the course caused an approximation to the experts' values. OECD students see *Sustainability* much more complex than Non OECD ones.

	OECD		Non OECD		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	28.2	25.4	7.6	9.4	24.8

Table 8.75 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Country analysis

8.8.3 Analysis of results

The category relevance indicator analysis illustrates that Non OECD students usually give more relevance to *Social* and *Institutional* categories than OECD ones, who give more relevance to the *Technological/Economic* one.

On the complexity index, results showed in both cases that OECD students see *Sustainability* as a more complex concepts than Non OECD ones. Both student groups' results after taking the courses are closer to the reference one.

8.9 Students' speciality analysis

From all the case studies, the courses where there is a significant sample of students per speciality are the courses at the UPC. Case study UPC-1, UPC-2, UPC-3 and UPC-4.

In this study four engineering specialities are considered:

- Chemistry [CHE]

- Industrial (mechanics, electronics, electrics, Industrial Management) [IND]

- Architecture and Civil Engineering [ARC]

- Information and Communication Technologies [ICT]

8.9.1 Speciality analysis: Case study UPC-1

Cmap$_1$: Before taking the course

Variable		CHE	IND	ARC	ICT
Number of students	*NS*	21	90	21	65
Number total of concepts	NC_{S1}	175	571	161	467
Number total of links inter-categories	NL_{S2}	31	93	22	97
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	8.33	6.34	7.67	7.18

Table 8.76 Case study UPC-1. Cmap$_1$: Variables value. Speciality analysis

Therefore using the variables from the table 8.76 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
CHE	CR_i	55%	6%	6%	1%	0%	0%	22%	0%	6%	3%
IND	CR_i	32%	12%	3%	2%	0%	0%	44%	0%	3%	1%
ARC	CR_i	49%	19%	11%	1%	0%	0%	18%	0%	0%	2%
ICT	CR_i	38%	10%	5%	1%	0%	0%	42%	0%	1%	2%

Table 8.77 Case study UPC-1. Cmap$_1$: Category relevance variables. Speciality analysis

Graphically:

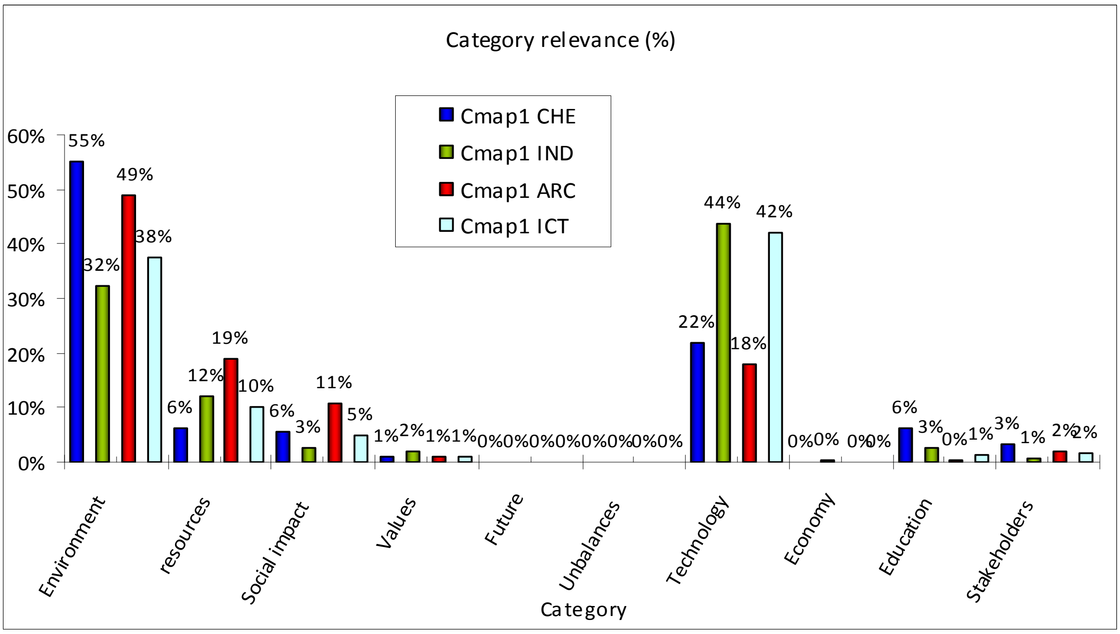

Figure 8.112 Case study UPC-1. Cmap$_1$: Category relevance index. Speciality analysis

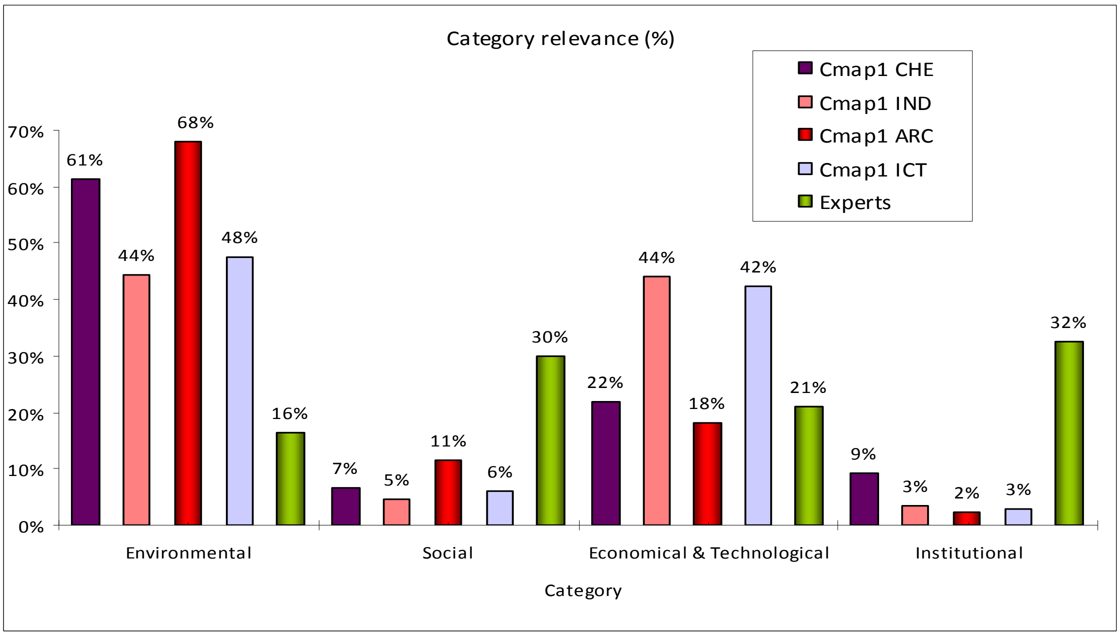

Figure 8.113 Case study UPC-1. $Cmap_1$: Category relevance index. 4 Categories. Speciality analysis

Complexity Index

	CHE	IND	ARC	ICT
Complexity index (CO)	1.2	0.7	0.8	1.1

Table 8.78 Case study UPC-1. $Cmap_1$: Complexity index. Speciality analysis

$Cmap_2$: After taking the course

Variable		CHE	IND	ARC	ICT
Number of students	*NS*	18	84	14	48
Number total of concepts	NC_{S1}	499	1784	392	1084
Number total of links inter-categories	NL_{S2}	83	392	63	228
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	27.72	21.24	28.00	22.58

Table 8.79 Case study UPC-1. $Cmap_2$: Variables value. Speciality analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
CHE	CR_i	24%	15%	5%	2%	0%	3%	21%	7%	1%	18%
IND	CR_i	34%	9%	7%	3%	0%	3%	18%	5%	1%	14%
ARC	CR_i	30%	14%	2%	2%	0%	4%	29%	3%	1%	12%
ICT	CR_i	29%	14%	5%	2%	0%	1%	26%	4%	0%	15%

Table 8.80 Case study UPC-1. $Cmap_2$: Category relevance variables. Speciality analysis

Graphically:

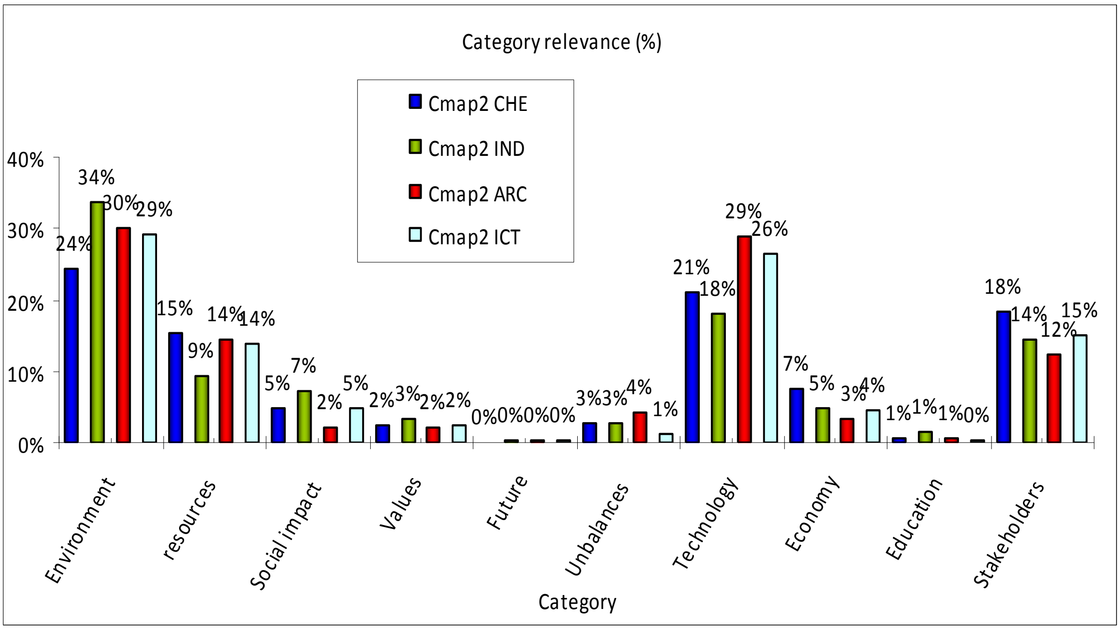

Figure 8.114 Case study UPC-1. Cmap$_2$: Category relevance index. Speciality analysis

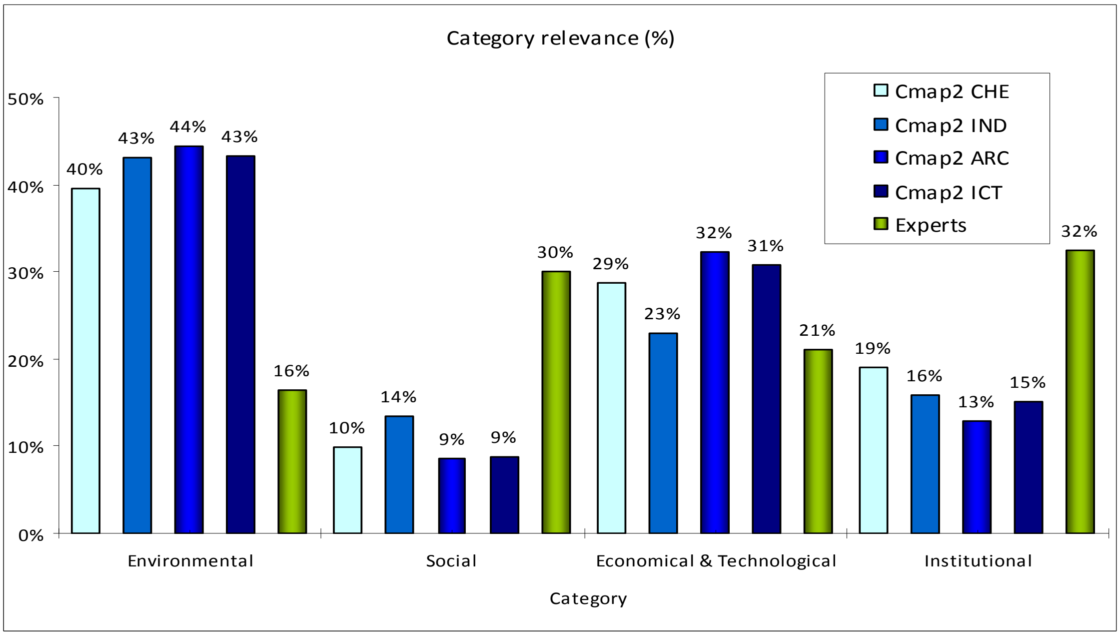

Figure 8.115 Case study UPC-1. Cmap$_2$: Category relevance index. 4 Categories. Speciality analysis

<u>Complexity Index</u>

	CHE	IND	ARC	ICT
Complexity index (CO)	12.8	9.9	12.6	10.7

Table 8.81 Case study UPC-1. Cmap$_2$: Complexity index. Speciality analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Chemistry students (figure 8.116), before taking the course gave too much relevance to *Environment* and *Resources*, the other categories have little values except *Technology*. After the course this misunderstanding is partially rectified.

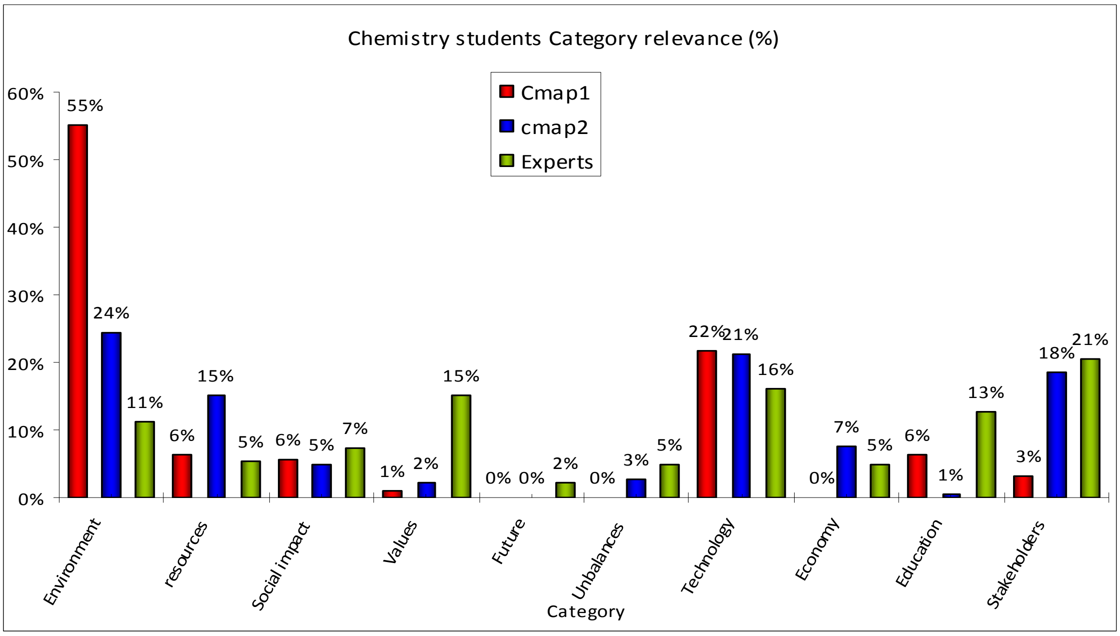

Figure 8.116 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Chemistry students

Industrial students (figure 8.117), before taking the course gave too much relevance to *Technology* and *Environment*, while the other categories have little values except *Resources*. After the course this misunderstanding is partially rectified, although *Environment* keeps having too high a relevance and “soft” categories only improve partially.

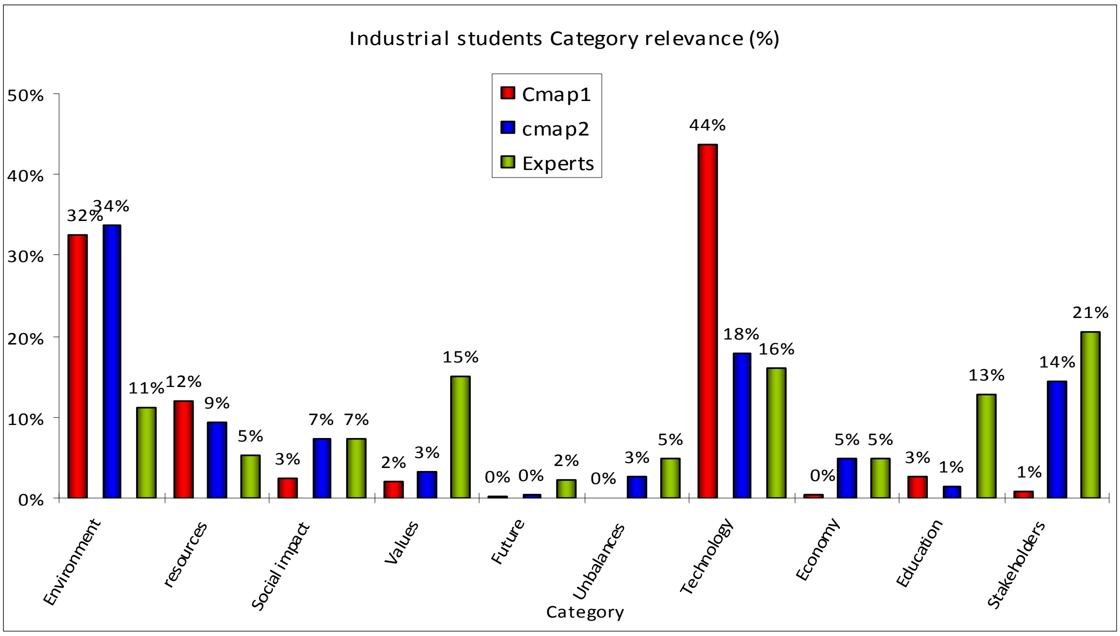

Figure 8.117 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Industrial students

Architecture and Civil students (figure 8.118), before taking the course gave too much relevance to *Environment*, *Resources* and *Social impact*; the other categories have little values except *Technology*. After the course this misunderstanding is partially rectified, although *Environment* continues to have too high a relevance, *Technology* increases too much and "soft" categories show very little improvement.

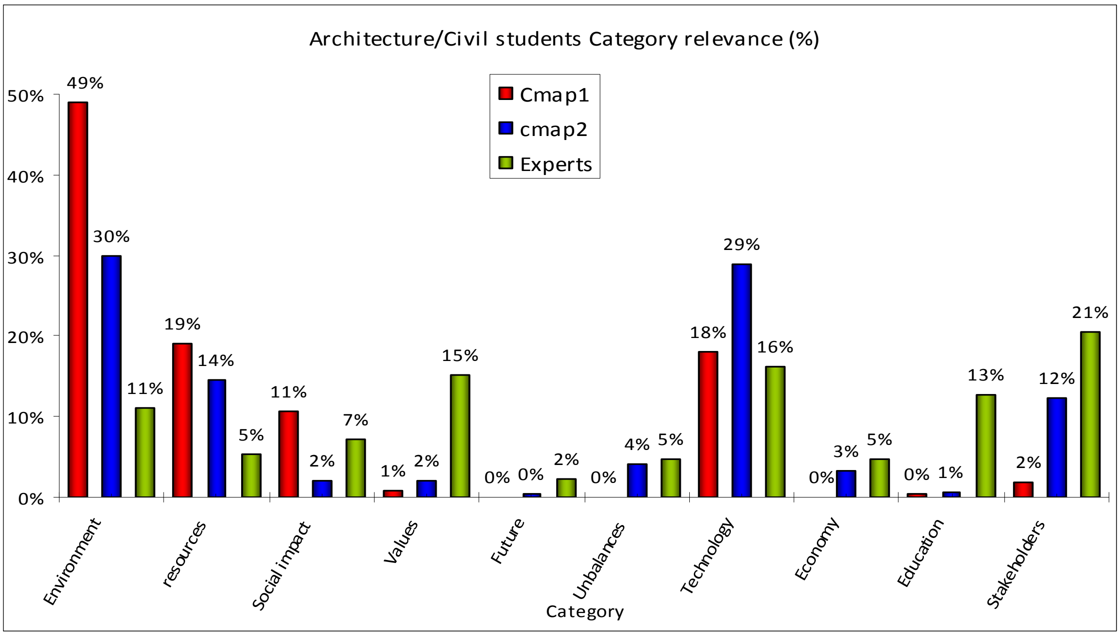

Figure 8.118 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Architecture and Civil students

ICT students (figure 8.119), before taking the course gave too much relevance to *Environment*, and *Technology*; the other categories have small values except *Resources*. After the course this misunderstanding is partially rectifiec, although *Environment* and *Technology* keep having too high a relevance, *Resources* get worse results and "soft" categories show very little improvement.

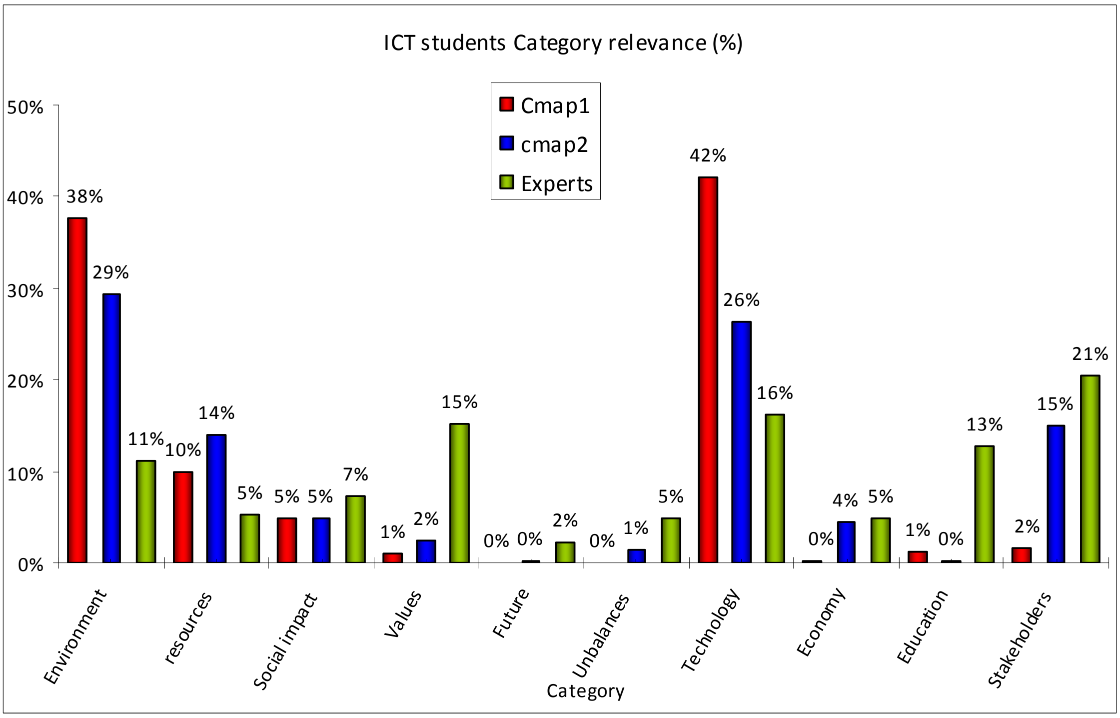

Figure 8.119 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. ICT students

The analysis of the category relevance index under the four categories taxonomy, in figure 8.120, confirms the misunderstanding of engineering students, who before taking the course gave too much value to the *Environmental* and *Technological* categories and too little to *Social* and *Institutional* ones. After the course this misunderstanding is partially rectified. There are no significant differences between specialities.

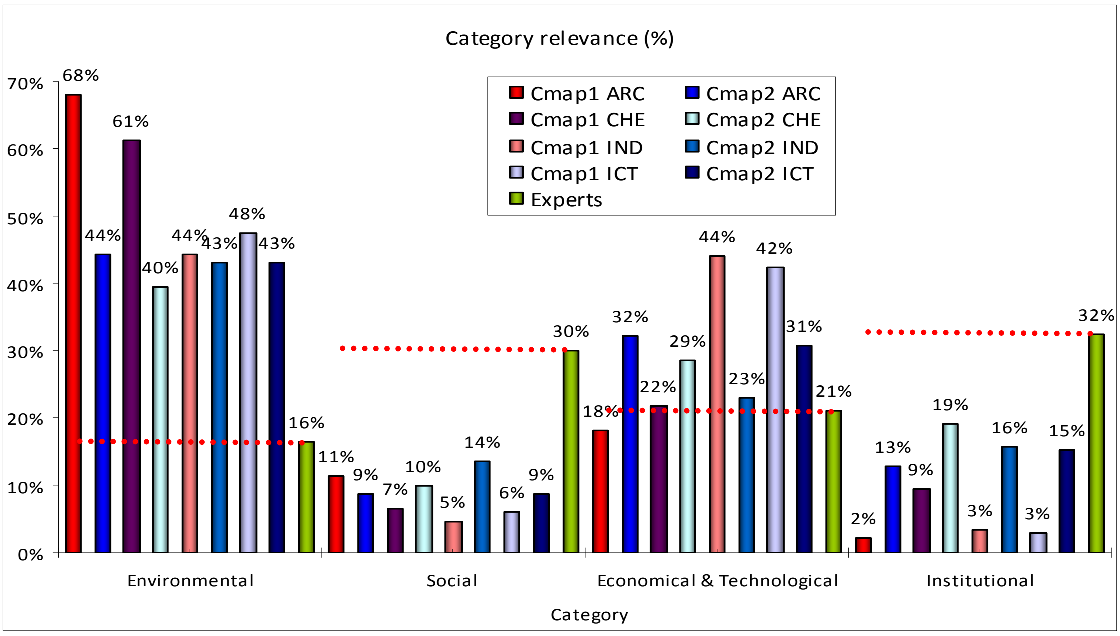

Figure 8.120 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Speciality analysis

In relation to the complexity index the results obtained in the four specialities, in table 8.82 and figure 8.121 show that before taking the course the students saw sustainability as not a complex subject. After taking the course all groups increase the complexity index to the same value.

	CHE		IND		ARC		ICT		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	1.2	12.8	0.7	9.9	0.8	12.6	1.1	10.7	24.8

Table 8.82 Case study UPC-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

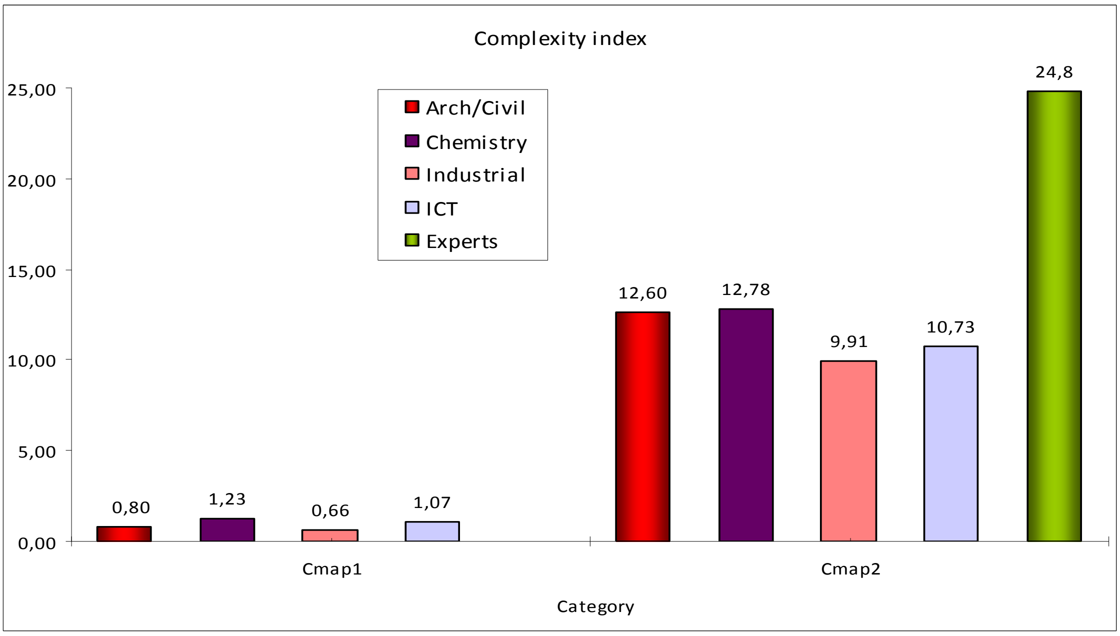

Figure 8.121 Case study UPC-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

8.9.2 Speciality analysis: Case study UPC-3

Cmap$_1$: Before taking the course

Variable		IND	ICT
Number of students	*NS*	17	10
Number total of concepts	NC_{S1}	221	131
Number total of links inter-categories	NL_{S2}	50	23
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	13.00	13.10

Table 8.83 Case study UPC-3. Cmap$_1$: Variables value. Speciality analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
IND	CR_i	43%	9%	4%	0%	0%	0%	28%	1%	2%	6%
ICT	CR_i	27%	16%	4%	0%	0%	0%	35%	0%	7%	4%

Table 8.84 Case study UPC-3. Cmap$_1$: Category relevance variables. Speciality analysis

Graphically:

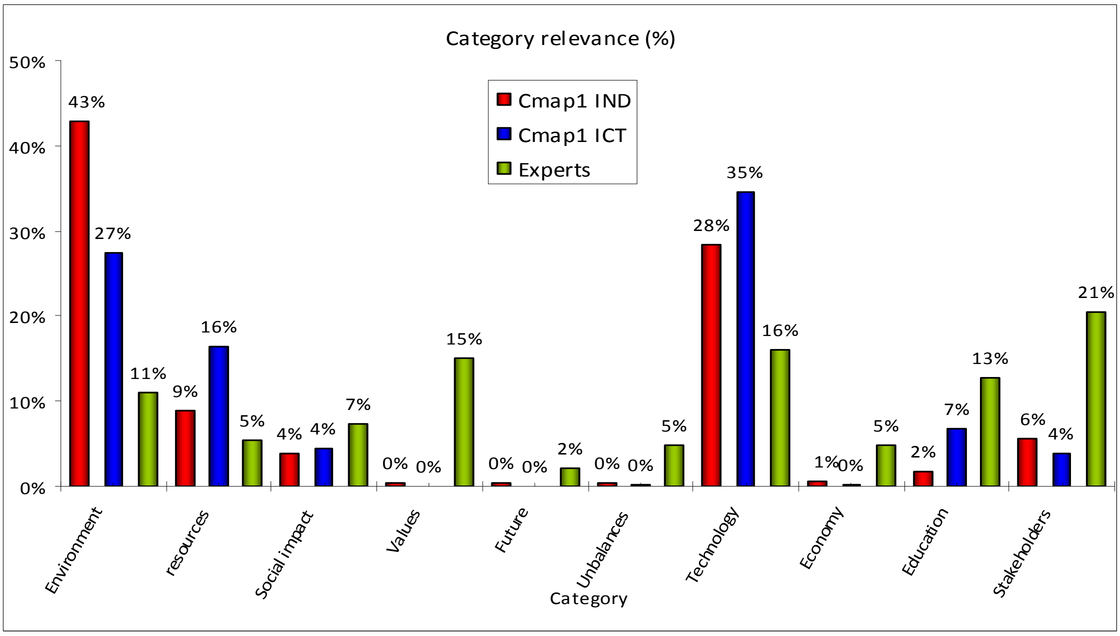

Figure 8.122 Case study UPC-3. Cmap$_1$: Category relevance index. Speciality analysis

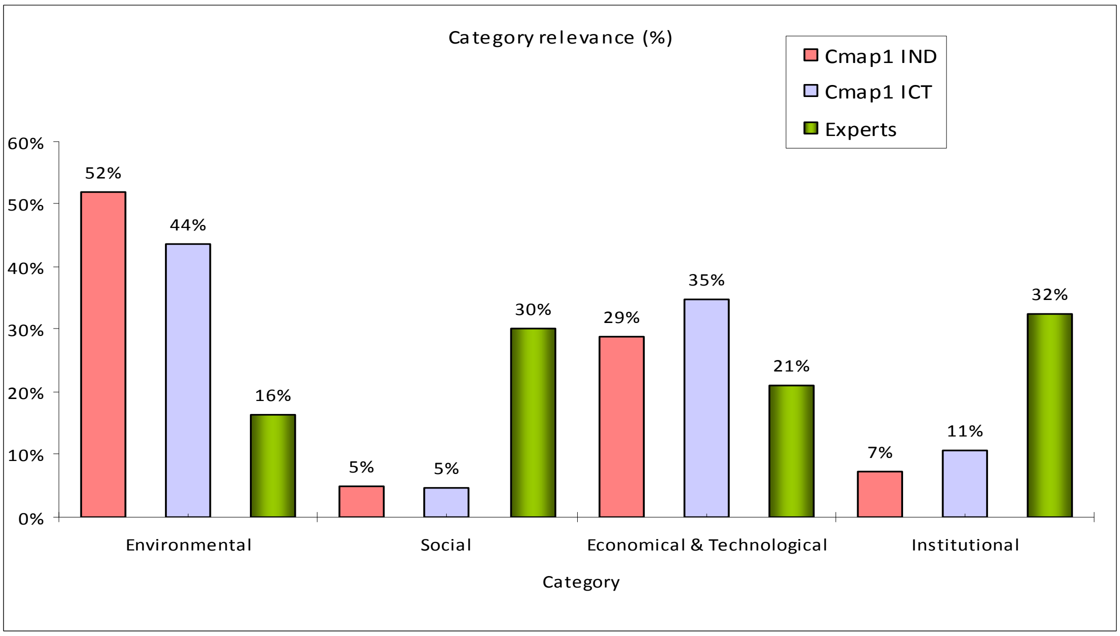

Figure 8.123 Case study UPC-3. $Cmap_1$: Category relevance index. 4 Categories. Speciality analysis

Complexity Index

	IND	ICT
Complexity index (CO)	3.82	3.01

Table 8.85 Case study UPC-3. $Cmap_1$: Complexity index. Speciality analysis

$Cmap_2$: After taking the course

Variable		IND	ICT
Number of students	*NS*	11	8
Number total of concepts	NC_{S1}	331	220
Number total of links inter-categories	NL_{S2}	86	54
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	30.09	27.5

Table 8.86 Case study UPC-3. $Cmap_2$: Variables value. Speciality analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
IND	CR_i	26%	11%	7%	1%	0%	1%	16%	6%	7%	24%
ICT	CR_i	18%	10%	2%	2%	0%	0%	19%	1%	9%	37%

Table 8.87 Case study UPC-3. $Cmap_2$: Category relevance variables. Speciality analysis

Graphically:

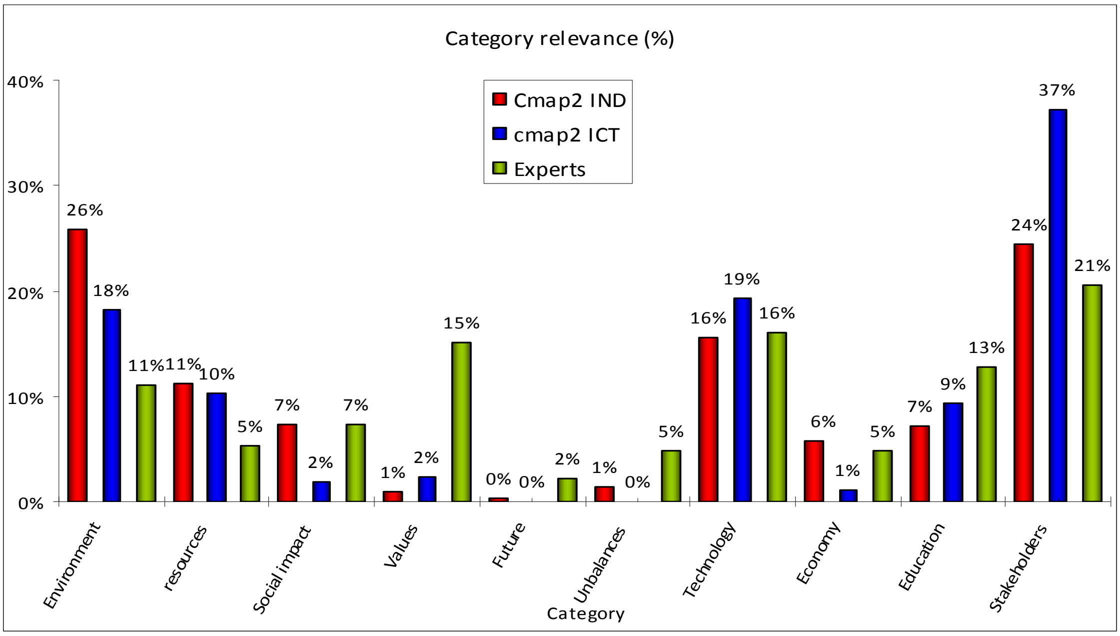

Figure 8.124 Case study UPC-3. Cmap$_2$: Category relevance index. Speciality analysis

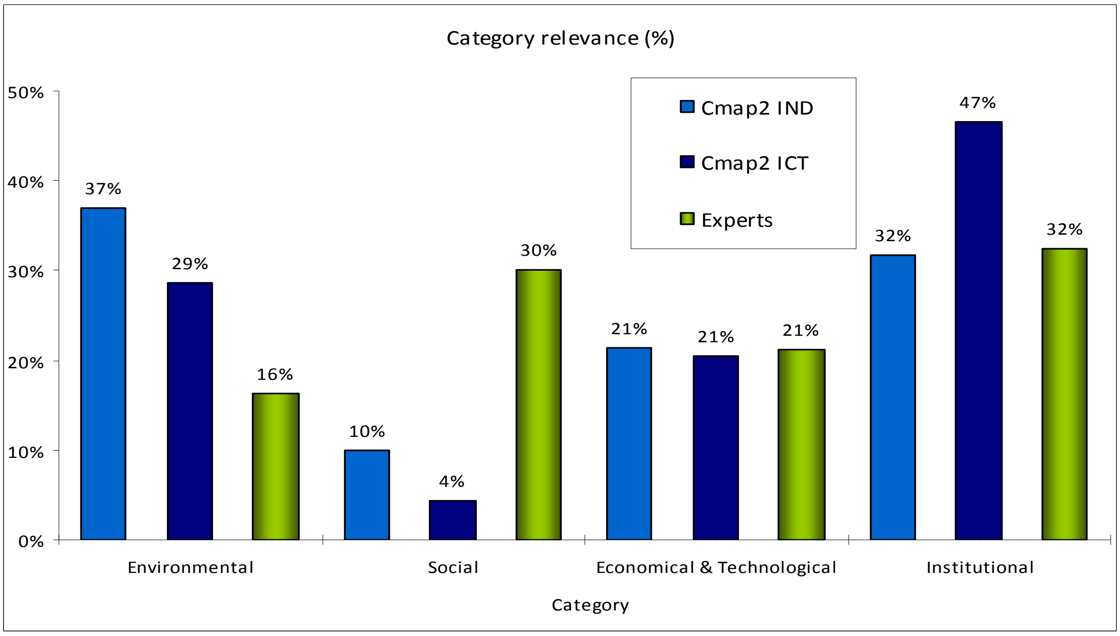

Figure 8.125 Case study UPC-3. Cmap$_2$: Category relevance index. 4 Categories. Speciality analysis

Complexity Index

	IND	ICT
Complexity index (CO)	23.5	18.6

Table 8.88 Case study UPC-3. Cmap$_2$: Complexity index. Speciality analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

The analysis of the category relevance index under the four categories taxonomy, in figure 8.126, confirms the misunderstanding of engineering students, who before taking the course gave too much value to *Environmental*, *Technological* and *Resources* categories and too little if any to *Social* ones. After the course this misunderstanding is partially rectified. There are no significant differences between specialities.

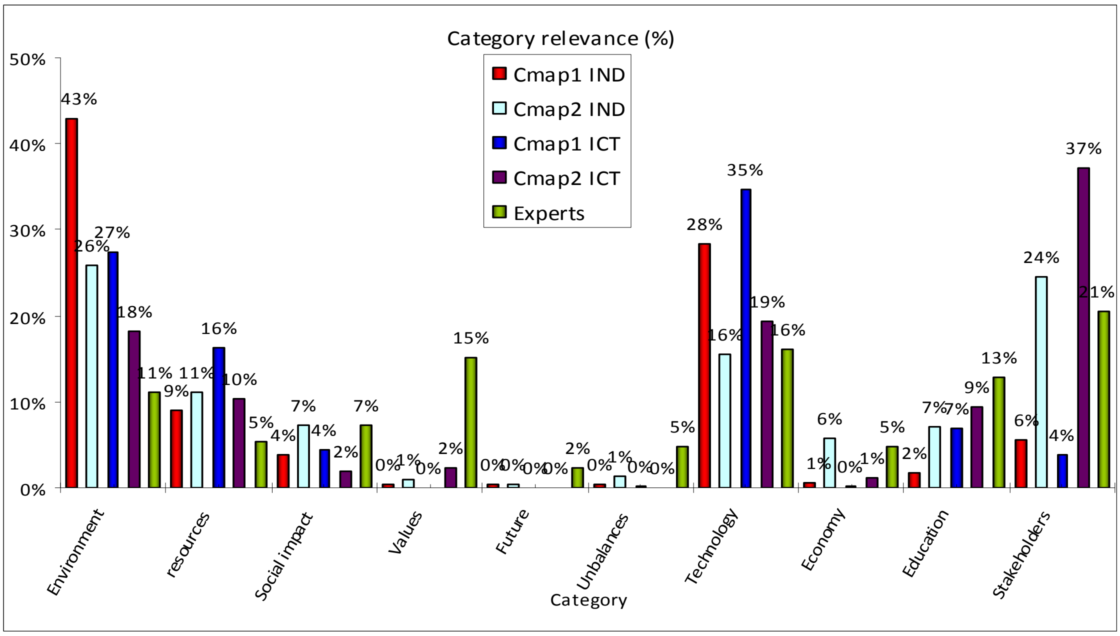

Figure 8.126 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.127, confirms the misunderstanding of engineering students, who before taking the course gave too much value to *Environmental* and *Technological* categories and too little to *Social* and *Institutional* ones. After the course this misunderstanding is partially rectified. There are no significant differences between specialities.

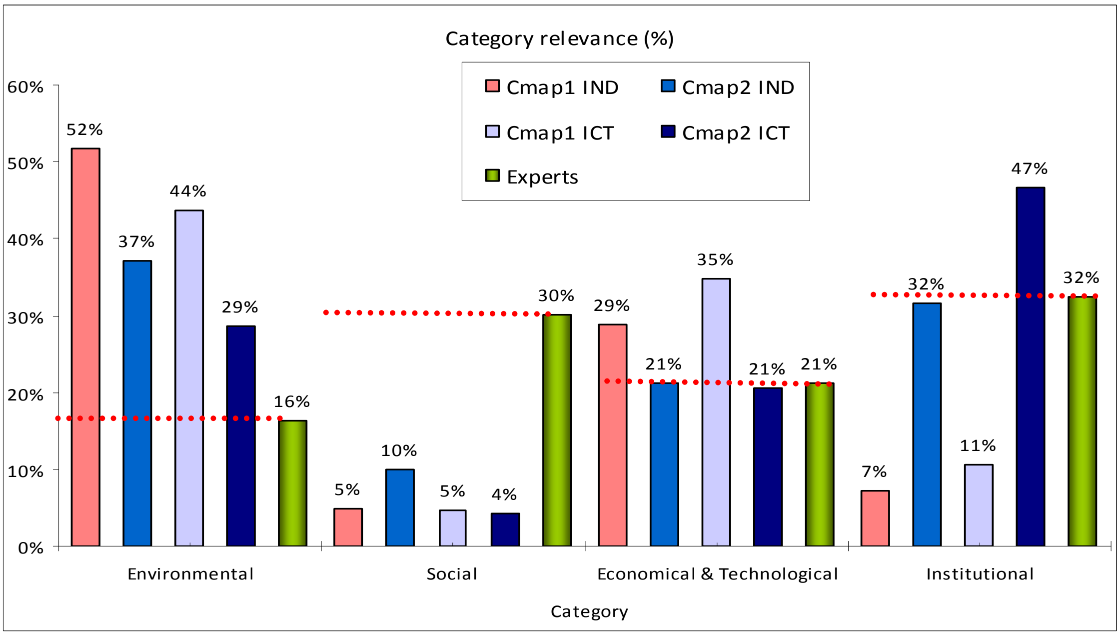

Figure 8.127 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Speciality analysis

In relation to the complexity index the results obtained in the two specialities, in table 8.89 and figure 8.128 show that before taking the course the students saw sustainability as a not complex subject. After taking the course all groups increase the complexity index.

	IND		ICT		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	3.82	23.53	3.01	18.56	24.8

Table 8.89 Case study UPC-3. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

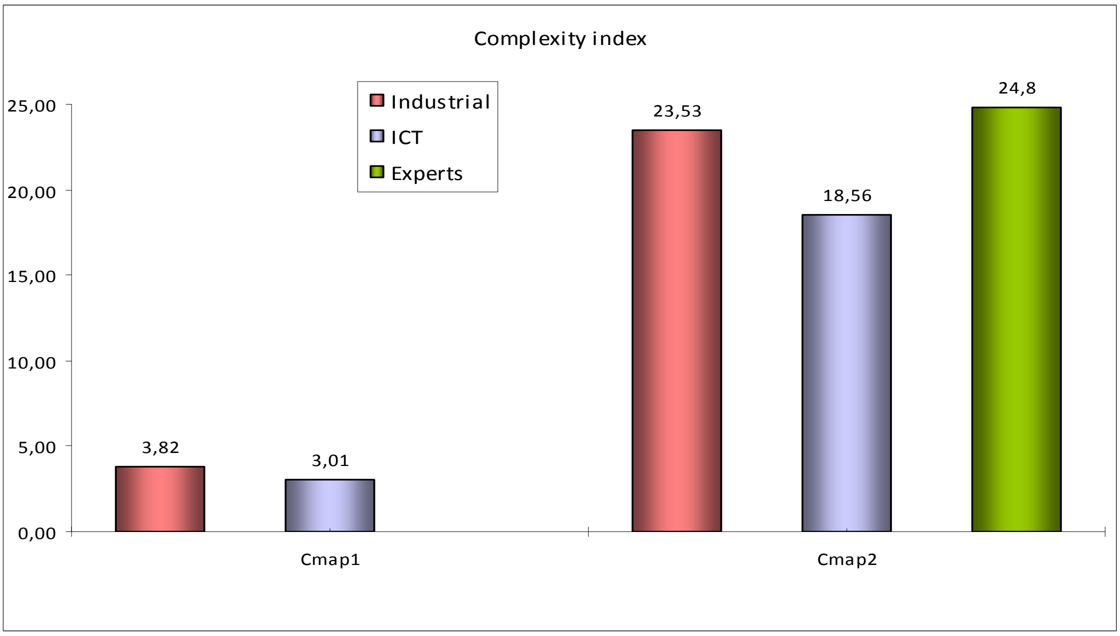

Figure 8.128 Case study UPC-3. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

8.9.3 Speciality analysis: Case study UPC-4

Cmap$_1$: Before taking the course

Variable		CHE	ARC	POL
Number of students	*NS*	6	5	5
Number total of concepts	NC_{S1}	107	102	92
Number total of links inter-categories	NL_{S2}	99	31	37
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	17.83	20.40	18.40

Table 8.90 Case study UPC-4. $Cmap_1$: Variables value. Speciality analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
CHE	CR_i	24%	1%	11%	12%	3%	0%	12%	7%	9%	23%
ARC	CR_i	35%	10%	1%	5%	5%	2%	16%	0%	3%	22%
POL	CR_i	18%	7%	7%	18%	2%	3%	6%	5%	8%	27%

Table 8.91 Case study UPC-4. $Cmap_1$: Category relevance variables. Speciality analysis

Graphically:

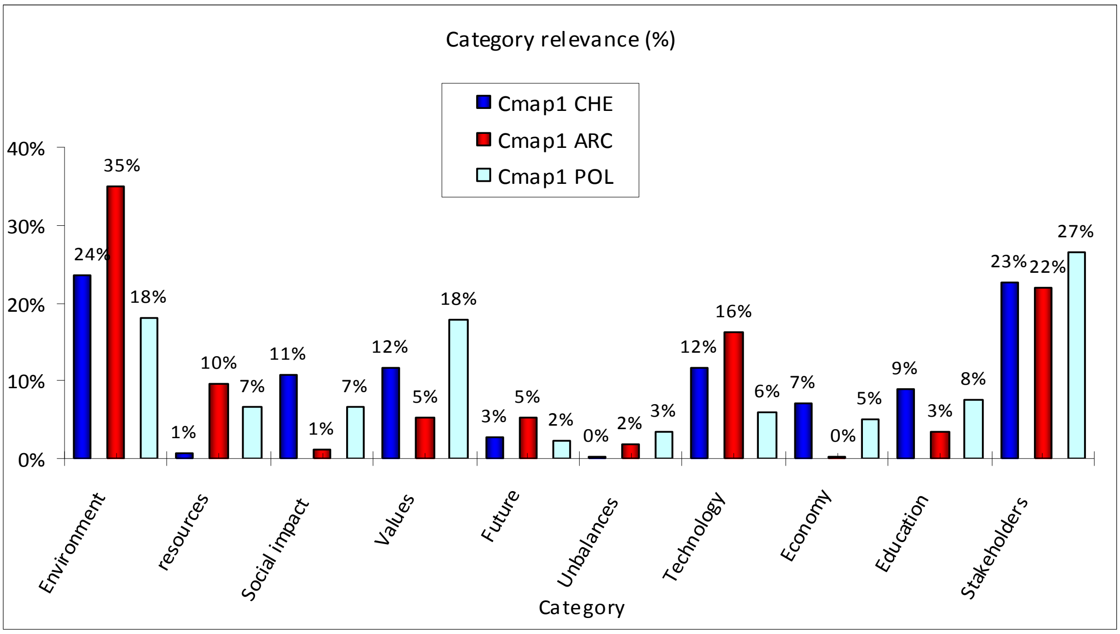

Figure 8.129 Case study UPC-4. $Cmap_1$: Category relevance index. Speciality analysis

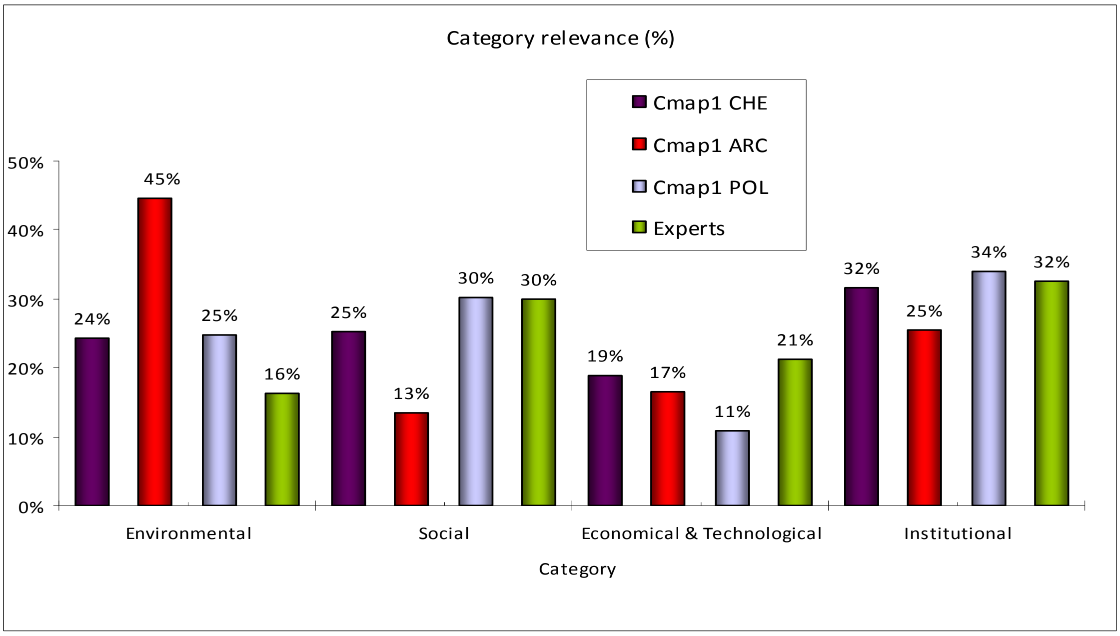

Figure 8.130 Case study UPC-4. $Cmap_1$: Category relevance index. 4 Categories. Speciality analysis

Complexity Index

	CHE	ARC	POL
Complexity index (CO)	29.4	12.6	13.6

Table 8.92 Case study UPC-4. $Cmap_1$: Complexity index. Speciality analysis

Cmap$_2$: After taking the course

Variable		CHE	ARC	POL
Number of students	*NS*	4	3	3
Number total of concepts	NC_{S1}	79	41	68
Number total of links inter-categories	NL_{S2}	67	28	33
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	19.75	13.67	22.67

Table 8.93 Case study UPC-4. Cmap$_2$: Variables value. Speciality analysis

Therefore using the variables from table 8.93 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
CHE	CR_i	17%	0%	11%	7%	1%	0%	13%	6%	15%	29%
ARC	CR_i	5%	10%	5%	14%	2%	2%	31%	10%	16%	3%
POL	CR_i	7%	4%	2%	33%	1%	6%	7%	2%	22%	17%

Table 8.94 Case study UPC-4. Cmap$_2$: Category relevance variables. Speciality analysis

Graphically:

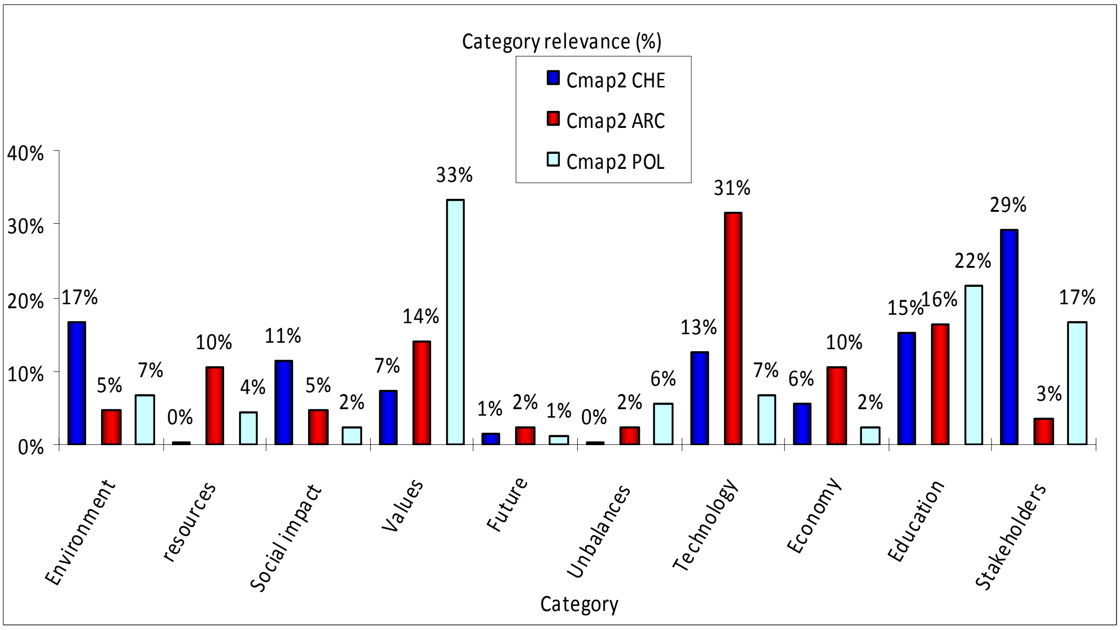

Figure 8.131 Case study UPC-4. Cmap$_2$: Category relevance index. Speciality analysis

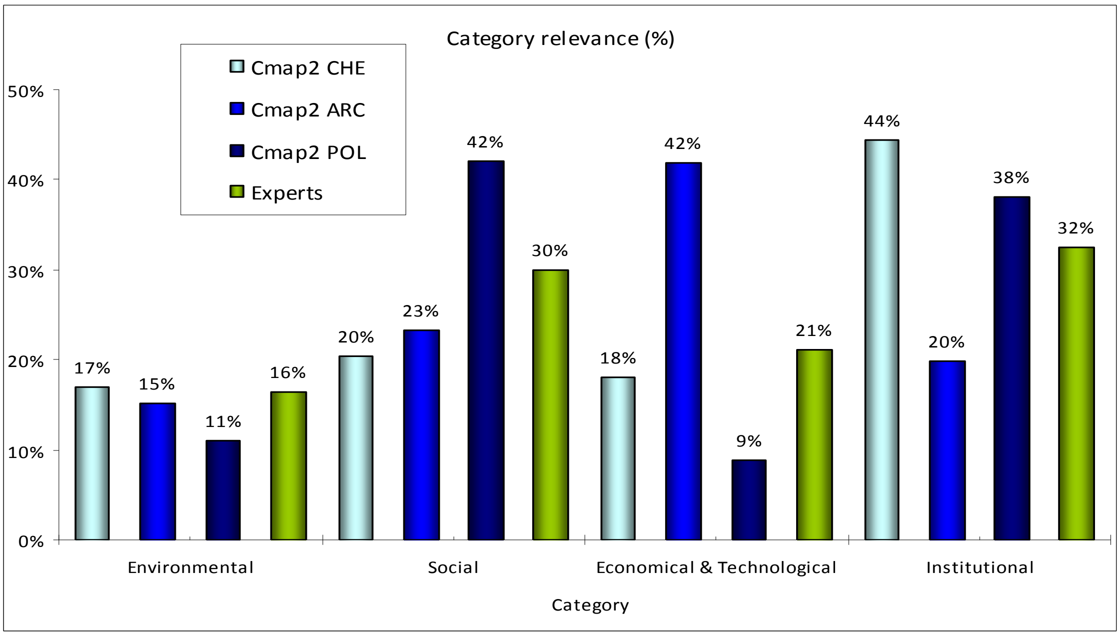

Figure 8.132 Case study UPC-4. $Cmap_2$: Category relevance index. 4 Categories. Speciality analysis

Complexity Index

	CHE	ARC	POL
Complexity index (CO)	12.9.7	12.7	24.9

Table 8.95 Case study UPC-4. $Cmap_2$: Complexity index. Speciality analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Chemistry students, in figure 8.133, before taking the course gave too much relevance to *Environment* and *Social impact*, the other categories have small values especially *Unbalances*. After the course this misunderstanding is partially rectified.

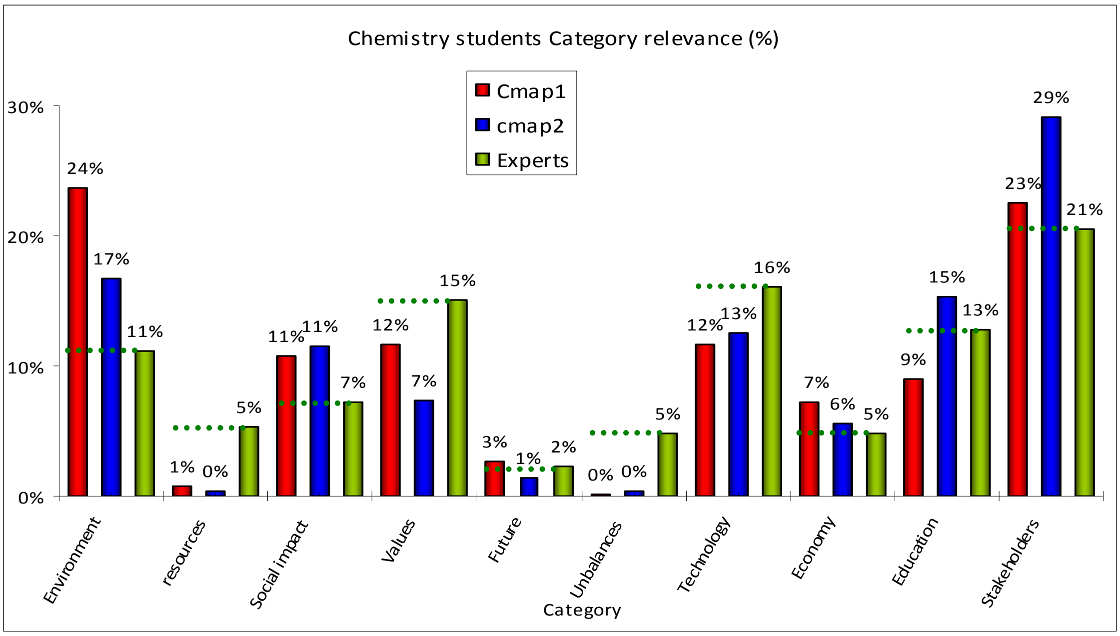

Figure 8.133 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Chemistry students

Architecture and Civil students, in figure 8.134, before taking the course gave too much relevance to *Environment*, *Resources* and *Future*; the other categories have small values except *Technology* and *Stakeholders*. After the course this misunderstanding is rectified in almost all categories except for *Technology* which increases twice and *Stakeholders* which decreases significantly.

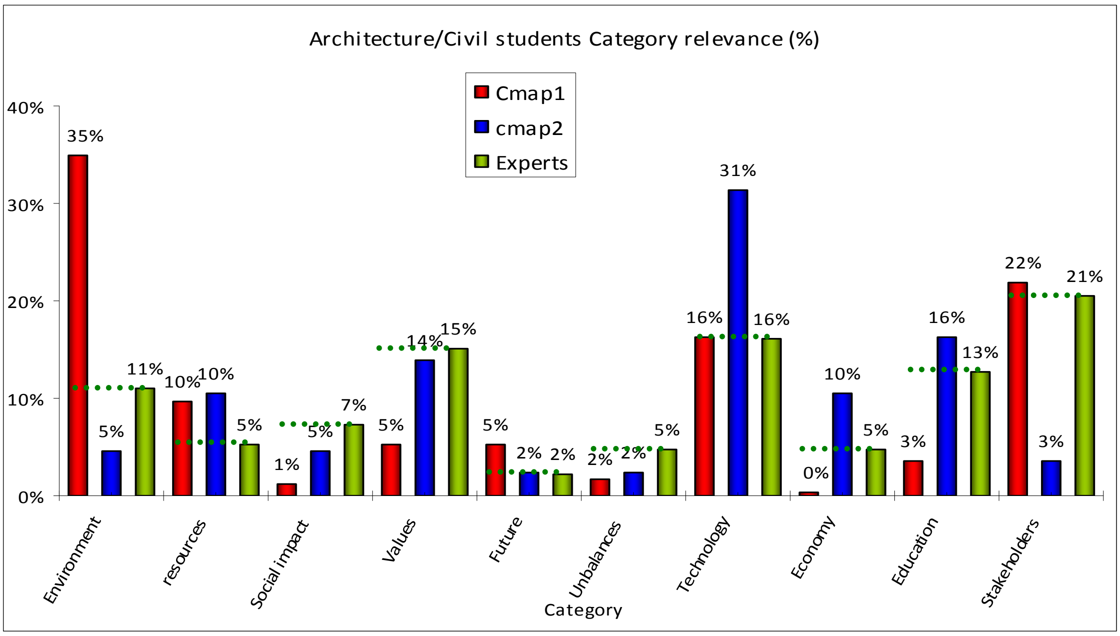

Figure 8.134 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Architecture and Civil students

SD Policies students, in figure 8.135, before taking the course gave too much relevance to *Environment*, *Stakeholders* and slightly to *Values* and *Resources*. SD Policies students are the first example that gives *Technology* so little value. (This could be because most of these students have a humanistic and social degree background). After the course this misunderstanding is rectified, although *Technology* keeps having too low a relevance and *Values* has a lot of relevance.

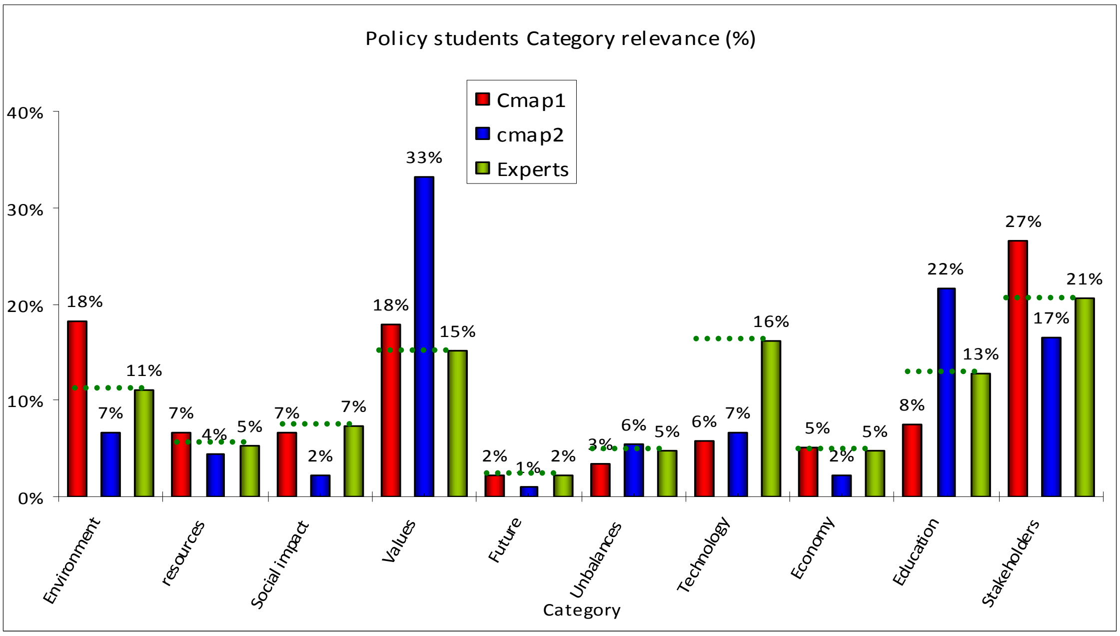

Figure 8.135 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis. Policy students

The analysis of the category relevance index under the four categories taxonomy, in figure 8.136, shows that before taking the course *Architecture* students give much more relevance to the *Environment* category, this high value is neutralised after the course, but most of its goes to the *Technology* category. It is important to highlight the importance that SD Policies students give to *Social* aspects, both before and after the course.

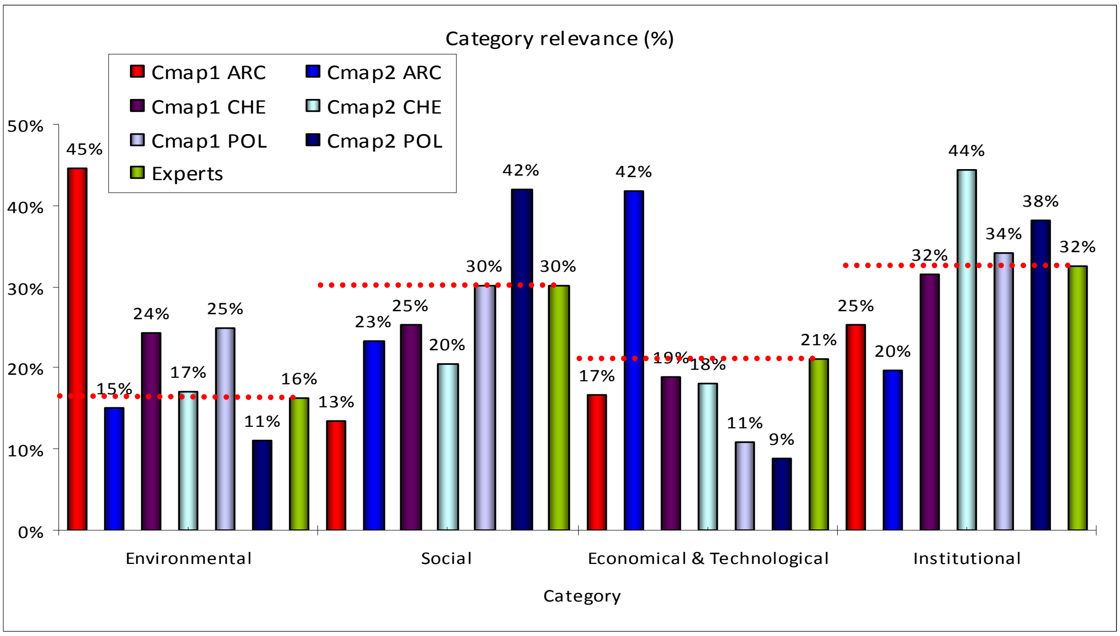

Figure 8.136 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Speciality analysis

In relation to the complexity index the results obtained in the two specialities, table 8.96 and figure 8.137 show that before taking the course student saw sustainability as a not very complex subject. After taking the course all groups increase their complexity index values. Chemistry students are the ones who see *Sustainability* more complex, both before and after taking the course.

	CHE		ARC		POL		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	29.4	29.7	12.6	12.7	13.6	24.9	24.8

Table 8.96 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

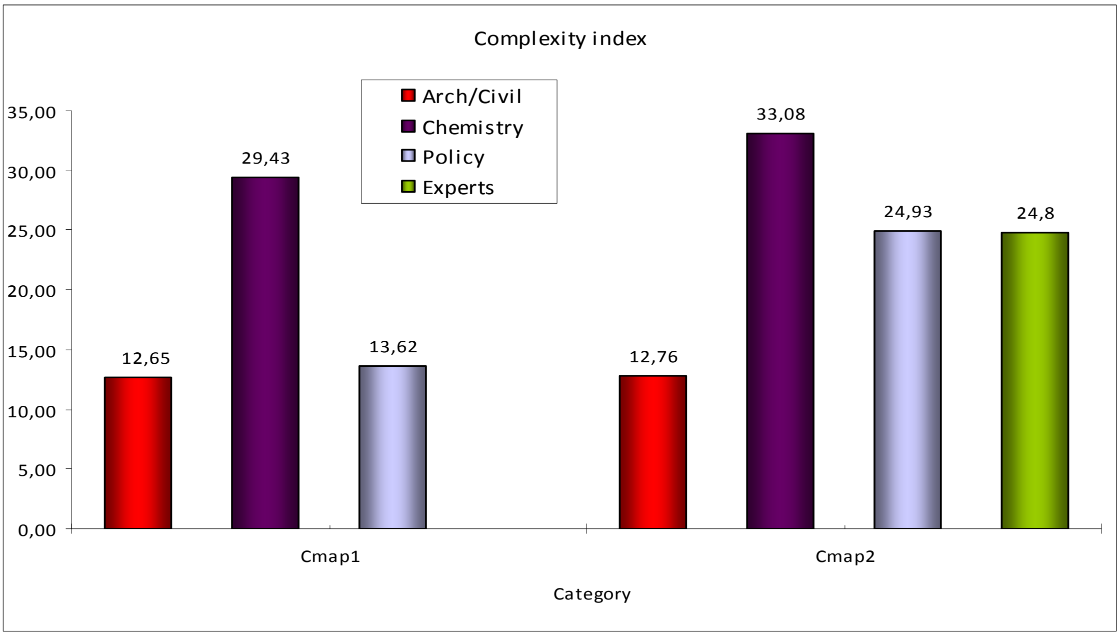

Figure 8.137 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Speciality analysis

8.9.4 Analysis of results

The speciality analysis of the three case studies show that there are no significant differences between Architecture/Civil, Chemistry, Industrial and ICT students, neither before or after taking the courses. One important comment is that SD Policies students from the UPC-4 case study give clearly more relevance to *Social* category than the students from other specialities. This specificity is attributed to the background of the SD Policy students which is basically related to Humanities and Social Sciences.

8.10 Students gender analysis

8.10.1 Gender analysis: Case study UPC-1

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	146	55
Number total of concepts	NC_{S1}	965	443
Number total of links inter-categories	NL_{S2}	192	64
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	6.61	8.05

Table 8.97 Case study UPC-1. Cmap$_1$: Variables value. Gender analysis

Therefore using the variables from table 8.97 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	37%	11%	4%	2%	0%	0%	40%	0%	2%	2%
Female	CR_i	43%	13%	4%	1%	0%	0%	32%	0%	2%	1%

Table 8.98 Case study UPC-1. Cmap$_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	0.87	0.94

Table 8.99 Case study UPC-1. Cmap$_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	171	56
Number total of concepts	NC_{S1}	3808	1351
Number total of links inter-categories	NL_{S2}	774	234
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	22.27	24.13

Table 8.100 Case study UPC-1. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.100 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	32%	11%	6%	2%	0%	2%	20%	5%	1%	16%
Female	CR_i	28%	11%	5%	4%	1%	3%	23%	5%	0%	16%

Table 8.101 Case study UPC-1. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	10.08	10.08

Table 8.102 Case study UPC-1. Cmap$_2$: Complexity index. Gender analysis.

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.138 shows that there's has been an improvement since the initial conceptual map. The results after taking the course are closer to the experts' ones. But there are no differences between male and female students.

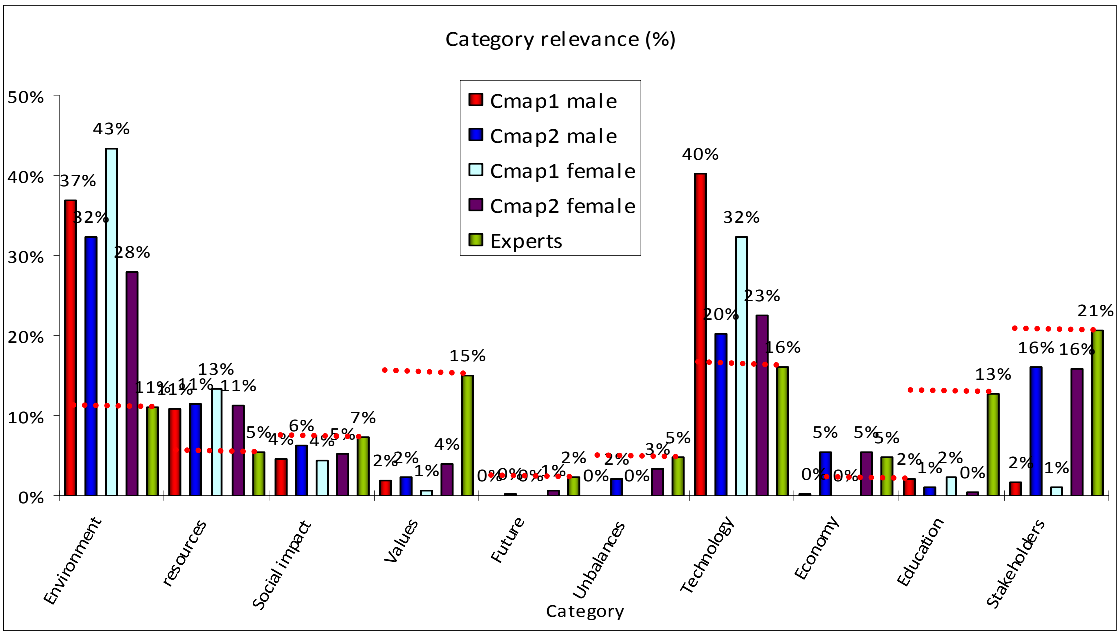

Figure 8.138 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.139, confirms the misunderstanding of both gender students, whiobefore taking the course gave too much value to *Environmental* and *Technological/Economic* category and too little to *Social* and *Institutional* ones. After the course this misunderstanding if partially rectified in both genders. There are no significant differences between the two genders.

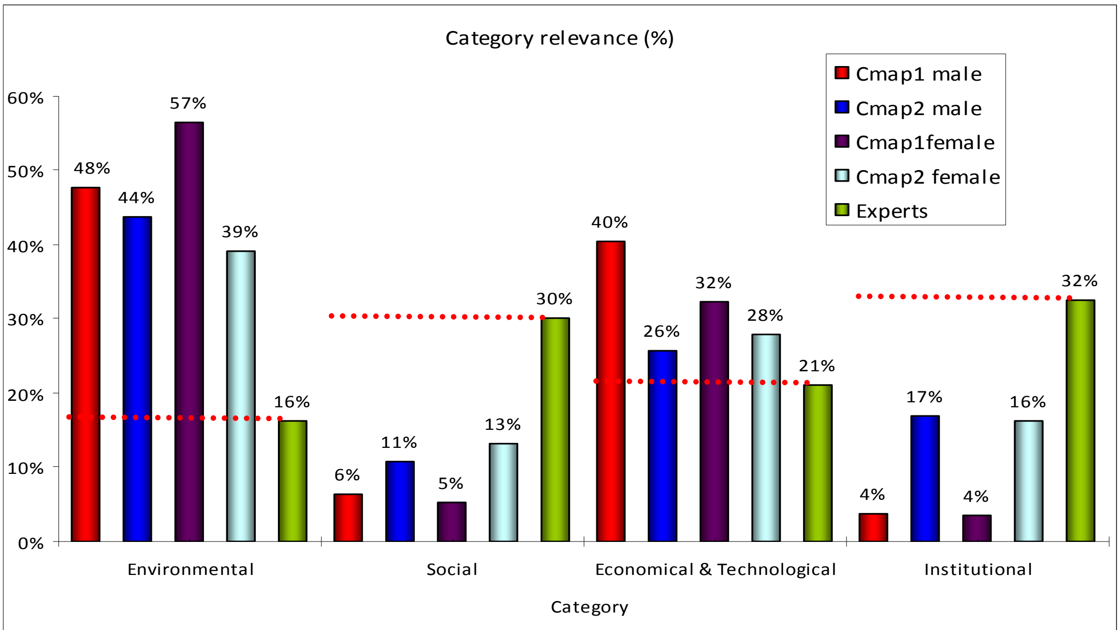

Figure 8.139 Case study UPC-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.103 and figure 8.140, the results obtained show the same values for both genders.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	0.87	10.08	0.94	10.08	24.8

Table 8.103 Case study UPC-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

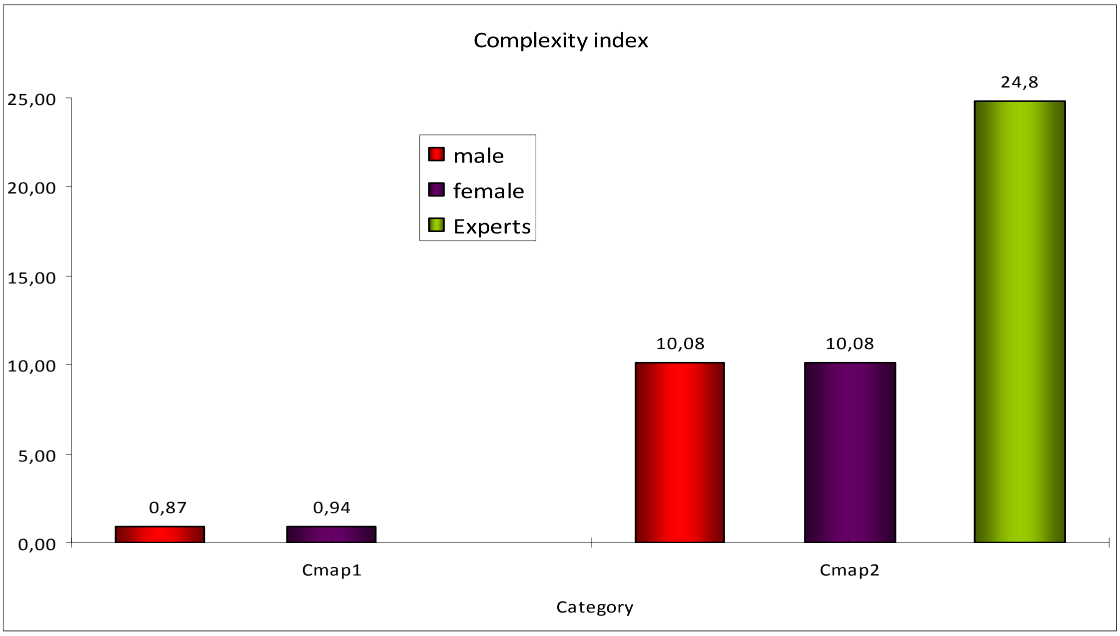

Figure 8.140 Case study UPC-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.2 Gender analysis: Case study UPC-2

$Cmap_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	30	5
Number total of concepts	NC_{S1}	255	40
Number total of links inter-categories	NL_{S2}	102	16
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	8.50	8.00

Table 8.104 Case study UPC-2. $Cmap_1$: Variables value. Gender analysis

Therefore using the variables from table 8.104 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	38%	20%	6%	0%	0%	0%	30%	1%	2%	2%
Female	CR_i	48%	11%	7%	0%	0%	0%	26%	0%	3%	2%

Table 8.105 Case study UPC-2. $Cmap_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	2.89	2.56

Table 8.106 Case study UPC-2. $Cmap_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	37	6
Number total of concepts	NC_{S1}	861	167
Number total of links inter-categories	NL_{S2}	186	34
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	23.17	27.83

Table 8.107 Case study UPC-2. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.107 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	35%	11%	7%	1%	0%	5%	14%	2%	2%	13%
Female	CR_i	27%	19%	7%	1%	1%	6%	12%	4%	2%	11%

Table 8.108 Case study UPC-2. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	11.70	15.77

Table 8.109 Case study UPC-2. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.141 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones. But there are no differences between male and female students.

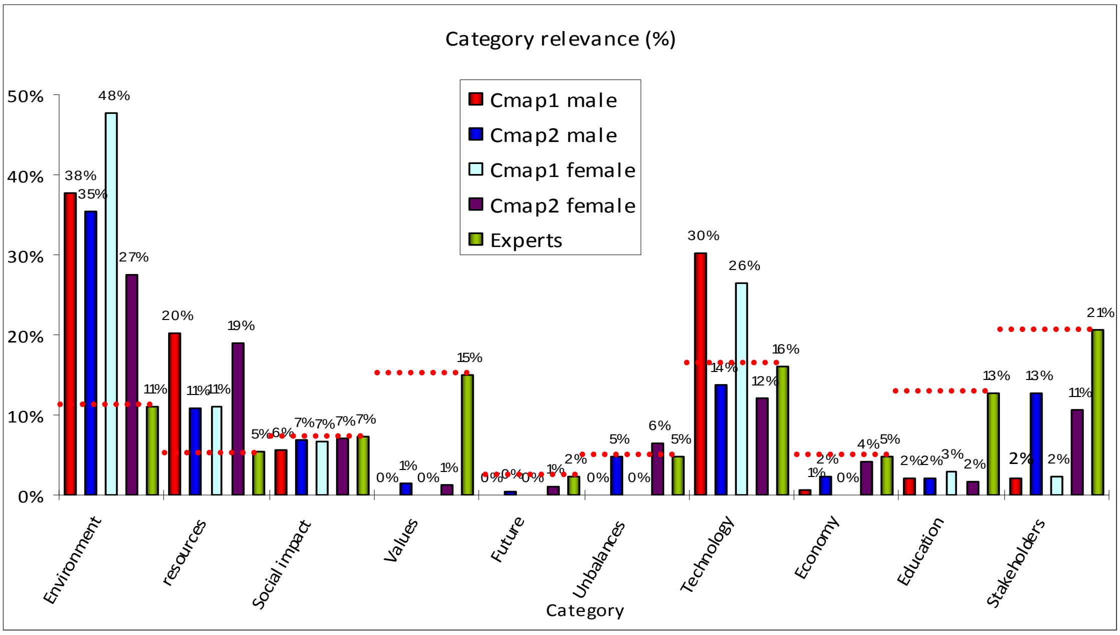

Figure 8.141 Case study UPC-2. Comparison of relevance index: Cmap$_1$-Cmap$_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.142, confirms the misunderstanding of both gender students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* categories and too little to the *Social* and *Institutional* ones. After the course this misunderstanding is partially rectified in both genders. There are no significant differences between the two genders.

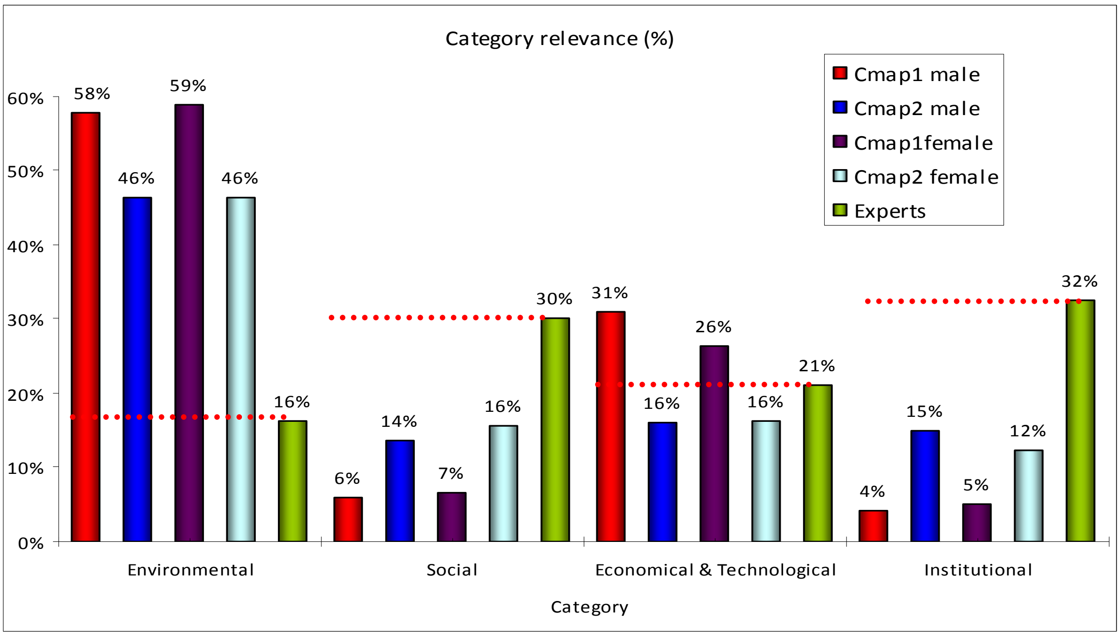

Figure 8.142 Case study UPC-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.110 and figure 8.143, the results obtained show the same values for both genders, although after taking the course female students see *Sustainability* a being more complex than male students.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	2.89	11.70	2.56	15.77	24.8

Table 8.110 Case study UPC-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

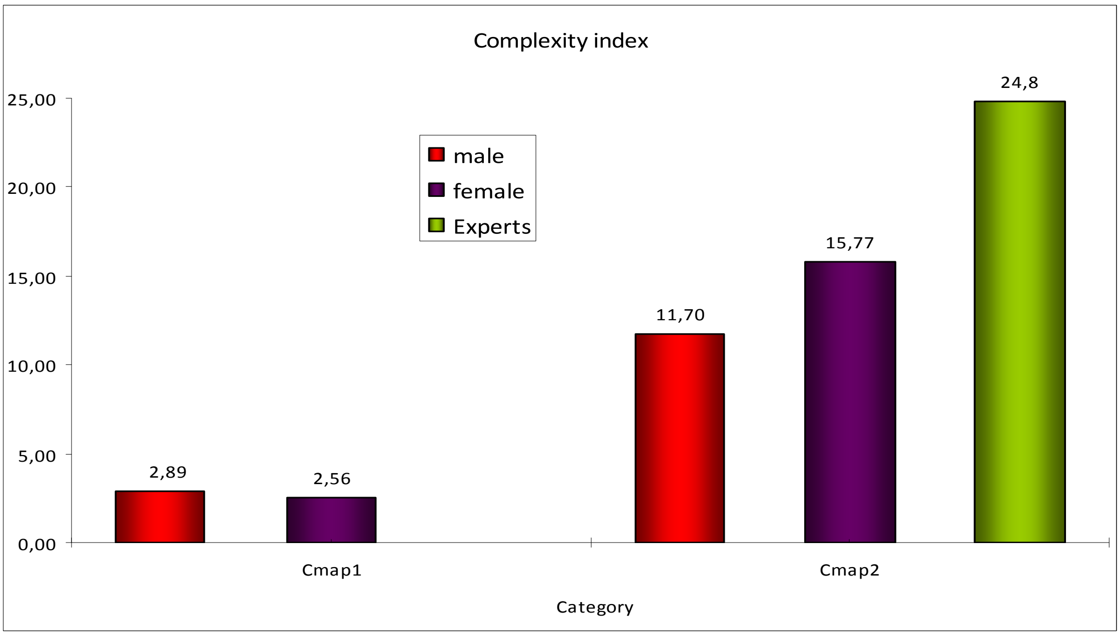

Figure 8.143 Case study UPC-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.3 Gender analysis: Case study UPC-3

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	24	6
Number total of concepts	NC_{S1}	305	79
Number total of links inter-categories	NL_{S2}	68	14
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	12.71	13.17

Table 8.111 Case study UPC-3. Cmap$_1$: Variables value. Gender analysis

Therefore using the variables from table 8.111 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	37%	12%	3%	0%	0%	0%	30%	1%	3%	6%
Female	CR_i	46%	6%	6%	0%	0%	1%	29%	0%	2%	3%

Table 8.112 Case study UPC-3. Cmap$_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	3.60	3.07

Table 8.113 Case study UPC-3. Cmap$_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	20	11
Number total of concepts	NC_{S1}	550	308
Number total of links inter-categories	NL_{S2}	142	68
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	27.50	28.00

Table 8.114 Case study UPC-3. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from the previous table the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	22%	11%	4%	1%	0%	1%	17%	4%	8%	31%
Female	CR_i	32%	14%	4%	1%	0%	1%	21%	9%	2%	17%

Table 8.115 Case study UPC-3. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	19.53	17.31

Table 8.116 Case study UPC-3. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.144 shows that there's has been an improvement since the initial conceptual map. The results after taking the course are closer to the experts' ones. But there are no important differences between male and female students.

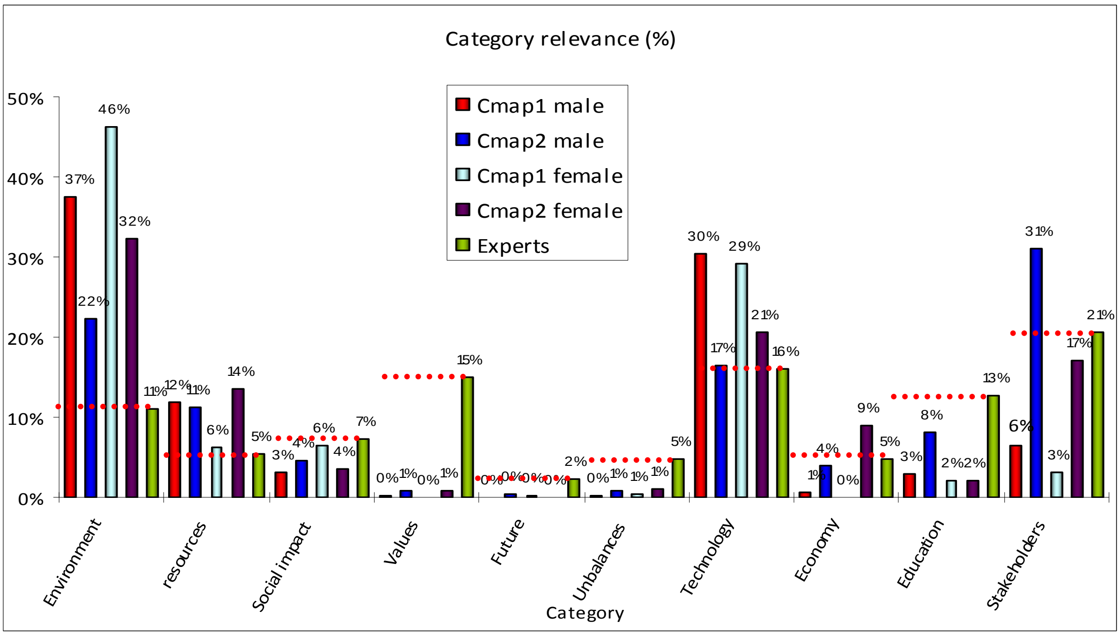

Figure 8.144 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, next figure, confirms the misunderstanding of both gender students, who before taking the course gave too much value to *Environmental* and *Technological/Economic* category and too little to *Social* and *Institutional* ones. After the course this misunderstanding if partially rectified in both genders. There are no significant differences between the two genders despite the fact that male students give twice the value to the *Institutional* category than female ones.

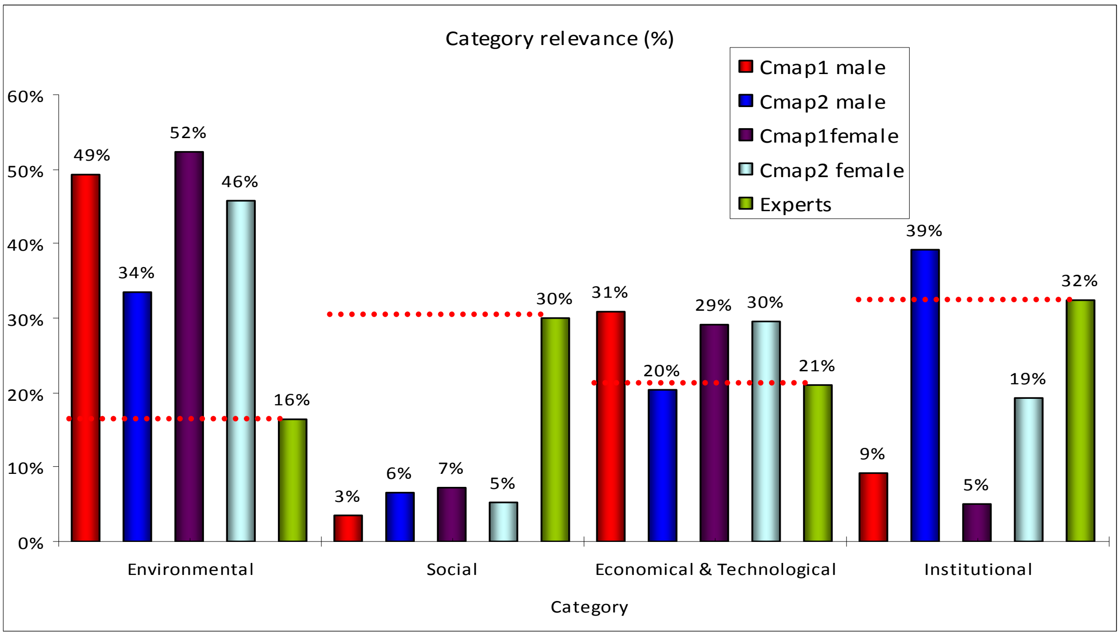

Figure 8.145 Case study UPC-3. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.117 and figure 8.146, the results obtained show the same values for both genders.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	3.60	19.53	3.07	17.31	24.8

Table 8.117 Case study UPC-3. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

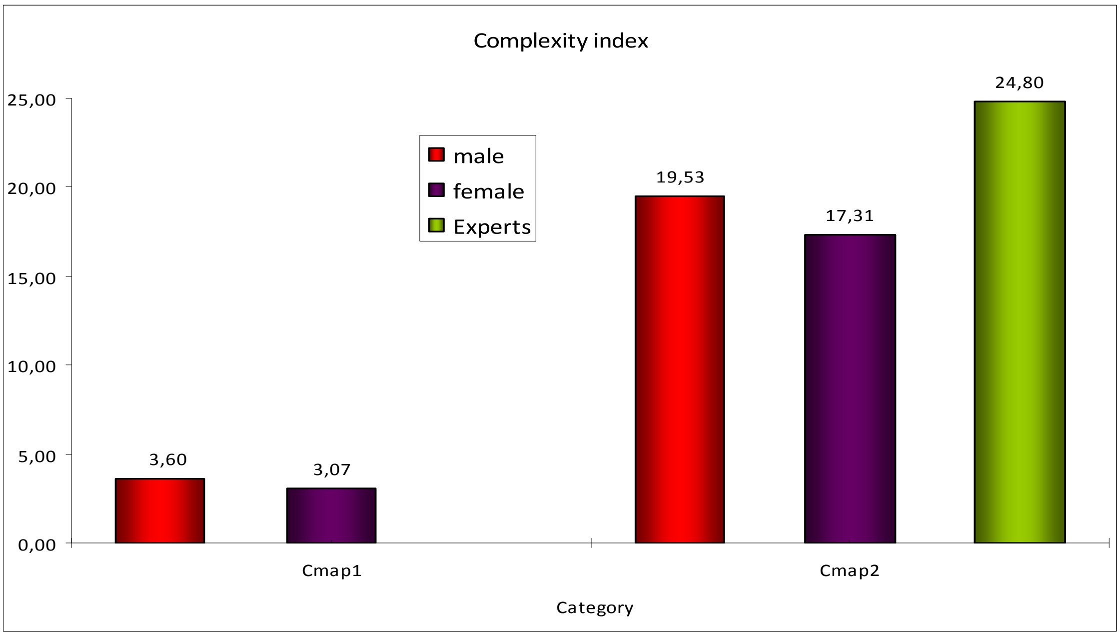

Figure 8.146 Case study UPC-3. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.4 Gender analysis: Case study UPC-4

Cmap₁: Before taking the course

Variable		Male	Female
Number of students	*NS*	9	10
Number total of concepts	NC_{S1}	221	151
Number total of links inter-categories	NL_{S2}	119	78
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	24.56	15.10

Table 8.118 Case study UPC-4. $Cmap_1$: Variables value. Gender analysis

Therefore using the variables from table 8.118 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	24%	6%	8%	14%	3%	2%	11%	4%	5%	23%
Female	CR_i	34%	2%	4%	8%	3%	1%	13%	5%	8%	23%

Table 8.119 Case study UPC-4. $Cmap_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	32.47	11.78

Table 8.120 Case study UPC-4. $Cmap_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	10	9
Number total of concepts	NC_{S1}	209	97
Number total of links inter-categories	NL_{S2}	127	57
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	20.90	10.78

Table 8.121 Case study UPC-4. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.121 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	16%	5%	7%	19%	2%	2%	21%	4%	11%	13%
Female	CR_i	7%	5%	2%	18%	1%	3%	23%	8%	19%	14%

Table 8.122 Case study UPC-4. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	26.54	6.83

Table 8.123 Case study UPC-4. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.147 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones. But there are no differences between male and female students.

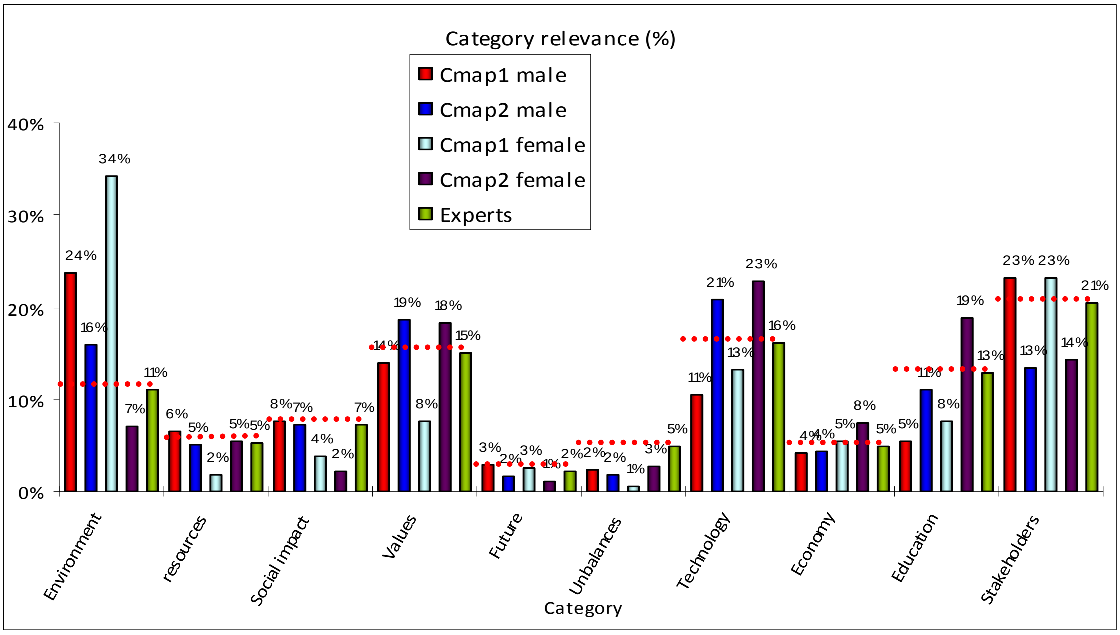

Figure 8.147 Case study UPC-4. Comparison of relevance index: Cmap$_1$-Cmap$_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.148, confirms the misunderstanding of both gender students, who before taking the course gave too much value to *Environmental*. After the course this misunderstanding if rectified in both genders. There are no significant differences between the two genders.

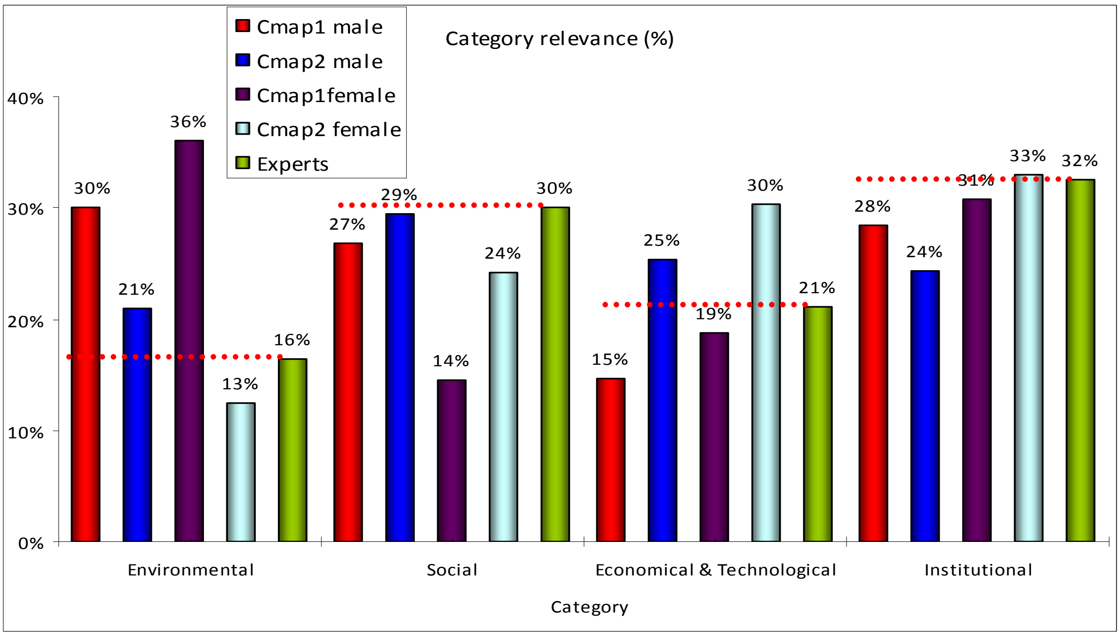

Figure 8.148 Case study UPC-4. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.124 and figure 8.149, the results obtained show that male students see *Sustainability* as being much more complex than female ones. It is also interesting to see that in both cases the complexity index decreases after the course.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	32.47	26.54	11.78	6.83	24.8

Table 8.124 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

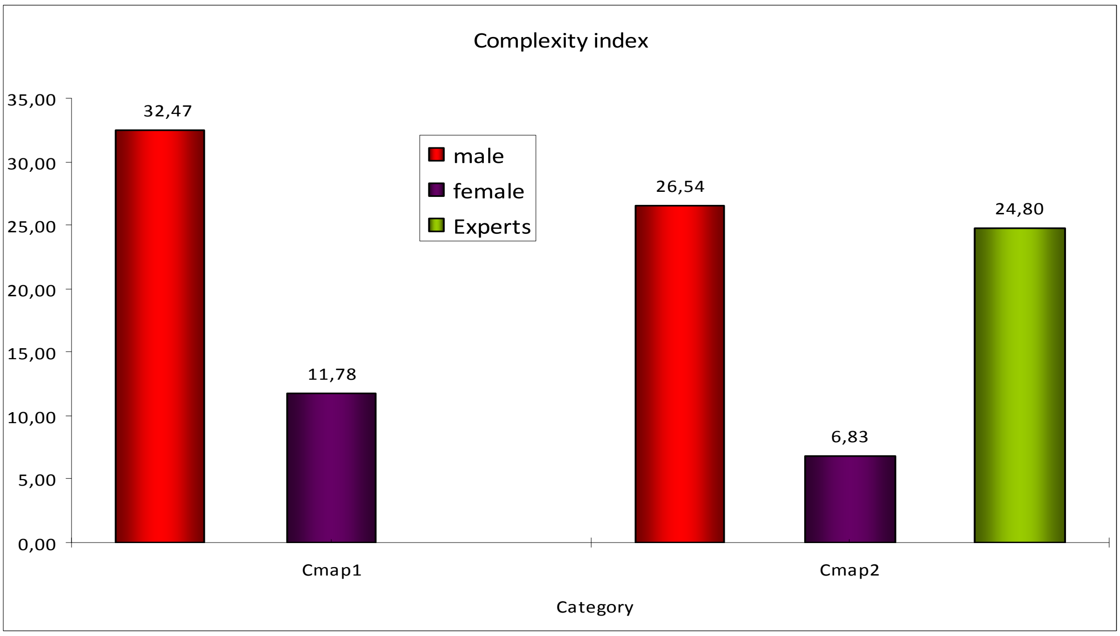

Figure 8.149 Case study UPC-4. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.5 Gender analysis: Case study DUT-1

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	27	4
Number total of concepts	NC_{S1}	209	22
Number total of links inter-categories	NL_{S2}	8	3
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	7.74	5.50

Table 8.125 Case study DUT-1. Cmap$_1$: Variables value. Gender analysis

Therefore using the variables from table 8.125 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	11%	11%	0%	0%	2%	0%	68%	1%	0%	0%
Female	CR_i	15%	22%	1%	0%	0%	0%	60%	1%	0%	0%

Table 8.126 Case study DUT-1. Cmap$_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	0.23	0.41

Table 8.127 Case study DUT-1. Cmap$_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	23	2
Number total of concepts	NC_{S1}	219	24
Number total of links inter-categories	NL_{S2}	63	13
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.52	12

Table 8.128 Case study DUT-1. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.128 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	19%	9%	11%	0%	0%	0%	35%	6%	3%	8%
Female	CR_i	18%	32%	9%	0%	0%	0%	5%	9%	9%	14%

Table 8.129 Case study DUT-1. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	2.61	7.80

Table 8.130 Case study DUT-1. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.150 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones. But there are no differences between male and female students. There are some "strange" values at Cmap2 from female students, but this could be because the sample was too small with only 2 female students.

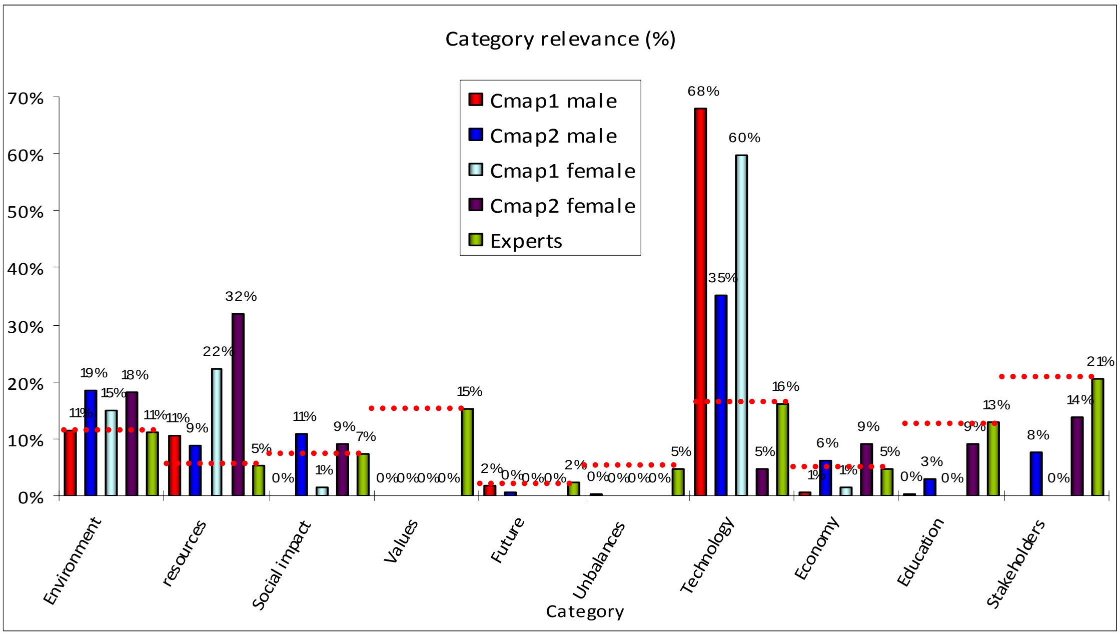

Figure 8.150 Case study DUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.151, confirms the misunderstanding of both gender students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* categories and too little to the *Social* and *Institutional* ones. After the course this misunderstanding if partially rectified in both genders. There are no significant differences between the two genders.

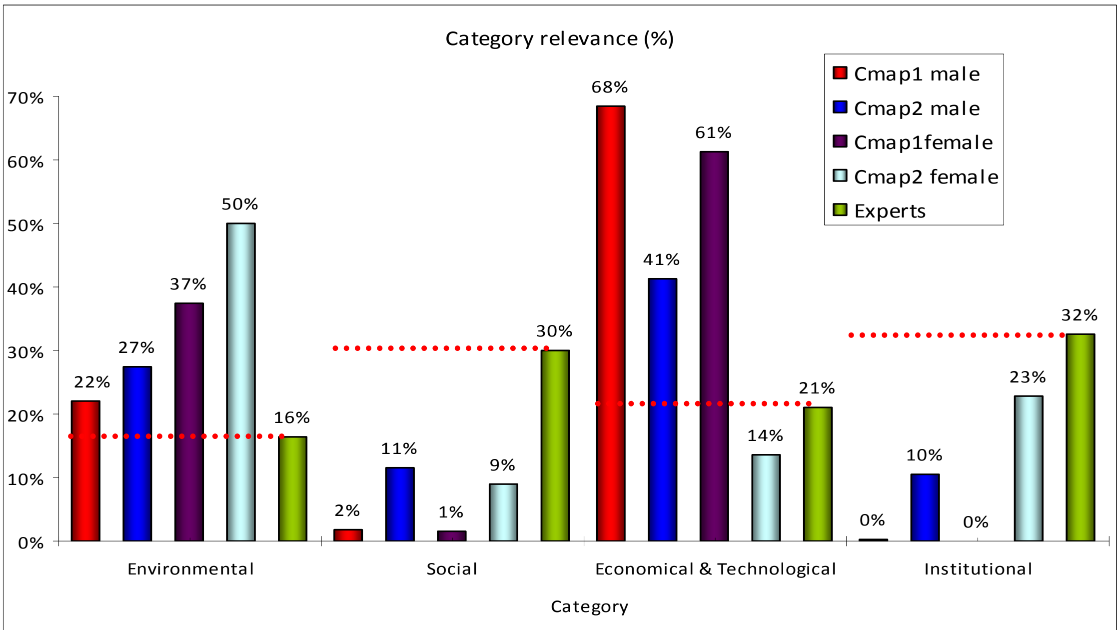

Figure 8.151 Case study DUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.131 and figure 8.152, the results obtained before show the same values for both genders, although after taking the course female students see *Sustainability* as more complex than male students.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	0.23	0.41	2.61	7.80	24.8

Table 8.131 Case study DUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

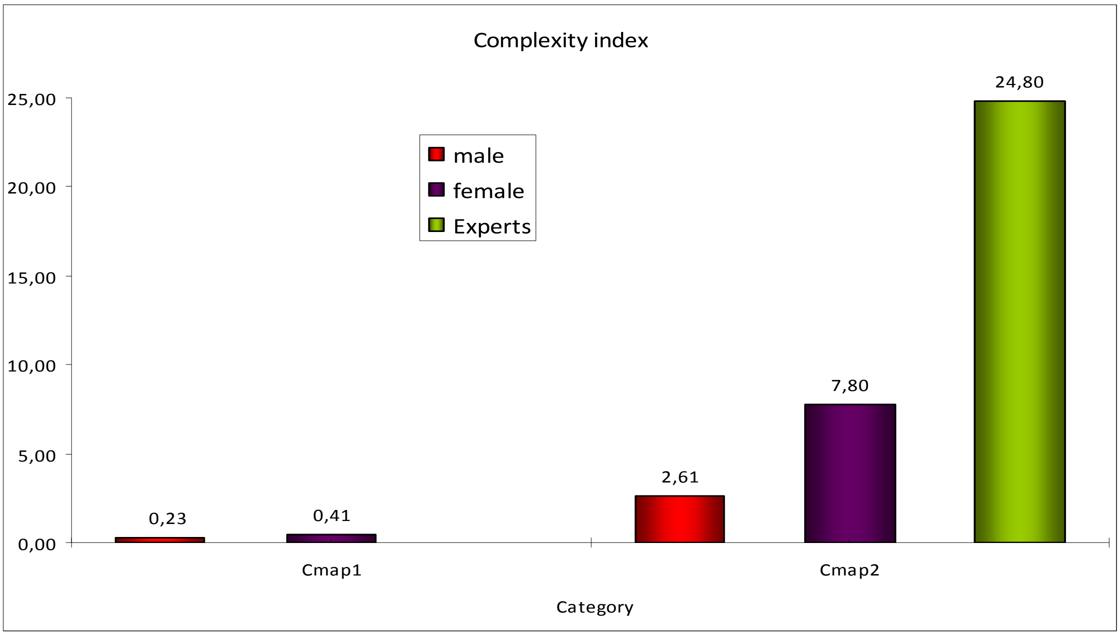

Figure 8.152 Case study DUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.6 Gender analysis: Case study CUT-1

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	30	20
Number total of concepts	NC_{S1}	450	280
Number total of links inter-categories	NL_{S2}	206	207
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	15.00	14.00

Table 8.132 Case study CUT-1. $Cmap_1$: Variables value. Gender analysis

Therefore using the variables from table 8.132 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	37%	8%	4%	0%	1%	0%	42%	2%	1%	4%
Female	CR_i	27%	6%	12%	1%	1%	1%	45%	2%	1%	4%

Table 8.133 Case study CUT-1. $Cmap_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	10.30	14.49

Table 8.134 Case study CUT-1. $Cmap_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	29	23
Number total of concepts	NC_{S1}	488	410
Number total of links inter-categories	NL_{S2}	310	267
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	16.83	17.83

Table 8.135 Case study CUT-1. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.135 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	25%	10%	4%	4%	1%	4%	31%	5%	7%	9%
Female	CR_i	28%	9%	7%	2%	0%	7%	22%	7%	6%	11%

Table 8.136 Case study CUT-1. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	17.99	20.69

Table 8.137 Case study CUT-1. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.153 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones. But there are no differences between male and female students.

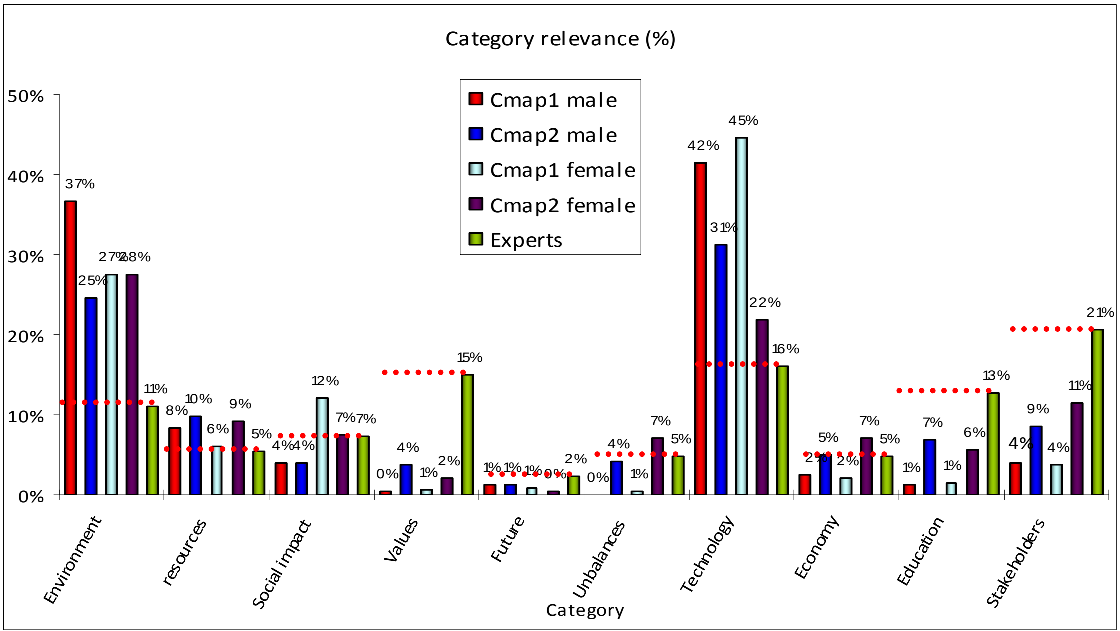

Figure 8.153 Case study CUT-1. Comparison of relevance index: Cmap$_1$-Cmap$_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.154, confirms the misunderstanding of both gender students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* categories and too little to the *Social* and *Institutional* ones. After the course this misunderstanding if partially rectified in both genders. There are no significant differences between the two genders.

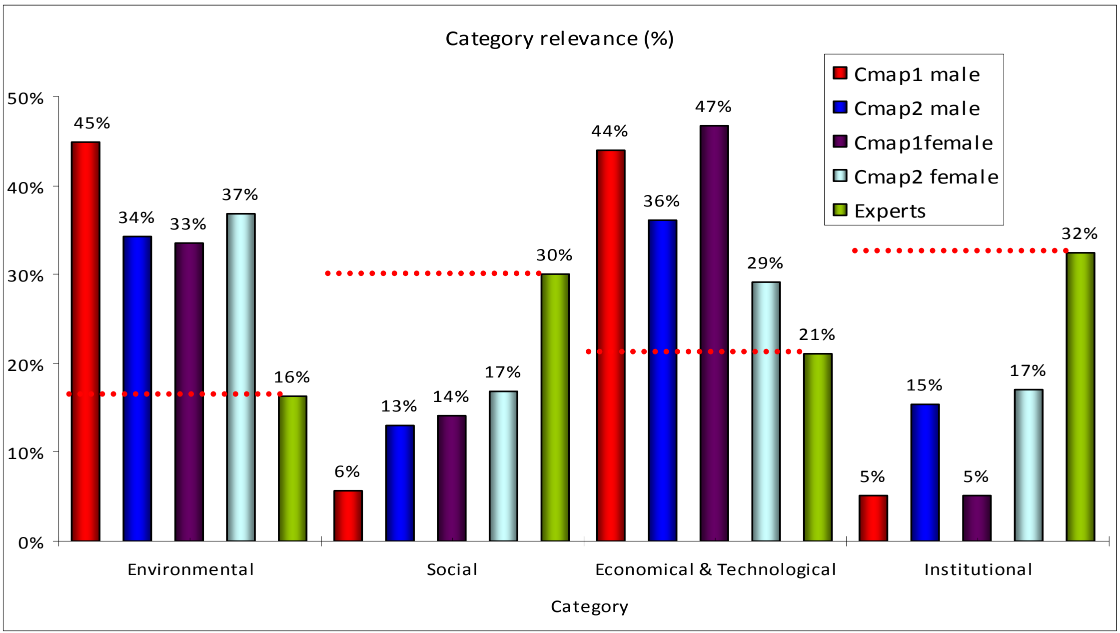

Figure 8.154 Case study CUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.138 and figure 8.155, the results obtained show almost the same values for both genders, female students having slithly higher values.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	10.30	14.49	17.99	20.69	24.8

Table 8.138 Case study CUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

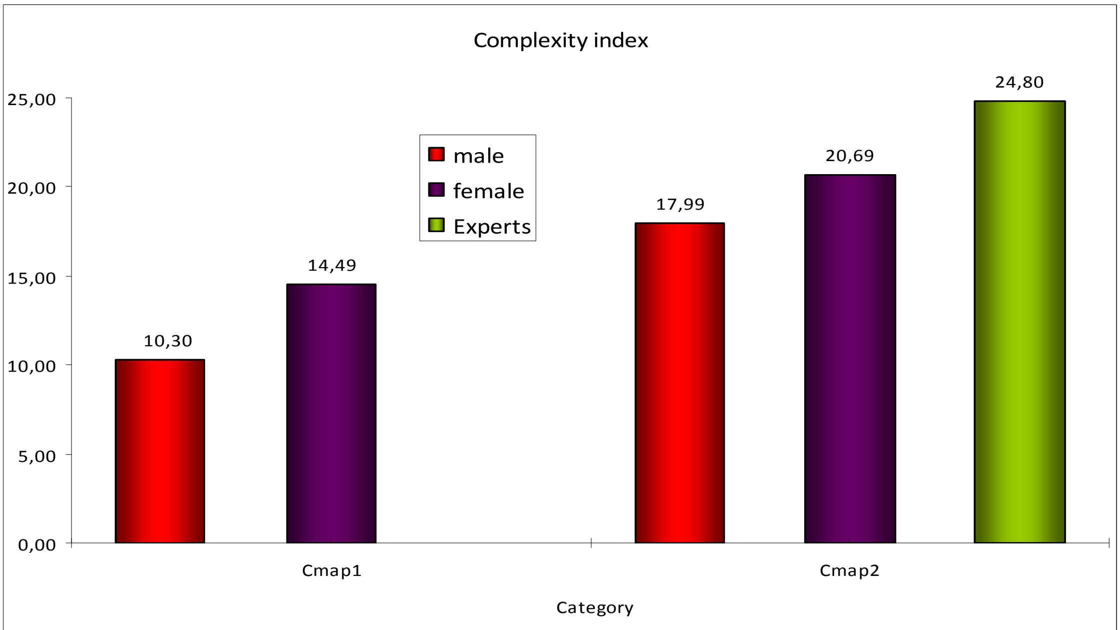

Figure 8.155 Case study CUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.7 Gender analysis: Case study KPI-1

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	19	17
Number total of concepts	NC_{S1}	185	118
Number total of links inter-categories	NL_{S2}	50	31
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.74	6.94

Table 8.139 Case study KPI-1. Cmap$_1$: Variables value. Gender analysis

Therefore using the variables from table 8.139 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	16%	2%	20%	0%	0%	0%	23%	12%	11%	8%
Female	CR_i	15%	1%	10%	0%	0%	1%	36%	11%	17%	3%

Table 8.140 Case study KPI-1. Cmap$_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	2.56	1.27

Table 8.141 Case study KPI-1. Cmap$_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	12	11
Number total of concepts	NC_{S1}	197	164
Number total of links inter-categories	NL_{S2}	90	83
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	16.42	14.91

Table 8.142 Case study KPI-1. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.142 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	20%	3%	8%	1%	0%	0%	40%	9%	9%	10%
Female	CR_i	14%	3%	12%	0%	0%	0%	36%	10%	10%	13%

Table 8.143 Case study KPI-1. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	12.31	11.25

Table 8.144 Case study KPI-1. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.156 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones. But there are no differences between male and female students.

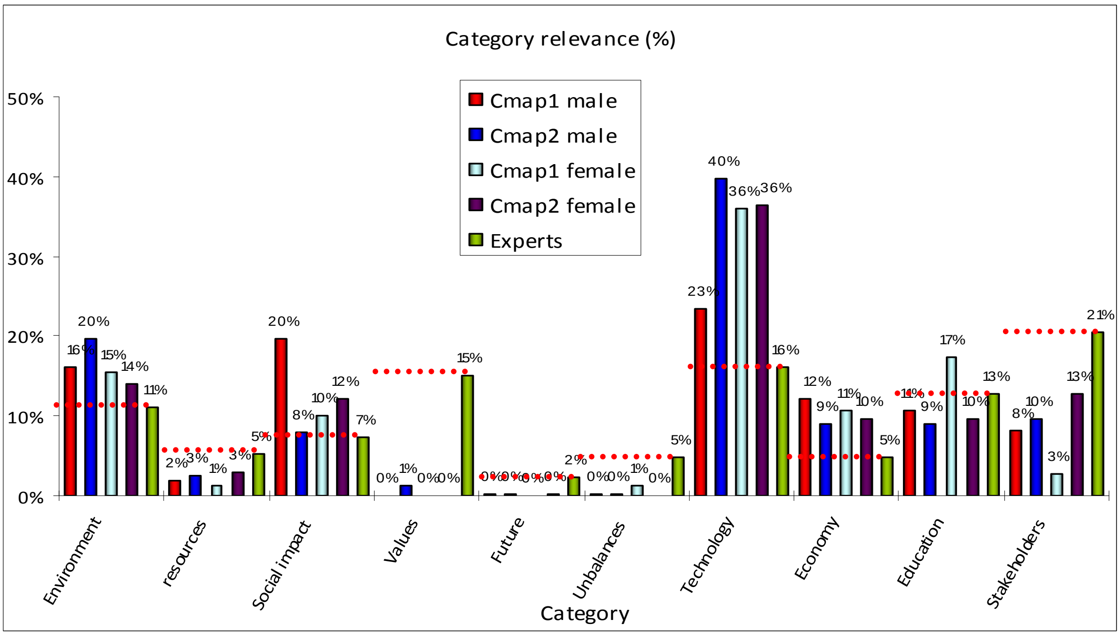

Figure 8.156 Case study KPI-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.157, confirms the misunderstanding of both gender students, who before taking the course gave too much value to the *Technological/Economic* category and too little to the *Social* and *Institutional* ones. After the course this misunderstanding does not improve in any gender. There are no significant differences between the two genders.

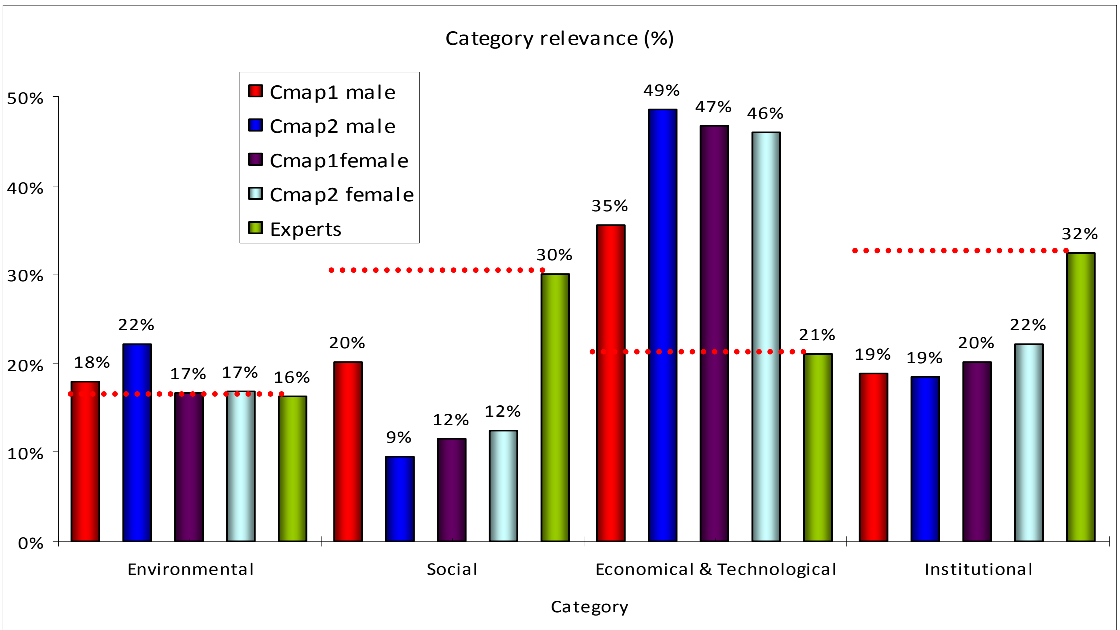

Figure 8.157 Case study KPI-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.145 and figure 8.158, the results obtained show approximately the same values for both genders.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	2.56	12.31	1.27	11.25	24.8

Table 8.145 Case study KPI-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

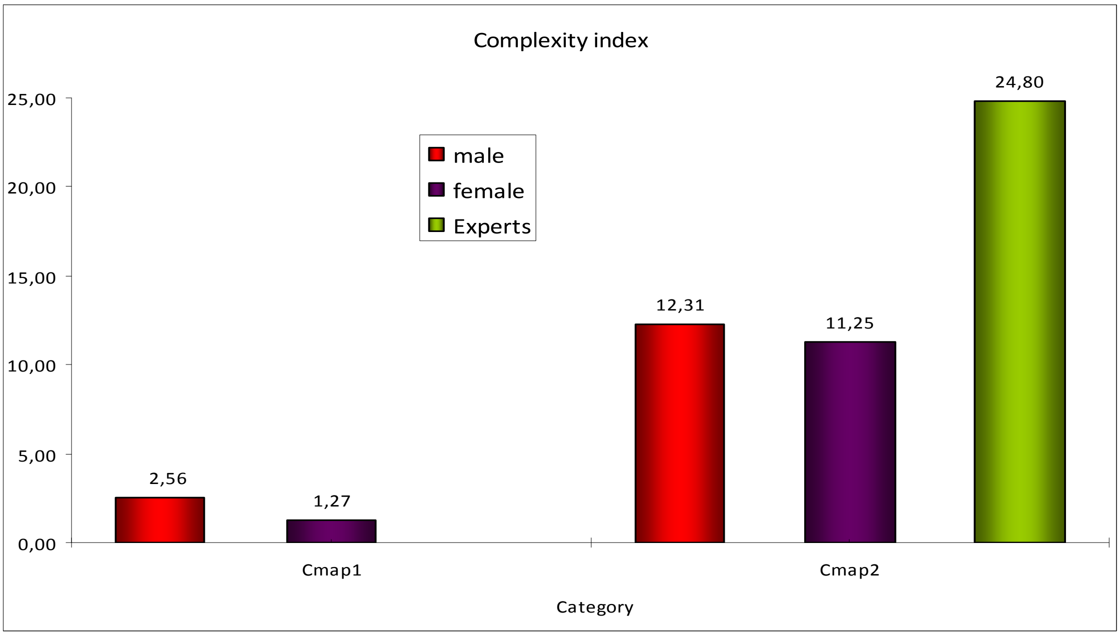

Figure 8.158 Case study KPI-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.8 Gender analysis: Case study EUT-1

<u>$Cmap_1$: Before taking the course</u>

Variable		Male	Female
Number of students	*NS*	5	5
Number total of concepts	NC_{S1}	53	43
Number total of links inter-categories	NL_{S2}	15	4
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	10.60	8.60

Table 8.146 Case study EUT-1. $Cmap_1$: Variables value. Gender analysis

Therefore using the variables from table 8.146 the indexes' values are:

<u>Category relevance index</u>

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	6%	15%	1%	0%	8%	0%	68%	0%	1%	2%
Female	CR_i	29%	1%	5%	0%	6%	0%	42%	5%	2%	8%

Table 8.147 Case study EUT-1. $Cmap_1$: Category relevance variables. Gender analysis

<u>Complexity Index</u>

	Male	Female
Complexity index (CO)	3.18	0.69

Table 8.148 Case study EUT-1. $Cmap_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	21	7
Number total of concepts	NC_{S1}	205	45
Number total of links inter-categories	NL_{S2}	38	14
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	9.76	6.43

Table 8.149 Case study EUT-1. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.149 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	15%	11%	1%	3%	1%	0%	60%	2%	1%	6%
Female	CR_i	4%	4%	0%	0%	3%	0%	73%	2%	2%	11%

Table 8.150 Case study EUT-1. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	1.77	1.29

Table 8.151 Case study EUT-1. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.159 shows that there's has been an improvement from the initial conceptual map, the results after taking the course are closer to the experts' ones except for female students who even increase the difference comparedwith the experts in the *Technology* category. But there are no major differences between male and female students.

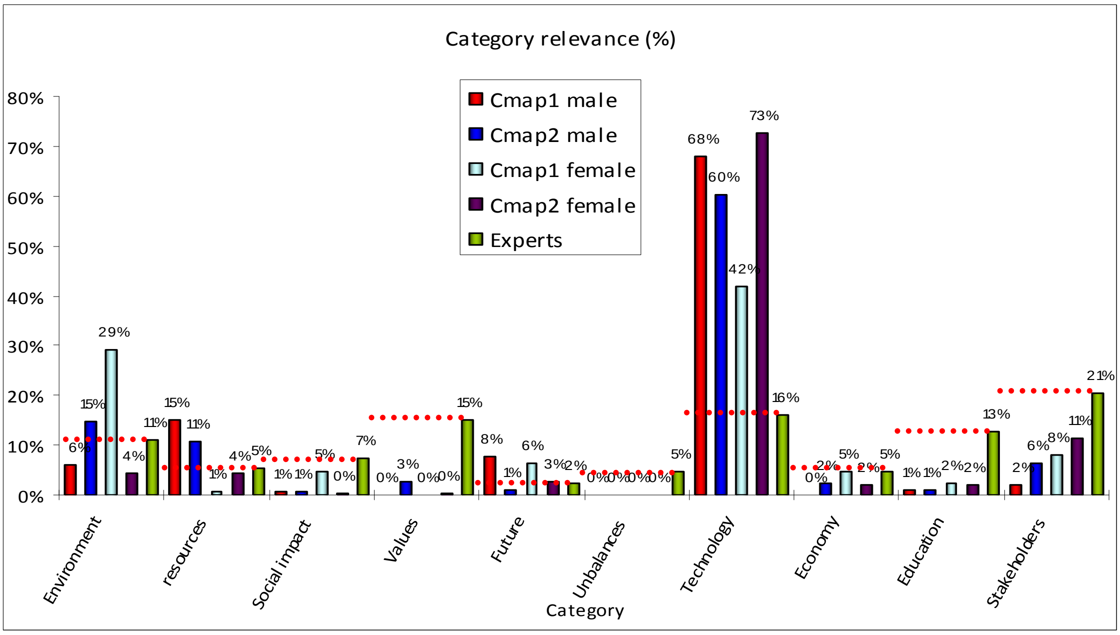

Figure 8.159 Case study EUT-1. Comparison of relevance index: Cmap$_1$-Cmap$_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.160, confirms the misunderstanding of both gender students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* category and too little to the *Social* and *Institutional* ones. After the course this misunderstanding is partially rectified in both genders except for female students who even increase the difference compared with the experts in the *Technological/Economic* category. There are no significant differences between the two genders.

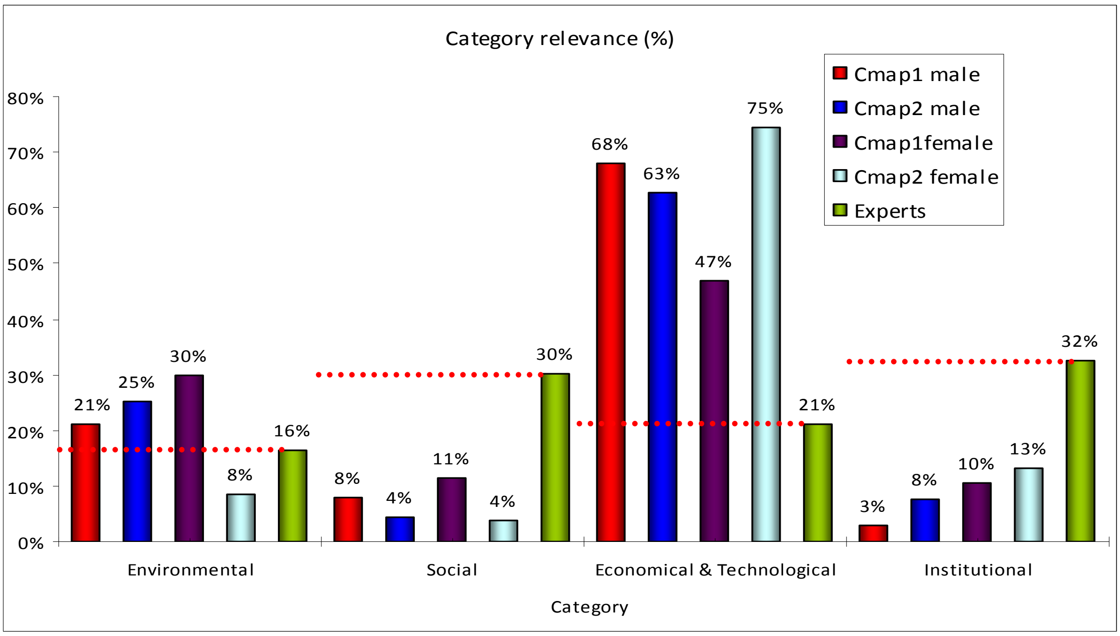

Figure 8.160 Case study EUT-1. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.152 and figure 8.161, the results obtained show similar values for both genders, although after taking the course male students see *Sustainability* as less complex than before taking it.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	3.18	1.77	0.69	1.29	24.8

Table 8.152 Case study EUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

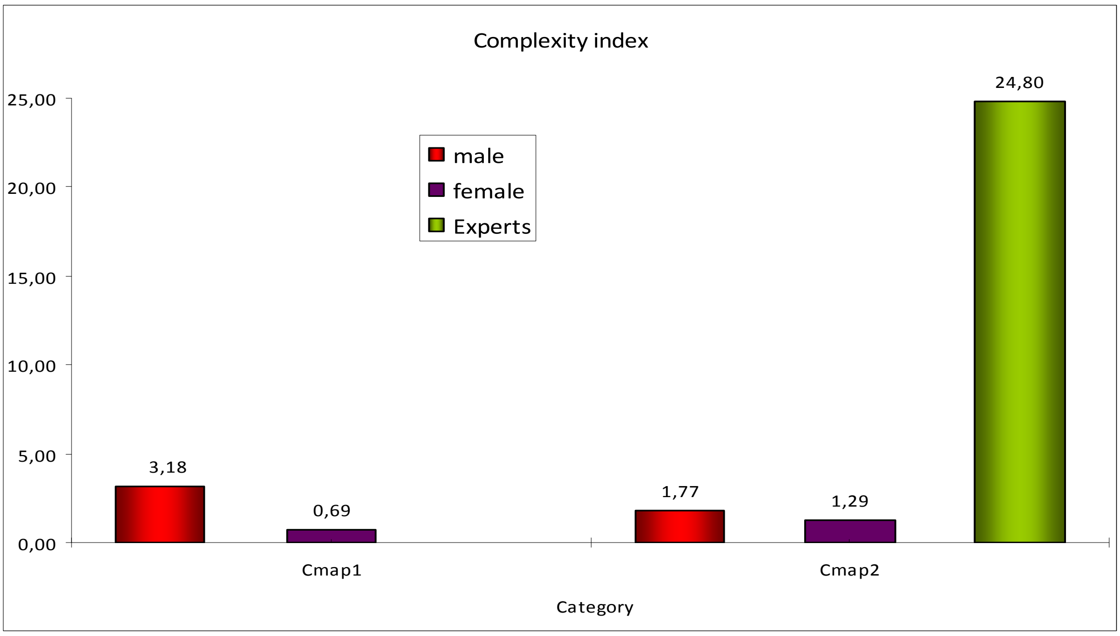

Figure 8.161 Case study EUT-1. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.9 Gender analysis: Case study EUT-2

Cmap$_1$: Before taking the course

Variable		Male	Female
Number of students	*NS*	52	8
Number total of concepts	NC_{S1}	332	51
Number total of links inter-categories	NL_{S2}	42	2
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	6.38	6.38

Table 8.153 Case study EUT-2. Cmap$_1$: Variables value. Gender analysis

Therefore using the variables from table 8.153 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	9%	11%	0%	0%	0%	0%	75%	0%	0%	4%
Female	CR_i	11%	1%	0%	0%	1%	0%	85%	0%	1%	1%

Table 8.154 Case study EUT-2. Cmap$_1$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	0.52	0.16

Table 8.155 Case study EUT-2. Cmap$_1$: Complexity index. Gender analysis

Cmap$_2$: After taking the course

Variable		Male	Female
Number of students	*NS*	17	1
Number total of concepts	NC_{S1}	204	17
Number total of links inter-categories	NL_{S2}	49	3
Number of concepts per students (Eq. 7.1)	$\overline{NC}$	12.00	17

Table 8.156 Case study EUT-2. Cmap$_2$: Variables value. Gender analysis

Therefore using the variables from table 8.156 the indexes' values are:

Category relevance index

Category		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Male	CR_i	20%	9%	0%	0%	4%	0%	50%	1%	0%	9%
Female	CR_i	18%	24%	0%	6%	6%	12%	6%	12%	0%	6%

Table 8.157 Case study EUT-2. Cmap$_2$: Category relevance variables. Gender analysis

Complexity Index

	Male	Female
Complexity index (CO)	3.46	5.10

Table 8.158 Case study EUT-2. Cmap$_2$: Complexity index. Gender analysis

Comparison between Cmap1, Cmap2 and Experts Cmap.

Figure 8.162 shows that there's has been an improvement since the initial conceptual map, the results after taking the course are closer to the experts' ones except for E*nvironment* category. There are no major differences between male and female students.

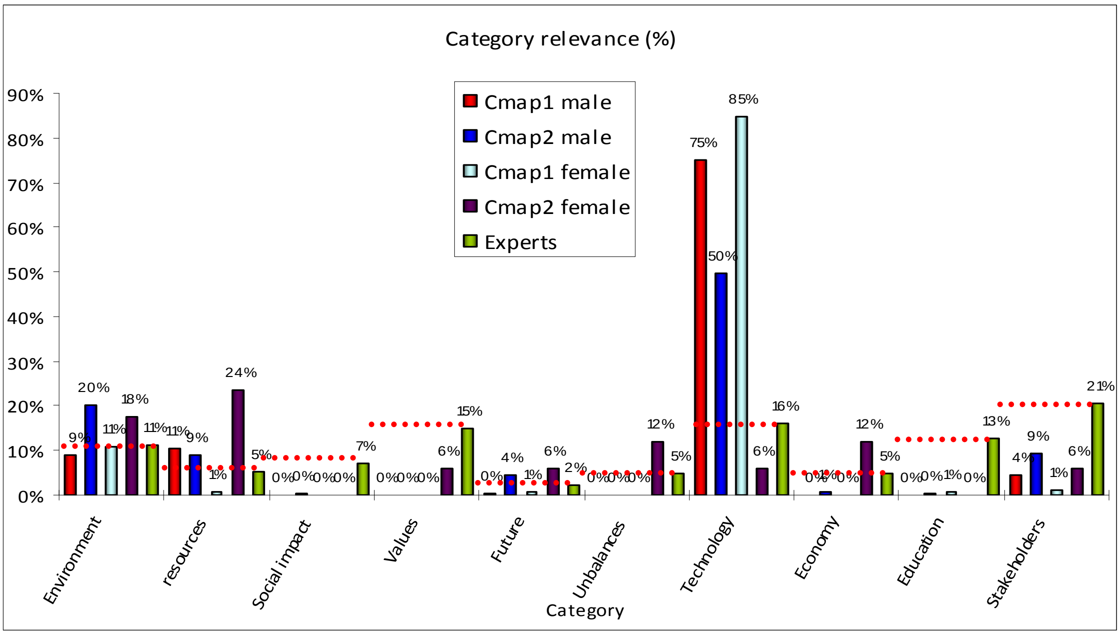

Figure 8.162 Case study EUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

The analysis of the category relevance index under the four categories taxonomy, in figure 8.163, confirms the misunderstanding for both gender students, who before taking the course gave too much value to the *Environmental* and *Technological/Economic* categories and too little to the *Social* and *Institutional* ones. After the course this misunderstanding if partially rectified in both genders except in the *Environmental* category. There are no significant differences between the two genders.

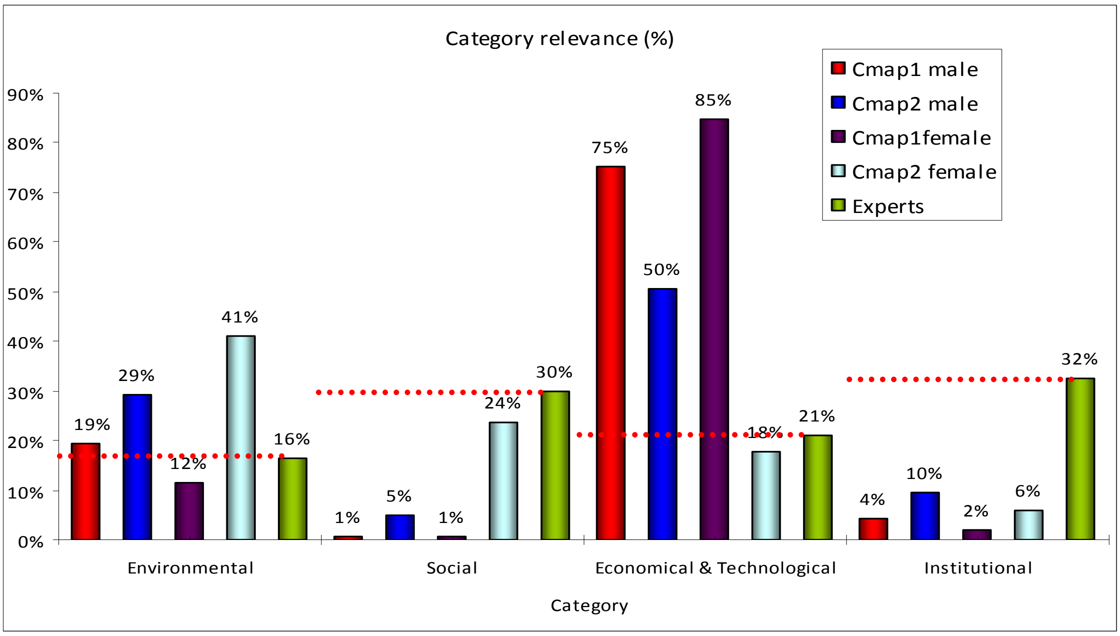

Figure 8.163 Case study EUT-2. Comparison of relevance index: $Cmap_1$-$Cmap_2$-Experts Cmap. 4 Categories. Gender analysis

In relation to the complexity index, see table 8.159 and figure 8.164, the results obtained show similar values for both genders, *Sustainability* is seen as a bit more complex after taking the course, although the results are far from the experts' ones.

	Male		Female		Experts
	Cmap1	Cmap2	Cmap1	Cmap2	
Complexity index (CO)	0.52	3.46	0.16	5.10	24.8

Table 8.159 Case study EUT-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

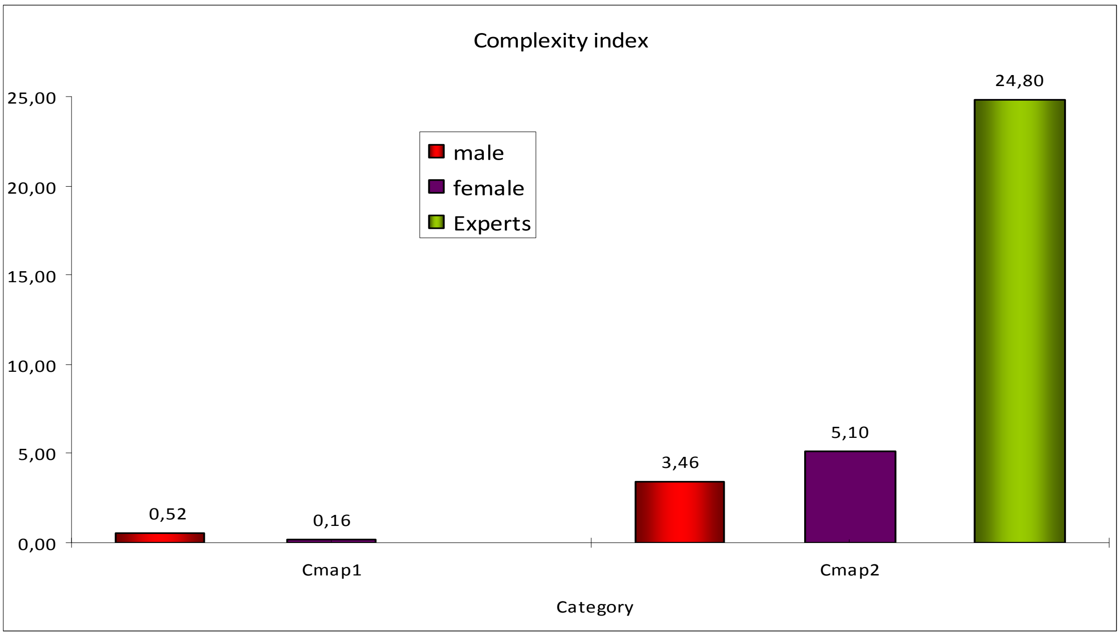

Figure 8.164 Case study EUT-2. Comparison of complexity index: $Cmap_1$-$Cmap_2$-Experts Cmap. Gender analysis

8.10.10 Analysis of results

When analysing the *Category Relevance* index there's not a clear different pattern for male and female students, it can be concluded that both genders distribute the concepts among the categories similarly.

The *Complexity* index also showed similar results for both genders; although in some case studies (UPC-2, DUT-1, CUT-1) female students get higher values after taking the courses. Only in the UPC-4 case study do the males have a significantly higher complexity index.

8.11 Conclusions

There have been analysed 10 SD related courses/seminaries from 5 European Technological Universities:

- Technical university of Catalonia (Spain): 4 case studies.
- Delft University of Technology (The Netherlands): 2 case studies.
- Chalmers University of Technology (Sweden): 1 case study.
- Kiev Polytechnic Institute (Ukraine): 1 case study.
- Eindhoven University of Technology (The Netherlands): 2 case studies.

The effect of independent variables such as the speciality of the students (Architecture/Civil, Chemistry, Industrial, ICT, SD Policies), nationality (OECD countries, No OECD) and gender has also been studied.

The case studies have been assessed by conceptual maps using two indexes: Category Relevance (CR) under both 10 and 4 category taxonomy and Complexity (CO). The definition and evaluation process of these two indexes is explained in chapters 5 and 7 of this work.

These results are analysed in chapter 11, where the understanding of the students is compared to the pedagogical methodology used in each case study.

References

- Segalas, J.; Ferrer-Balas, D.; Pujadas, M. & Mulder, K. (2008a). Learning evaluation from a n international seminar on Sustainable Technology Development using conceptual maps. International Conference Engineering Education in Sustainable Development. Graz. pp. 27-37.
- Segalas, J.; Mulder, K.; Kordas, O.; Wennersten, R. & Nikiforovich, E. (2008b). Sustainable Development course at National Technical University of Ukraine: a joint venture of 4 European universities. International Conference Engineering Education in Sustainable Development. Graz. pp. 246-255.

[1] <http://www.oecd.org>.

9 Pedagogy for sustainable development. Interview analysis

This chapter analyses the experts on ESD opinion on the most suitable learning approaches and pedagogical methodologies to teach/learn SD in engineering universities. Two studies are presented: interviews of experts from European technological universities and the results of a workshop carried out during the international conference EESD held in Graz in September 2008. The results of these two studies are presented and the most common approaches are introduced.

9.1 Introduction

Chapter 3 analyses different pedagogical methodologies and their suitability to teaching/learning sustainable development (SD) in engineering universities. The state of the art showed that there is consensus about the need to move from a mechanistic/traditional way of teaching to an ecological/alternative one in order to allow engineering students to achieve SD competences in both cognitive (knowledge and understanding) and metacognitve (skills and abilities and attitudes) domains. Chapter 5 defines the research methodology that was applied to obtain experts' opinions on the theme. Semi-structured interviews are proposed as the most appropriate methodology to evaluate the opinion of engineering experts on pedagogical strategies that best allow SD learning in engineering.

This chapter presents the results of the two studies carried out:

- The experts' interview analysis.
- The results of a workshop carried out during the last EESD conference held in Graz in September 2008.

9.2 Interview analysis

The interview sample is formed by 455 experts from 17 European technological universities. Figure 9.1 shows the origin of the experts by university. The name and position of the experts interviewed can be checked in appendix 2.

Experts were asked[1] about which pedagogical strategies were most suitable for teaching courses on sustainable development and which were most permeable for the introduction of SD in "normal" courses (Segalas et al. 2007).

From the interviews the following statements should be pointed out:

- Erik De Graaff suggested: *Didactics are a tool, they are important in themselves but are used to achieve a certain learning objective, and the objective for SD is changing attitudes. Thus, one needs to create a situation where students can be confronted with the consequences of their decisions, where they can learn from their own experience. The accent should be put on how to use a strategy more than on the strategy itself. One should create a more specific environment to make sure that the students are working in the direction and the areas that one desires them to work*.

- Anja de Groene declared: T*he best way to motivate students to SD is to relate SD to their profession, otherwise they don't find any application and they think that it has nothing to do with them.*
- John Holmberg says: *For ESD the process of teaching is as important as the contents in SD.* In that direction David Selvy, also says: *Pedagogy should integrate the principles of SD (equity, futures orientation, participation, etc.), as those concepts have an implication not only for what has to be taught in the curriculum but also for the pedagogical process. Thus, the learning process itself must be sustainable, participatory, etc., and involve the lecturer's role as a role model.*
- Ana Nÿstrom proposed*: Challenge the way of students think in every way, question their own beliefs.*
- Leo Jansen about the kind of curriculum suggested that *curriculum should be action orientated with real life situations and students not sitting in one room learning about SD. They should learn for true SD by engagement with action oriented projects.*

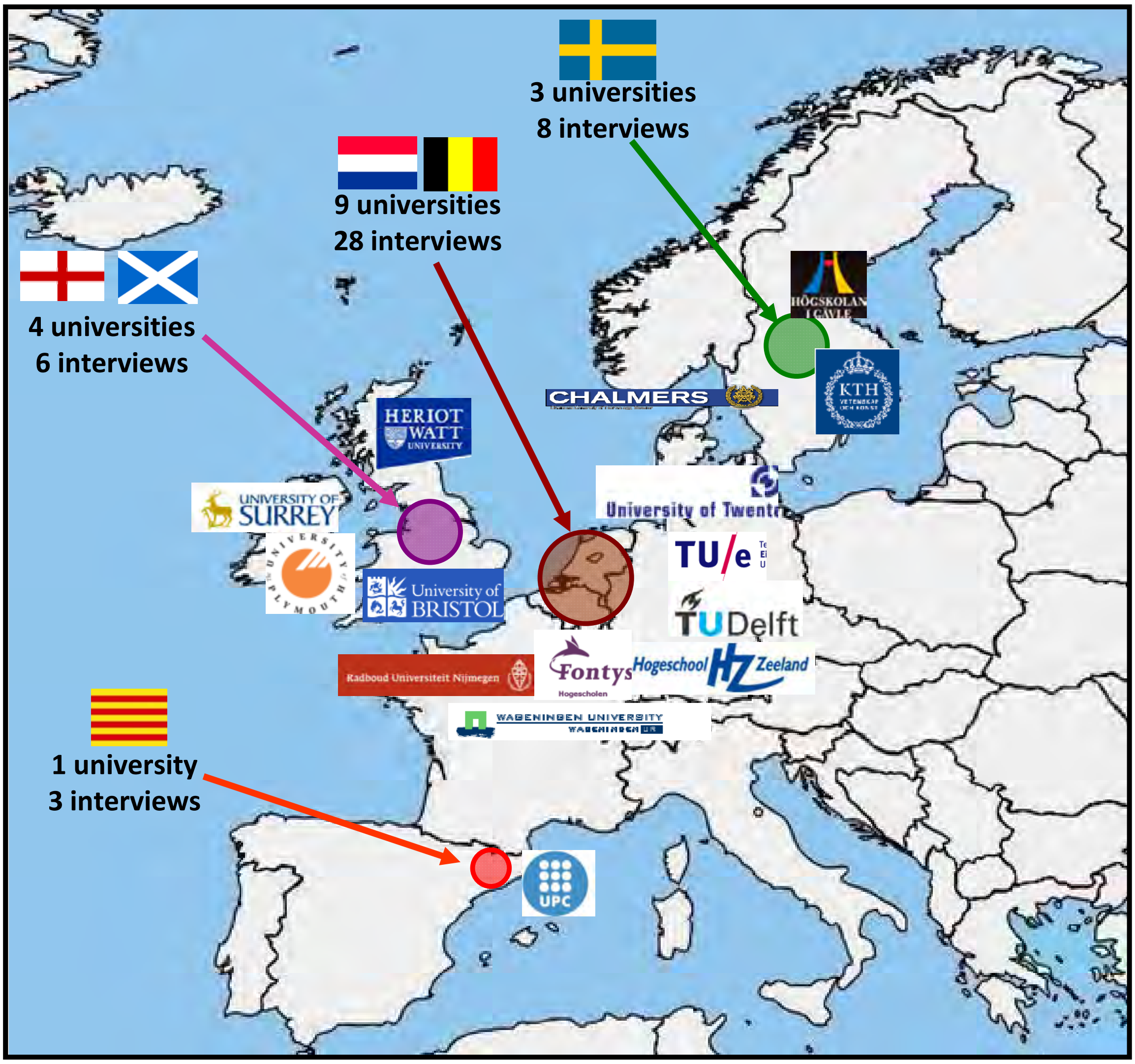

Figure 9.1 Origin of experts on ESD and Engineering Education interviewed

- Miquel Barcelo highlighted that *the role of the teacher is essential, both in the sense of his/her skills and attitudes to teach, and to motivate students to learn. Pedagogical methodologies are just tools which efficacy in the learning process depends more on the teacher aptitudes and the student motivation than in the kind of methodology.*

- Enric Carrera emphasises *that the learning process should be related to real situations that imply experiential and emotional situations.*

Table 9.1 shows a map of the interview results where the pedagogical methodologies that each expert suggested in the interview is shown.

Measuring the pedagogical strategies and techniques statistically, the interviews show that about 90 % of experts interviewed propose Project Based Learning as the most permeable active learning strategy for the introduction of sustainability. Nevertheless lecturing (71%) is also seen as very important in the very first steps of the learning processes where information needs to be given to the students before they start applying this knowledge in other active learning steps. All the activities proposed are related to active learning (PBL, case studies, visits, role plays, etc.). All experts highlighted that more than applying one specific methodology, a multi-pedagogy approach is appropriate in order to reach all kinds of students and allow the acquisition of meta-cognitive competences related to SD.

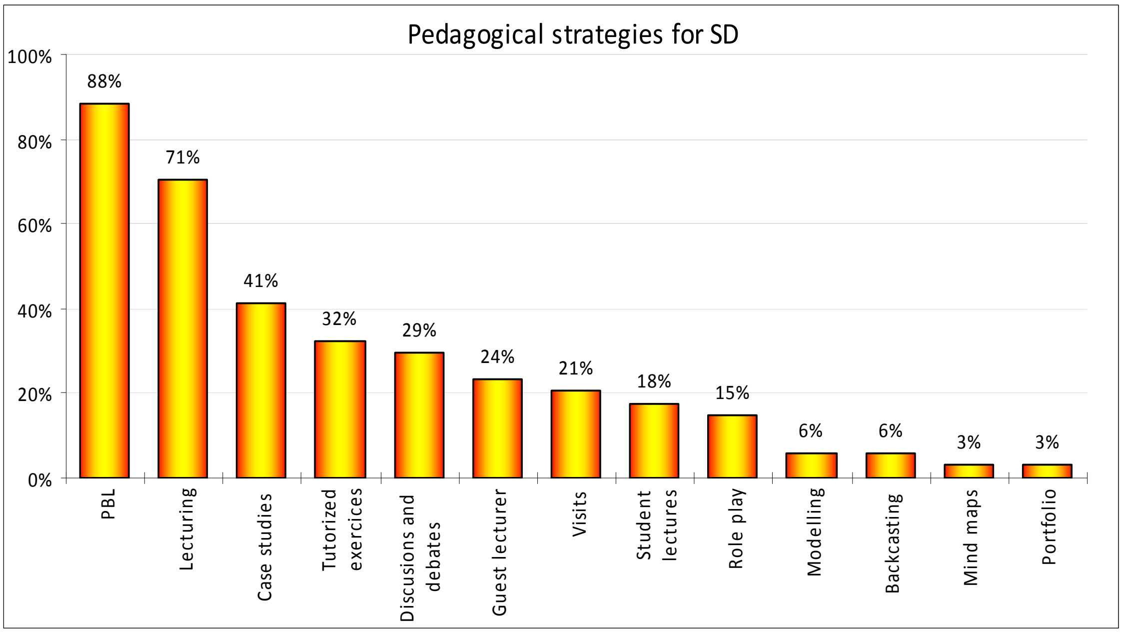

Figure 9.2 Percentage of experts that has highlighted the importance of a pedagogical strategy

Expert	PBL	Lecturing	Case studies	Tutorized exercises	Discussions and debates	Guest lecturer	Visits	Student lectures	Role play	Modelling	Backcasting	Mind maps	Portfolio
Peet	X	X	X								X		
Pessers	X												
De Werk	X	X			X						X		
Kamp	X	X											
Overschie				X		X	X	X				X	
Heemink	X									X			
Infante Fereira	X												
de Graaff		X	X										
Klein Woud	X	X				X							
Lemkowitz	X	X	X		X	X							
De Groene	X	X	X										
Lobezno	X	X	X										
Augustijn	X							X					
Toxopeus	X	X		X		X							
Kersten	X	X					X						
Van der Meer	X	X	X										
Geraets	X	X							X				
Dankelman	X	X		X	X	X							
Te Boekhorst	X	X		X	X	X							
Lemmens	X	X	X		X								
Kirkels	X	X	X		X								
Van Noort	X	X	X		X								
Slingerland	X	X		X	X				X	X			X
Roorda		X	X	X		X	X						
Installé	X			X									
Sammalisto	X	X	X					X					
Brandt	X	X	X	X	X	X	X	X	X				
Holmberg		X											
Nyström	X	X			X				X				
Andersson	X	X		X	X								
Svanstrom	X	X	X	X	X								
Lundqvist	X	X		X	X	X		X	X				
Craik	X												
Bamber	X	X											
Selby	X		X				X						
Dyer	X		X				X						
Clift	X		X										
Heslop	X	X	X	X			X	X					
Barceló		X	X	X	X			X	X				
Grau		X	X		X			X					
Carrera		X	X	X	X				X				

Table 9.1 Experts' opinion on the best pedagogy to learning SD in engineering universities

9.3 EESD '08 Workshop analysis

During the international conference on Engineering Education in Sustainable Development held at the Graz University of Technology in October 2008, a workshop was carried out where participants were asked to give their opinion about which pedagogy is better to learn sustainability at engineering universities. See Figure 9.3. In the workshop 15 experts from technological universities participated.

In the pedagogy domain EESD experts were asked: "*Which is the shift and the required transformation in the pedagogy used in Engineering Education Institutions to train engineers to become change agents for sustainability*?" Among the answers, the following statements are interesting in the context of this chapter:

- *There is a need to change to system analysis thinking. Pedagogy must promote systemic thinking among the students.*
- *Pedagogy has to shift from the predominance of a technology focus to a more societal focus, where the role of technology in society is considered.*
- *The basic shift is related to the teaching/learning attitudes instead of only tools. It is more a question of how we use the pedagogical methodologies than of the methodologies themselves. In that sense the attitudinal role of the teacher is crucial.*
- *Pedagogy should include more multidisciplinary approaches like PBL because sustainability cannot be achieved with a "narrow view".*
- *Shift to Active Learning Education with more practical project work. As a means of moving from only theoretical thinkers towards change agents.*

Figure 9.3 EESD '08 workshop participants at work

9.4 Conclusions

The analysis of both studies: interviews with experts and the workshop at the EESD conference, indicates that there are many commonalities in relation to pedagogy for EESD. They are summed up in the next paragraph.

Sustainability needs systemic thinking; a lot of pictures are still in a mechanistic/traditional mode, understanding divided into boxes, etc. According to the experts and practitioners interviewed, to create a pedagogical approach that optimizes the understanding of flows of relationships between concepts of all kinds is necessary. In addition sustainability is a clear multidisciplinary "potpourri" (Environmental, social, economic, values, future, culture, diversity, etc…) which asks for transdisciplinarity and thus, different ways of teaching to introduce the transdisciplinary culture are needed. Moreover these learning processes must be active and cooperative. The literature supporting the notion that active, student-centred learning is superior to passive, teacher-centred instruction is encyclopaedic (Felder et al. 2000). *The accent should be put on how to use a strategy more than on the strategy itself. One should create a specific environment to make sure that the students are working in the direction and the areas that one desires them to work*. The role of the teacher is also very important; the "*practice what you preach*" quote is especially relevant when wanting students to learn about SD attitudes.

Chapter 11 compares the opinion of the experts with the literature review realized in chapter 3 of this thesis.

References

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[1] Appendix 1 contains the interview questionnaire.

10 A curriculum for sustainable development. Interview analysis

This chapter analyses the ESD experts' opinion on the preferred way of introducing SD in the engineering curriculum. First the different means of introducing SD competences in the curriculum are evaluated. Next the drivers and barriers for embedding SD in all courses are pointed out. Finally the lessons learned by the experts' experiences are highlighted, and recommendations to implement ESD successfully within universities are presented.

10.1 Introduction

Chapter 4 presented the results of a literature review on strategies to introduce SD in the engineering curricula. This chapter analyses the expert opinion regarding this issue. Experts were first questioned[1] regarding university policies on the introduction of SD and the way it had been developed and put into practice and second about the curriculum design for ESD.

From the interview analysis some commonalities will be pointed out. These are structured in two areas: what strategies are suggested/applied to introducing SD in the curriculum (courses, minors, etc.); and curriculum SD embedding approaches that were developed at experts' universities.

10.2 Strategies to introduce SD in the curriculum

There are basically three strategies to introduce SD in the curriculum according to the universities analysed and the interviews of their sustainability experts:

- Specific course in SD.
- Minor/specialization in SD.
- Master's degree in SD or TSD.

10.2.1 Course on SD

In relation to the course on SD, there are different aspects to consider with different approaches proposed.

What: It is important to have a course on SD in order to learn the SD basics; the course should be focused on the process of making technical choices and design processes rather than on technical knowledge and products as such.

When: Most experts propose the course at the very beginning of the degree: first year of studies or even first course of studies. A minority proposes to have this course mid term: after the basic/scientific courses (maths, physics, chemistry, etc.) are taken and before the application/technology courses (building structures, pneumatics, robotics, etc.) in order to show the applicability face of sustainability, to make SD practical and visible.

To whom: In most cases the course is elective for all students and only compulsory for some university departments, although the general feeling is that it should be compulsory in order to ensure that all graduating engineers have some basic knowledge of SD. The main barrier to achieving a compulsory SD course is that curricula are usually full and there is no room for new courses; moreover some departments do not see SD as important enough to have a compulsory course on the topic. In that sense experts highlighted that whenever there is a new design/restructuration of the curriculum, there is an opportunity to introduce a SD course. An example is the adaptation of curricula required by the EHEA, which allow some UPC departments the introduction of a compulsory course on SD for all students.

Most experts recognise that having an isolated specific course on SD is not the solution; it is necessary but not enough. It should be seen as basic courses (e.g. mathematics), which are taught at the beginning of the degree to introduce basic knowledge, knowledge which is then applied in most other courses. Therefore an SD course should introduce the SD basics and then SD should be applied in all other courses.

From the interviews, examples of specific SD courses can be found at UPC, DUT, CUT, Hogeschool Zeeland, EUT, University of Gävle, Royal Institute of Technology (KTH), University of Plymouth, University of Surrey and University of Bristol.

10.2.2 Minor on SD

In order to obtain an SD minor certificate, students should take a set of SD related courses and relate their final Master/Bachelor thesis to a SD topic. Examples of SD minors can be found at UPC, DUT, Fontys Eindhoven, EUT, KTH and University of Plymouth.

Usually the courses to obtain the SD minor imply a SD fundamentals course (this course is sometimes compulsory for all students) and two or more courses on SD technologies, where SD is applied to a specific engineering field. Generally this set of courses has from 11 to 20 ECTS.

Depending on the university, the final thesis on a SD topic is supervised either by a supervisor expert on SD or by two supervisors, an expert on SD and another from a specific field of knowledge. This last approach is very convenient in order to make SD comprehensive to non SD faculty.

10.2.3 Masters on SD

There are many universities which offer a Masters degree in SD or STD. At the European level, an overview of SD related master programs[2] was developed in the SDPROMO[3] project under the *Erasmus Mundus Action IV* framework. The database contains relevant information on 38 Masters.

In respect to applying these three strategies, there is a tradeoff between them. At some universities having a minor or a Masters on SD is taken as sufficient ESD. However not having a compulsory SD course allows students that do not take this elective minor/master to graduate without having taken any course on sustainability.

10.3 SD Curriculum embedding

The ideal situation is that every teacher handles SD itself in his/her courses. In order to achieve this goal universities have developed different strategies. The following figures show examples of these strategies in a conceptual map structure.

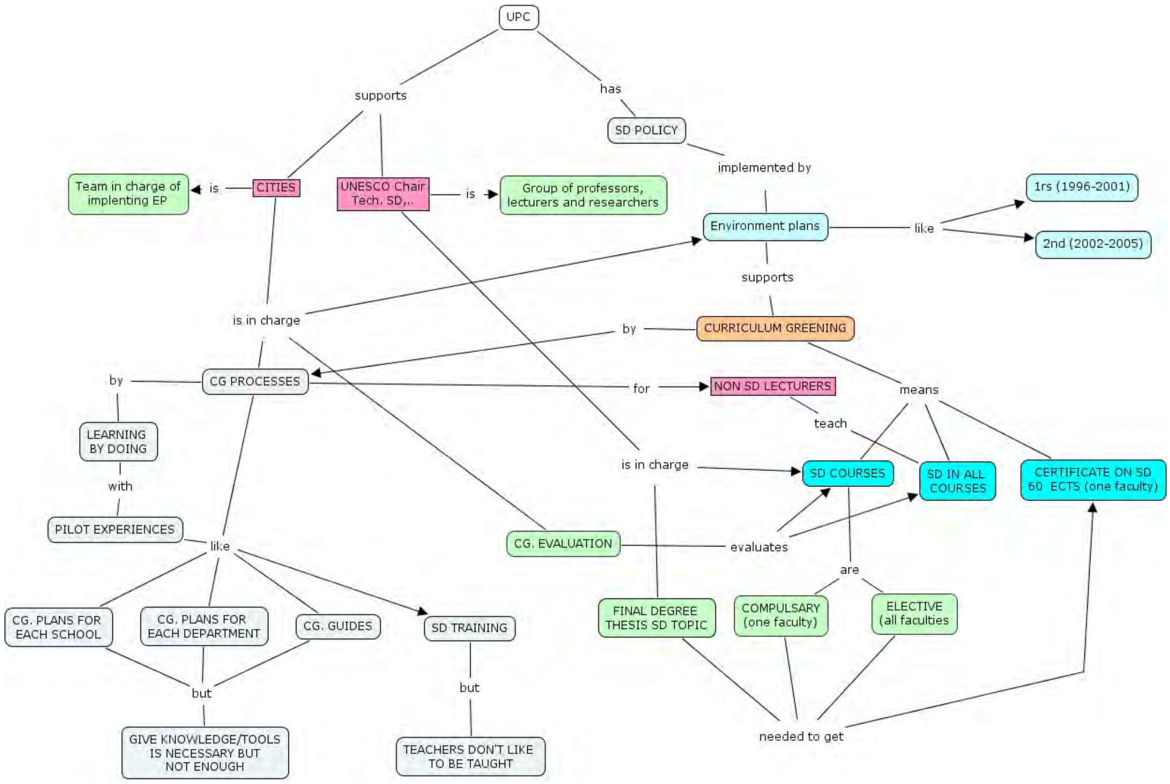

Figure 10.1 Technical University of Catalonia SD Curriculum Strategy

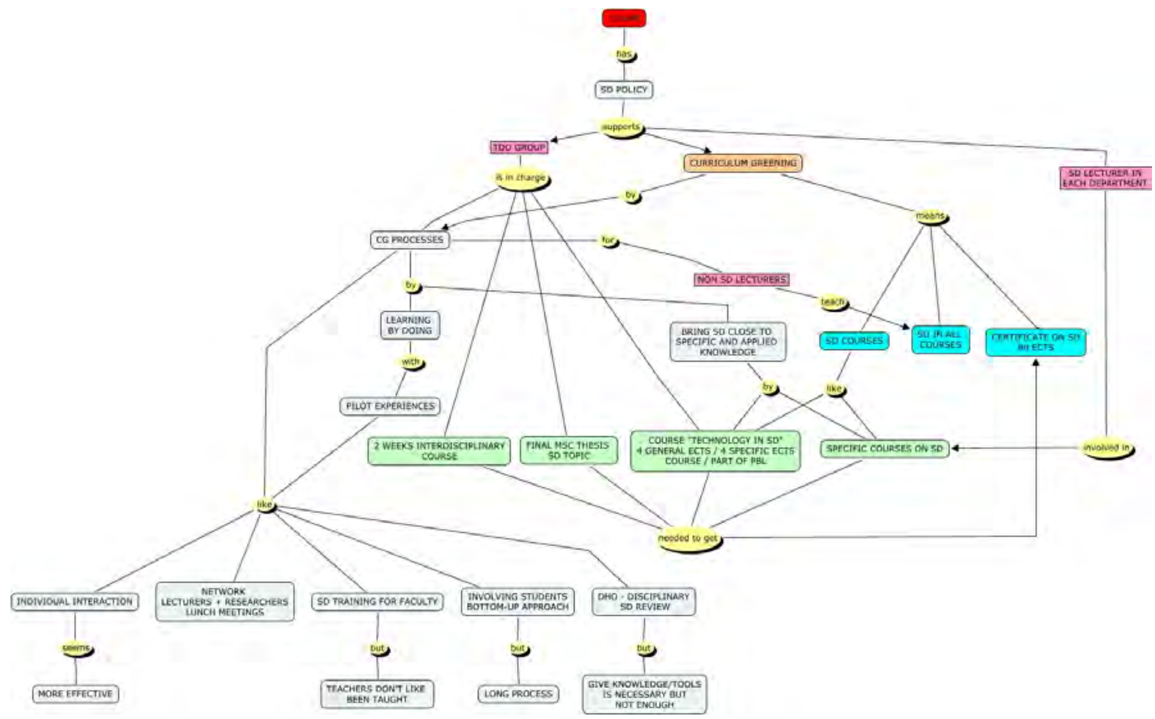

Figure 10.2 Delft University of Technology SD Curriculum Strategy

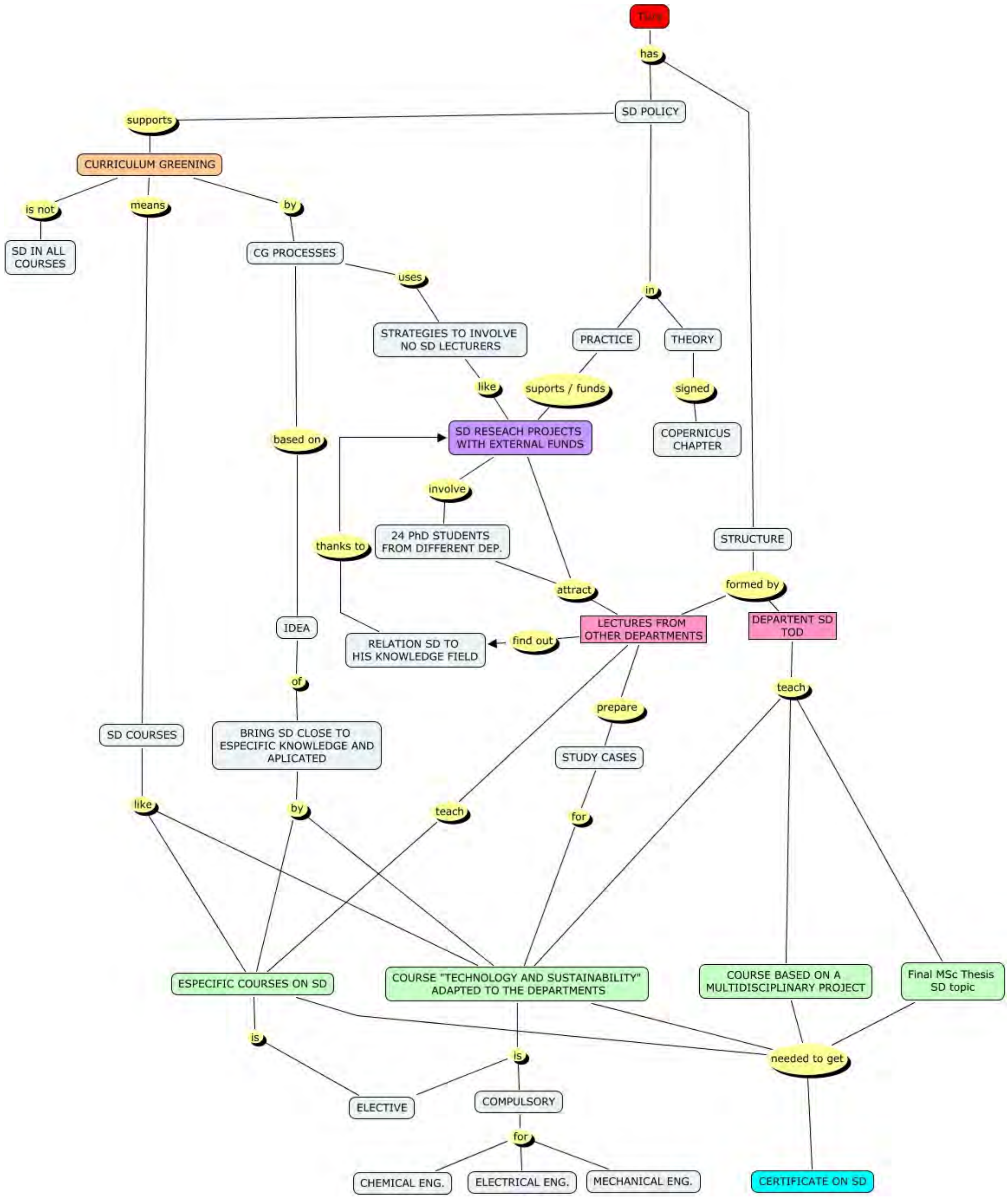

Figure 10.3 Eindhoven University of Technology SD Curriculum Strategy

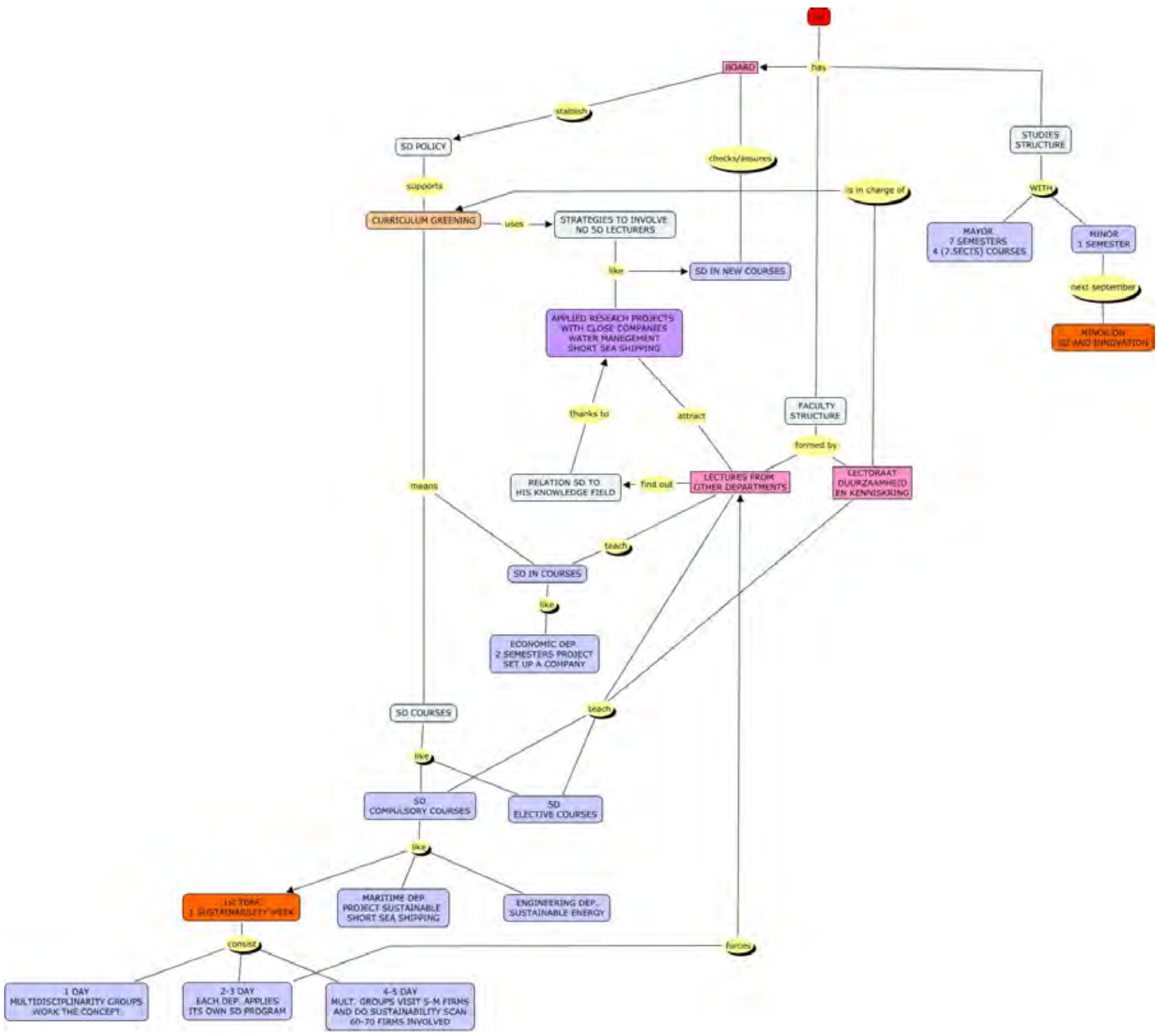

Figure 10.4 Hogeschool Zeeland SD Curriculum Strategy

All these approaches present several commonalities in terms of barriers, drivers and lessons learnt which are discussed in the next sections.

10.3.1 Barriers

In most cases the main problem is university inertia and its resistance to change. The University reacts too slowly to external changes and the disciplinary division of the university organisation hampers the integration of SD. Transdisciplinarity is not valued as it endangers the organisational foundations.

Careers and recognition of scientists are mainly determined by research (papers, publications, European projects, etc.) and little, if at all, by education, which is taken for granted. Thus faculty is pressed to put more effort into research, moreover SD education in not seen as very scientific by engineering academia.

Lecturers do not like people from outside to interfere in the content of their teaching. The lecturers' teaching autonomy is based on their specific expertise. "Lay" interference (which includes interference from other fields) is therefore a threat to his/her self esteem. Lecturers/experts will not go for a course on SD for the same reason, and are reluctant to facilitate the embedding of SD in their courses. They see SD as a threat to their courses as it is something new and ill defined from their point of view.

Embedding of SD in all courses is a very slow process. It is content specific and therefore requires an individual approach. Such painstaking and slow processes do not easily attract the interest of university managers.

10.3.2 Drivers

In some universities support from the university board has been a relevant driver. This support can be a life buoy in the storm of resistance from the sceptical faculty waves. Nevertheless the top-down approach is necessary although not sufficient.

The External demand for ESD from government agencies, companies and professional bodies is supportive too.

At some universities students' involvement acts as a driving force for change. A good example can be seen at DUT, where SD the students' association "OSIRIS"[4] is organising many SD awareness campaigns in the campus, pressing faculty to introduce SD in the curriculum. Another example can be found at Kiev Polytechnic Institute whose Students Science Association "SSA"[5] is also very active in promoting ESD within the university.

10.3.3 Lessons learnt

According to the experts, the major limitation for embedding sustainability in the engineering curriculum is the academic culture. Faculty lack of comprehensive SD perspective makes it feel threatened in its autonomy. Academic staff is not used to dialogue with regard to the content of teaching or research. This prevents adequate reactions to new societal challenges like SD. Integrating SD into a course is tricky if the lecturer is insecure regarding his/her power position in the department: it might trigger discussions regarding the credit points of his/her course, which are potentially a threat to his/her academic credibility, i.e. his/her position. Overcoming this resistance is the key point to embedding SD in the curriculum. In that direction the following approaches are proposed:

- Make it visible that SD is not a threat, that there are inherent linkages which are implicit in the discipline. By showing that there is something to be gained and that there are opportunities emerging from SD for them and for their disciplinary fields.
- An individual approach is the best way of involving lecturers (Peet et al., 2004; Holmberg et al., 2008), although it is highly resource consuming.
- To involve non ESD faculty in SD application projects with other departments, this facilitates the faculty's comprehension of sustainability better as it is applied in their field of expertise.
- Use multidisciplinary PBL with SD related problems. This will raise SD awareness of non SD teachers that participate in the projects.
- Earn some respect from your colleagues, do a good job and then ask for some collaboration and join them in ESD projects somehow.
- Excellence: Link professors on SD research, reward ESD pioneers. Promote research on SD excellence level.

At some universities (e.g. DUT, UPC, Radboud University Nijmegen, Université Catholique de Louvain, etc.) attempts were made to "teach the teachers". The results were rather disappointing. There were several reasons for that:

- In general, teachers do not want to be taught, as it creates a threat to their sense of autonomy, as was discussed above.
- There is strong pressure on lecturers to commit themselves to research. Research determines their careers, and education is often considered as an obligation that should be accomplished with minimum effort. Moreover, lecturers are pressured to attract research money. Therefore lecturers feel a pressure not to devote their time to investments in educational quality.
- Developing materials that can be used by other lecturers in their education was not very effective on its own. Most materials are left on the shelves.

Commitment from the university board has shown to be essential to support the process of change; this commitment should be reliable and supported by a strategic plan. This top-down approach is more successful at professional universities (hogeschools, polytechnics), where in the absence of an academic research culture, resistance to top-down instructions of lecturers to include SD in their courses is much lower. Nevertheless at research universities only top-down does not work, the board commitment is just a catalyst/facilitator and bottom-up approaches are also needed. Networking from below and facilitating from above is the key.

It is important to have a centralized group responsible for developing the SD strategic plan of the university. Examples of such a unit can be found at UPC - Centre of Sustainability[6]-, DUT - Technology Dynamics and Sustainable Development Department[7]-, CUT - Centre for Environment and Sustainability[8]-, EUT -Eindhoven Centre for Sustainability[9]. Examples that do not have any coordinating body can also be seen in some universities that signed ESD declarations (Table 1.1), but where no ESD improvement has been achieved.

Moreover it is also essential that all university departments are somehow involved in the attempts to introduce SD in the curricula. Therefore it is important to find allies in each department that become believers that push ESD within their own department.

ESD strategy should be encompassed in a broad strategy of embedding sustainability in all university life. What is commonly known as the "practice what you preach" approach reinforces and legitimates the ESD process, because it reduces the weak point of institutional incoherence. The Sustainability strategy must involve all the key areas of the university:

- Research: promoting SD research and introducing SD criteria in all research activities.
- In-house management: minimizing the environmental impact and introducing SD in all the management processes.
- Social interaction: participating with the challenges of its local, regional and international environment.

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- Peet, D.J.; Mulder, K.F. & Bijma, A. (2004). Integrating SD into Engineering courses at the Delft University of Technology. The individual interaction method. International Journal of Sustainability in Higher Education. Vol. 5, Nº 3, pp. 278-288.

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[1] Appendix 1 contains the interview questionnaire.

[2] <http://www.sdpromo.info/web/page.aspx?pageid=41399>.

[3] <http://www.sdpromo.info/web/page.aspx>.

[4] <http://www.osiris.tudelft.nl/>.

[5] <http://ssa.org.ua/>.

[6] <https://www.upc.edu/centresostenibilitat>.

[7] <http://www.tbm.tudelft.nl/live/pagina.jsp?id=0ad3e4b4-cf09-48f4-b739-fe1fa56e878b&lang=en>.

[8] <http://www.chalmers.se/gmv/EN/>.

[9] <http://w3.ieis.tue.nl/en/technology_for_sustainable_energy/>.

11 Testing propositions

This chapter compares the state-of-the-art and reviews the literature regarding the outcomes of the research carried out. First, the competences that engineering students should have after graduation are evaluated. Next, different SD pedagogical approaches are assessed by the analysis of 10 case studies made in chapter 8, where the SD understanding of students after taking sustainability related courses is measured. Finally, the curriculum strategies to introduce SD in engineering curriculum are presented and suggestions to embed SD within the curriculum are made.

11.1 Introduction

Chapter 1 addresses the role of education and it especially brings up the role of higher education in achieving a more sustainable society. In this respect, the Barcelona Declaration (2004) focuses on engineering education and states: "*It is undeniable that the world and its cultures need a different kind of engineer, one who has a long-term, systemic approach to decision-making, one who is guided by ethics, justice, equality and solidarity, and has a holistic understanding that goes beyond his or her own field of specialisation"*. Therefore a new kind of engineering education is needed. The object of this thesis is to determine the kind of education that is needed. It evaluates current approaches carried out in leading European technological universities in terms of sustainability education in engineering.

Three main questions have guided this research:

1. The What: Which SD competences must an engineer learn at university?
2. The How: How can these competences be acquired efficiently? The role of pedagogy.
3. The Where: Which education structure is more effective for the required pedagogy and also to embed SD in the curriculum?

The question about competences is analysed in chapter 2 (state-of-the-art). Chapter 6 compares the SD competences of students from Delft University of Technology, Chalmers University of Technology and the Technical University of Catalonia.

The pedagogy question is studied in chapter 3, which explains the state-of-the-art. Chapter 8 presents 10 case studies. Chapter 9 shows the conclusions of the interviews with experts on ESD analysis.

The curriculum question is introduced in chapter 4 and further developed in chapter 10 with the curriculum greening approaches carried out in ESD-leading universities and with the analysis of the interviews with ESD experts.

This chapter evaluates the research findings regarding these three questions: Competences, Pedagogy and Curriculum. The objective is to compare the results of the case studies presented in the previous chapters with the major research findings in this area.

11.2 Competence study

What competences do engineers need to acquire in order to fulfil the demands of society? Defining these competences will be useful to identify the overriding goals for education systems, and therefore help us to define new curricula. It will also help us to improve the assessments which try to measure how well engineers are prepared for SD challenges.

The description of competences embraces three strands:

- *Knowledge and understanding*: Theoretical knowledge of an academic field, the capacity to know and understand.
- *Skills and abilities*: practical and operational application of knowledge to certain situations.
- *Attitudes*: Values as an integral element of the way of perceiving and living with others in a social context.

Different approaches have been used to define the SD learning outcomes and/or competences that engineering students should have when graduating.

These different approaches to define competences, both at international and national level, together with the Barcelona Declaration have already been evaluated in chapter 2. The conclusions of these analyses are that the communalities between the approaches are very high and that most competences are related to: Critical thinking, Systemic thinking, Inter-trans-disciplinarity and Values and ethics.

In order to find out what the real situation at university level is, chapter 6 presents the analysis of the sustainability competences of bachelor engineering graduates from three European technological universities: Chalmers University of Technology (CUT) in Goteborg, Sweden, Delft University of Technology (DUT) in Delft, The Netherlands, and the Technical University of Catalonia (UPC) in Barcelona, Spain.

The comparison of the SD competences in the three European universities highlights the commonalities between them. Table 11.1 presents these commonalities sorted by cognitive domain and clustered in keywords. The maximum level of achievement in the three universities according to Bloom's and Krathwohl's taxonomies is also introduced in the table.

From the comparison of SD competences between the three universities, the study shows that there is a strong convergence in the fundamental meaning of competences, although there is also a scarce matching among the descriptions formulated. The analysis of competences showed divergences in their descriptions, which makes it difficult to compare the programmes from different universities. Therefore progress needs to be achieved towards more similar descriptions in order to allow the EHEA system to make use of the transferability of European degrees, also in the domain of SD. The definition of competences is a learning process. This study shows that the definition of SD competences still has to be much improved in order to facilitate their integration into the engineering curricula.

Cognitive domain	Key word	Level of achievement
Knowledge and understanding	World current situation	Comprehension
	Causes of unsustainability	Comprehension
	Sustainability fundamentals	Comprehension
	Science, technology and society	Comprehension
	Instruments for sustainable technologies	Knowledge
Skills and abilities	Self-learning	Application
	Cooperation and transdisciplinarity	Evaluation
	SD Problem solving	Synthesis
	Systemic thinking	Evaluation
	Critical thinking	Evaluation
	Social participation	Evaluation
Attitudes	Responsibility Commitment SD challenge acknowledgement	Valuing
	Respect Ethical sense Peace culture	Organization
	Concern Risk awareness	Value complex

Table 11.1 SD Key competence words for Bachelor degree at CUT, DUT and UPC

It is important to see the matching between the SD generic competences proposed at supra-university level (accreditation agencies, professional bodies, etc.) and the competences stated at the three evaluated universities. For example, all require *Critical thinking*, *Systemic thinking*, *Inter-trans-disciplinarity* and *Values and ethics* to bachelor engineer graduates. However an important point for discussion is whether these SD competences are assessed in the programs and how they are evaluated.

11.3 Pedagogy analysis

The literature review in chapter 3 showed that learning is an important condition but it does not guarantee a change. Thus, learning about SD does not guarantee changes in behaviour that support the necessary changes for Sustainability (Quist 2006).

Several theories substantiate that Sustainability needs systemic thinking; a lot of pictures are still in a mechanistic mode, and their understanding is divided into boxes, etc. According to the interviewed experts and practitioners, creating a pedagogical approach that optimizes the understanding of the flows of relationships between concepts of all kinds is needed. Sustainability is a clear transdisciplinary “potpourri” (which includes environment, society, economy, values, future, culture, diversity, technology, etc…) and thus, it needs transdisciplinary teaching/learning processes. Moreover, it should not be forgotten that these must be active and cooperative learning processes, taking into account that the process of teaching (“the teacher role”) is as important as the contents. Moreover, studies on learning reveal that students learn in different ways. Therefore a multi-pedagogical active methodology approach is needed in order to reach all students. Table 3.10 presents the contribution of different pedagogical strategies to ESD.

Keeping in mind this new pedagogical approach needed for ESD, chapters 8 and 10 present case studies of specific Sustainability courses offered in 5 European technological universities. The methodology of analysis consists of, first, evaluating the SD learning achieved by students and, second, relating this learning to the pedagogy used in each case. The following sections present the learning and pedagogy evaluation of the case studies and their interrelationship.

Code	University	Learning activity	ECTS	Sample (Cmap1/Cmap2)	Pedagogy
UPC-1	Technical University of Catalonia	Technology & Sustainability	5	201/226	Distance learning course. Contents on CD. Participation in virtual forum (10%). Exercises (30%).
UPC-2	Technical University of Catalonia	Technology & Sustainability	5	35/43	Distance learning course. Contents on CD. Participation in virtual forum (10%). Exercises (30%).
UPC-3	Technical University of Catalonia	Technology & Environment	5	30/31	Lecturing (60%). Cooperative learning, role play, student presentations.
UPC-4	Technical University of Catalonia	International Seminar on Sustainable Technology	5	19/19	Lecturing (25%). Project based learning. Participation in forums. Workshops
DUT-1	Delft University of Technology	Energy III	8 (0.7)	32/26	Lectures, workshops and written assignments.
DUT-2	Delft University of Technology	Societal aspects of information technology	4	68/45	Lecturing (70%). Group work (30%).
CUT-1	Chalmers University of Technology	Global Chemical Sustainability	7	51/53	Lectures. Guest lectures. Exercises. Role play. Seminars and Project Based Learning.
KPI-1	Kiev Polytechnic Institute	Sustainable Development	3	23/17	Lectures (25%). Role Play. Project Based Learning. Film watching & debate. Workshops. Student presentations.
EUT-1	Eindhoven University of Technology	Technology & Sustainability	3	10/28	Distance learning course. Contents on CD. Exercises. Lectures (6 hours)
EUT-2	Eindhoven University of Technology	Technology & Sustainability	3	60/18	Distance learning course. Contents on CD. Exercises. Lectures (6 hours)
			Total	529/506	

Table 11.2 Case study data

11.3.1 Pedagogy evaluation

The topography of approaches of active learning by Horvath et al. (2004) is used to evaluate the pedagogy of the case studies. This topography is represented as two orthogonal axes: focus (from individual, through group, to community) and nature (from instructive, through explorative to constructive). (See chapter 5 for further details). The following figure illustrates the evaluation of some pedagogical methodologies according to this topography.

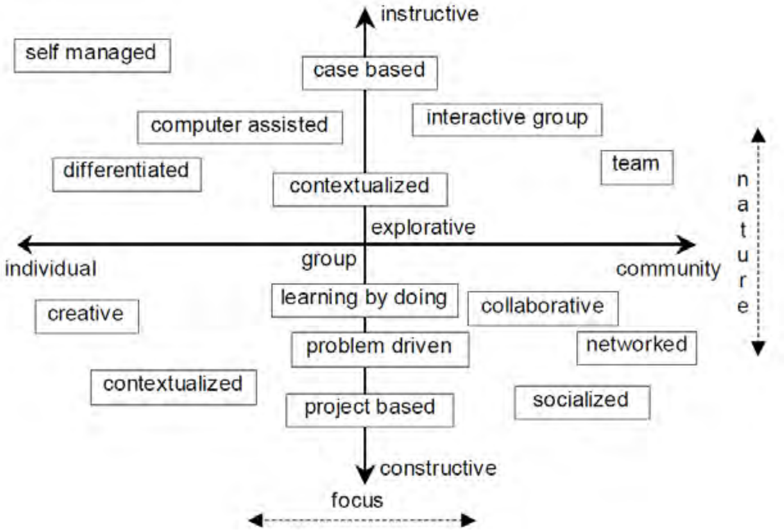


Figure 11.1 Topography of approaches of active learning (Horvath et al, 2004)

The pedagogy used in each case study is summarised in the table 11.2.

By means of the Horvath topography (Horvath et al., 2004), the case studies can be classified as illustrated in the next figure.

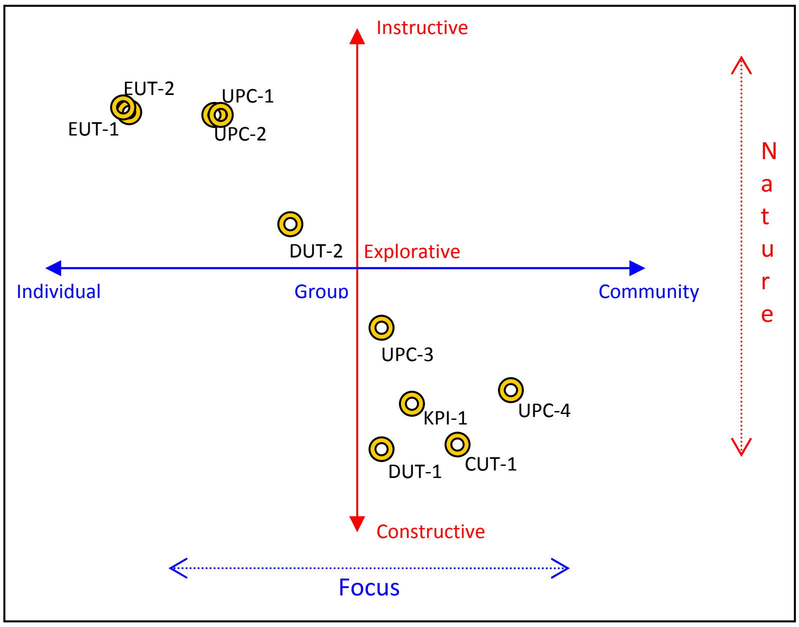


Figure 11.2 Case study topography of active learning approaches

The figure shows four case studies (UPC-1, UPC-2, EUT-1 and EUT-2) in which the focus is individual and based on instructional education. In all these cases, a distance learning platform is used and the contents are delivered in digital format. UPC-1 and UPC-2 use a forum distance platform where students share SD information and learning tools.

The UPC-3 case study includes some group activities with a role-play session and a cooperative-learning session.

The UPC-4 case study only lasted one week in the form of an intensive international seminar. During this week students participated in real forums (scientific and societal) related to sustainable issues as well as in different workshops. This is the case study which is most related to community. Students are clustered in groups and work on Sustainability problems. At the end they present their solutions and there is a debate with teachers and the other groups about the results achieved. It is important to point out that this sample involved 2nd cycle students who are taking a Masters on Sustainability; therefore their knowledge of Sustainability before taking the course was considerably higher than the students from the other case studies (Segalas et al., 2008a).

The CUT-1 case study uses all kinds of active-learning methodologies. Project-based learning in groups is the basis for constructive education and the guest lecturers and visits give relevance to community learning.

The KPI-1 case study is a two-week course taught to 2nd-cycle students who have never heard of Sustainability. Project-based learning in groups, role plays and debates were used, although there was no interaction with the community or the stakeholders (Segalas et al., 2008b).

The DUT-1 case study is a small unit related to sustainable development and equivalent to 0.7 ECTS. In this case study, students who are taking a degree, with a curriculum largely designed in project-based learning, learn how to apply sustainability aspects in their specialization projects.

The DUT-2 case study is a 3-ECTS unit for ICT students. The unit deals with the societal aspects of information technology. This group of students was not very motivated to learn about this topic. The pedagogy used is mainly lecturing (70%) and some group work (30%)

These 10 case studies have been compared taking into account the students' performance in both category relevance and complexity indexes.

11.3.2 Learning evaluation

Conceptual maps (Cmaps) are used as an assessment tool to evaluate the SD learning achieved by students. The study is specifically based on Cmap assessment with the lowest degree of directness and no concept, linking line, linking phrase or Cmap structure was provided to students. The following assessment components have been considered in the analysis: the number of concepts, the relevance of concepts, the number of links and the complexity of the Cmap.

The research design used is the quasi-experimental pretest-posttest design. This design (figure 7.1) requires a Cmap ($Cmap_1$) to be recorded in a single group of individuals before the learning activity (L_A) and only one observation ($Cmap_2$) after the administration of the learning activity, since there is only one group of individuals. Therefore by comparing the results before and after the course, the learning achieved can be evaluated. Nevertheless it should be borne in mind that conceptual maps are only evaluating the cognitive domain, which means how students understand Sustainability.

Two taxonomies have been applied in the analysis:

- a 4-category taxonomy (which shows the big picture): Environmental, Social, Technological & Economic and Institutional.
- a 10-category taxonomy (which gives more detailed information): Environmental, Resources, Social Impact, Values, Future, Unbalances, Technology, Economy, Education and Stakeholders.

In order to define what is expected to be learnt in these kinds of specific Sustainability courses, several EESD experts were also asked to draw an SD-related Cmap. The results of the Cmap analysis of this group of experts were taken as a reference and they were used to evaluate the results obtained by students.

In order to evaluate the Cmaps, two indexes were defined:

<u>A category-relevance index</u>: using the two taxonomies which have already been explained, this index provides information about what students think sustainability is most related to.

<u>A complexity index</u>: it evaluates how developed and inter-connected students see the concepts they have related to Sustainability, that is how complex do they see Sustainability.

In the next two sections, the results of the case-studies are compared with the experts' reference for each index.

11.3.3 Category-relevance index analysis

The category-relevance index of the student case studies and the one of the experts' reference group are compared in order to evaluate the performance of students. The evaluation of the category-relevance indexes is known by measuring the difference between the distribution of the category-relevance of students and experts.

To be able to obtain the comparison of the distribution of the category-relevance indexes, the difference between the students' value and the experts' is measured for each category. These values are normalized according to the relative value of each category. Finally, all the category differences are added to obtain an absolute value, which is then divided by the number of categories. The result gives information about how far the category distribution of the students differs from the experts.

The calculation process for the UPC-1 case study is shown as an example.

Analysis using the 10 category taxonomy

The next table shows the calculation of the category-relevance index. The variables are the following:

- *CR(Cmap1)* is the category-relevance distribution before taking the course.
- *CR(Cmap2)* is the category-relevance distribution after taking the course.
- *CR(Experts)* is the category-relevance distribution reference.
- $/(CR_{Ex}\text{-}CR_{Cm1})/CR_{Ex}/$ is the normalized difference between the experts' reference and the students before taking the course as an absolute value. It measures the previous knowledge of the students. The lower the value the more similar it is to the experts' results.
- $/(CR_{Ex}\text{-}CR_{Cm2})/CR_{Ex}/$ is the normalized difference between the experts' reference and the students after taking the course as an absolute value. It measures the knowledge after taking the course. The lower the value the more similar it is to the experts' results.
- $(CR_{Cm2}\text{-}CR_{Cm1})/CR_{Ex}$ is the comparison between the previous and posterior knowledge of the students. It measures their improvement. The higher the value, the greater the improvement.
- $\Sigma/10$ sums up all the category differences and gives a global value for the case study.

Category	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	$\Sigma/10$
CR(Cmap1)	39%	12%	4%	1%	0%	0%	38%	0%	2%	2%	
CR(Cmap2)	31%	11%	6%	3%	0%	2%	21%	5%	1%	16%	
CR(Experts)	11%	5%	7%	15%	2%	5%	16%	5%	13%	21%	
$(CR_{Ex}\text{-}CR_{Cm1})/CR_{Ex}$	251%	118%	38%	90%	98%	99%	135%	97%	83%	93%	110%
$(CR_{Ex}\text{-}CR_{Cm2})/CR_{Ex}$	181%	114%	17%	83%	89%	50%	30%	13%	94%	22%	69%
$(CR_{Cm2}\text{-}CR_{Cm1})/CR_{Ex}$	70%	5%	21%	7%	9%	49%	105%	84%	-11%	70%	41%

Table 11.3 Evaluation of the category-relevance index of case study UPC-1

These variables measure the differences between the students' and the experts' data. Therefore, for all the results, the lower the value, the better, except for the improvement variable, which is the only one for which the higher the value the better.

Table 11.4 shows that, in the UPC-1 case study, the category-relevance index has improved 41%, which is significant. Moreover it shows that, in general, the relative difference to the experts' results decreases in Cmap2. In this case study, only the results for C_9 (*Economy*) are lower after the course.

After doing this analysis for all of the case studies, the results obtained are shown in the next table. In this table, the case studies are classified from the most similar to the least similar to the experts' reference.

	Before the course (Cmap1)	After the course (Cmap2)	Improvement
Case study	$\sum_{1}^{10}\frac{(CR_{EX_i}-CR_{Cm1i})}{10\cdot CR_{EX_i}}$	$\sum_{1}^{10}\frac{(CR_{EX_i}-CR_{Cm2i})}{10\cdot CR_{EX_i}}$	$\sum_{1}^{10}\frac{(CR_{Cm2i}-CR_{Cm1i})}{10\cdot CR_{EX_i}}$
UPC-4	41%	25%	16%
DUT-2	82%	98%	-15%
KPI-1	83%	76%	7%
CUT-1	89%	59%	30%
UPC-3	102%	68%	34%
DUT-1	106%	76%	31%
UPC-1	110%	69%	41%
EUT-1	111%	89%	21%
EUT-2	111%	99%	9%
UPC-2	117%	72%	45%

Table 11.4 Comparison of the case study category-relevance index

Previous-knowledge analysis

Table 11.4 and Fig. 11.3 show that there are basically 3 groups of courses in relation to the category-relevance results obtained before taking the course. First, the results show that the students in the UPC-4 case study were the ones whose category-relevance index was closest to the experts'. Students in the UPC-4 case study were taking a Masters related to SD so, before the evaluated course; they had already been taking some other courses on SD. Therefore they were the best trained in SD before taking the course. Their first position reveals that Cmaps can be considered a good assessment tool as it corroborates their higher previous knowledge in SD.

The next group includes the DUT-2, KPI-1 and CUT-1 case studies. Students in the KPI-1 and CUT-1 case studies, were 2nd cycle/Masters students.

At the bottom, with the weakest understanding of Sustainability, there are the UPC-2, EUT-2, EUT-1, UPC-1, DUT-1 and UPC-3case studies.

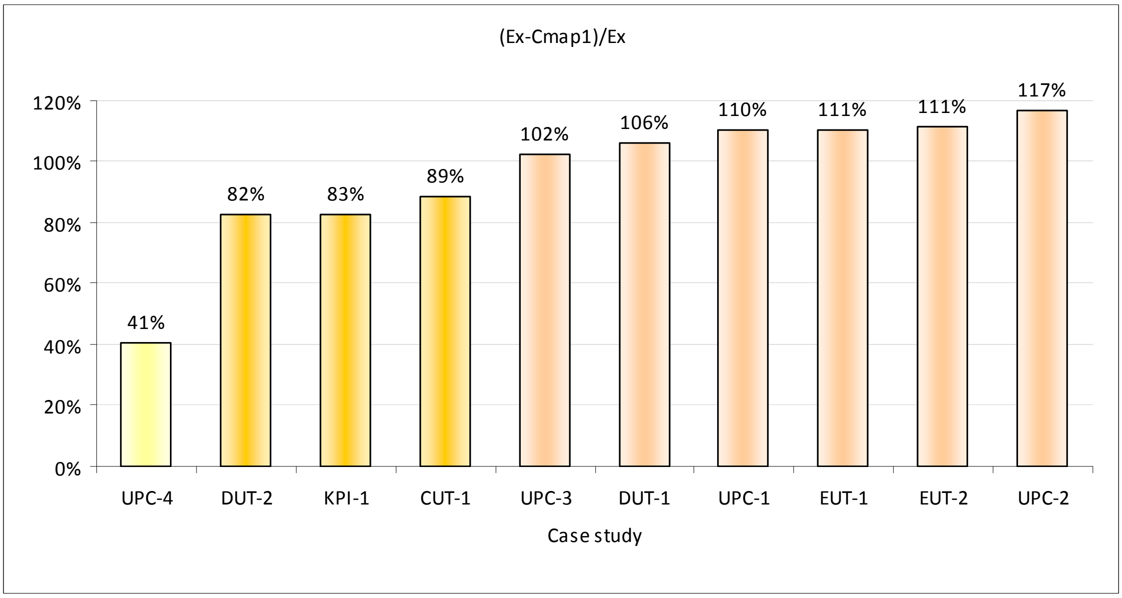


Figure 11.3 Category-relevance accumulative difference before the course. 10-category taxonomy. Classified from the best to the worst results

After-the-course knowledge analysis

As we can observe in the figure 11.4, after taking the course, again it is the UPC-4 case study that has the closest values to the experts. A group of case studies, led by CUT-1, have broader differences with respect to the experts, ranging from 59% to 76%. Finally, case studies EUT-1, DUT-2 and EUT-2 are at the end of the classification with the worst results.

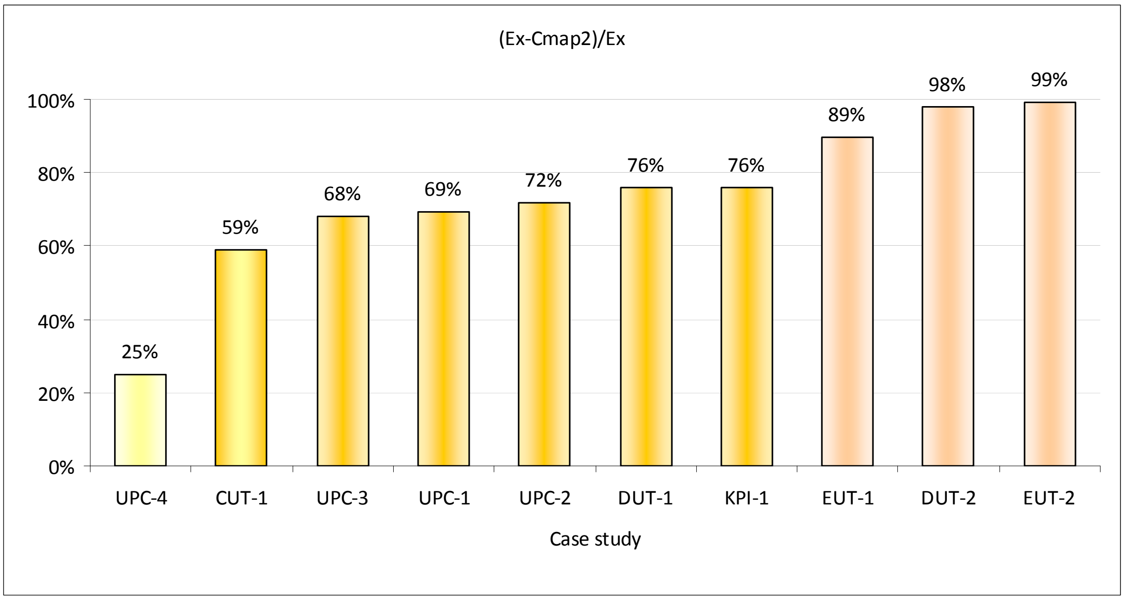


Figure 11.4 Category-relevance accumulative difference after taking the course. 10-category taxonomy. Classified from the best to the worst results

Improvement

To measure the improvement, the initial and final results of each case study are compared. As we can observe in figure 11.5, in all case studies except for the DUT-2 case study, the results after taking the course are closer to the experts. The comparison also highlights that the worse the initial situation, the easier it is to improve; therefore the improvement ratio is also generally higher in these case studies (UPC-3, DUT-1, UPC-1, UPC-2).

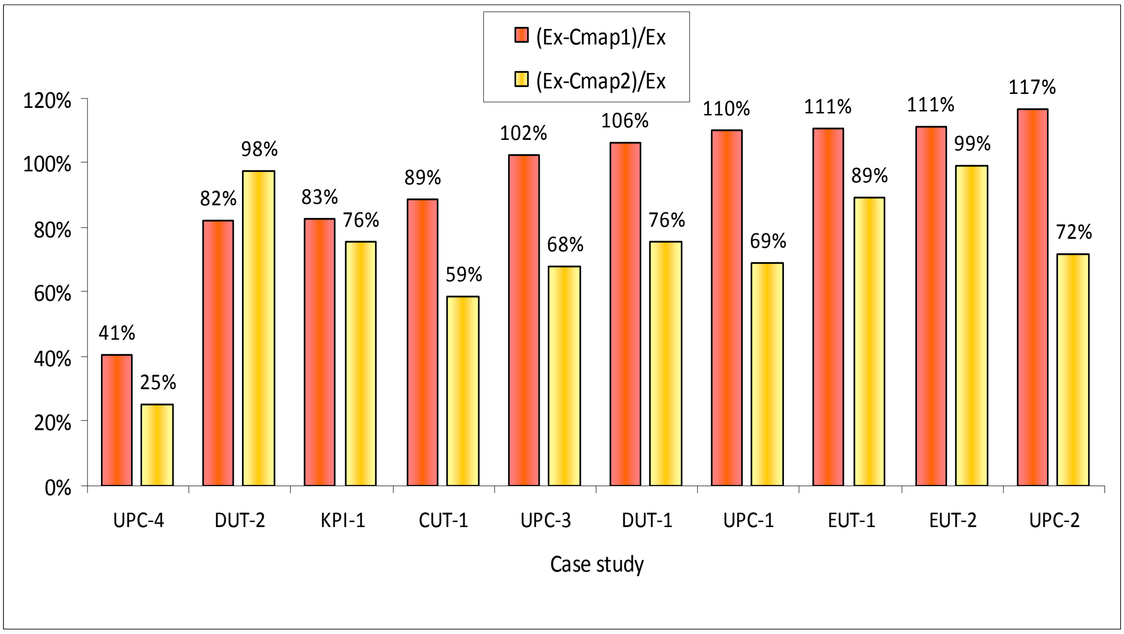


Figure 11.5 Category-relevance accumulative difference between case studies and experts. 10-category taxonomy

Each of the next figures (11.6a, 11.6b and 11.6c) shows the results for one single category which has been analysed in all the case studies. The improvement achieved in each category can be observed by comparing Cmap1 (in orange) with Cmap2 (in yellow). It is also important to take into account the reference of the Experts' Cmap (in green).

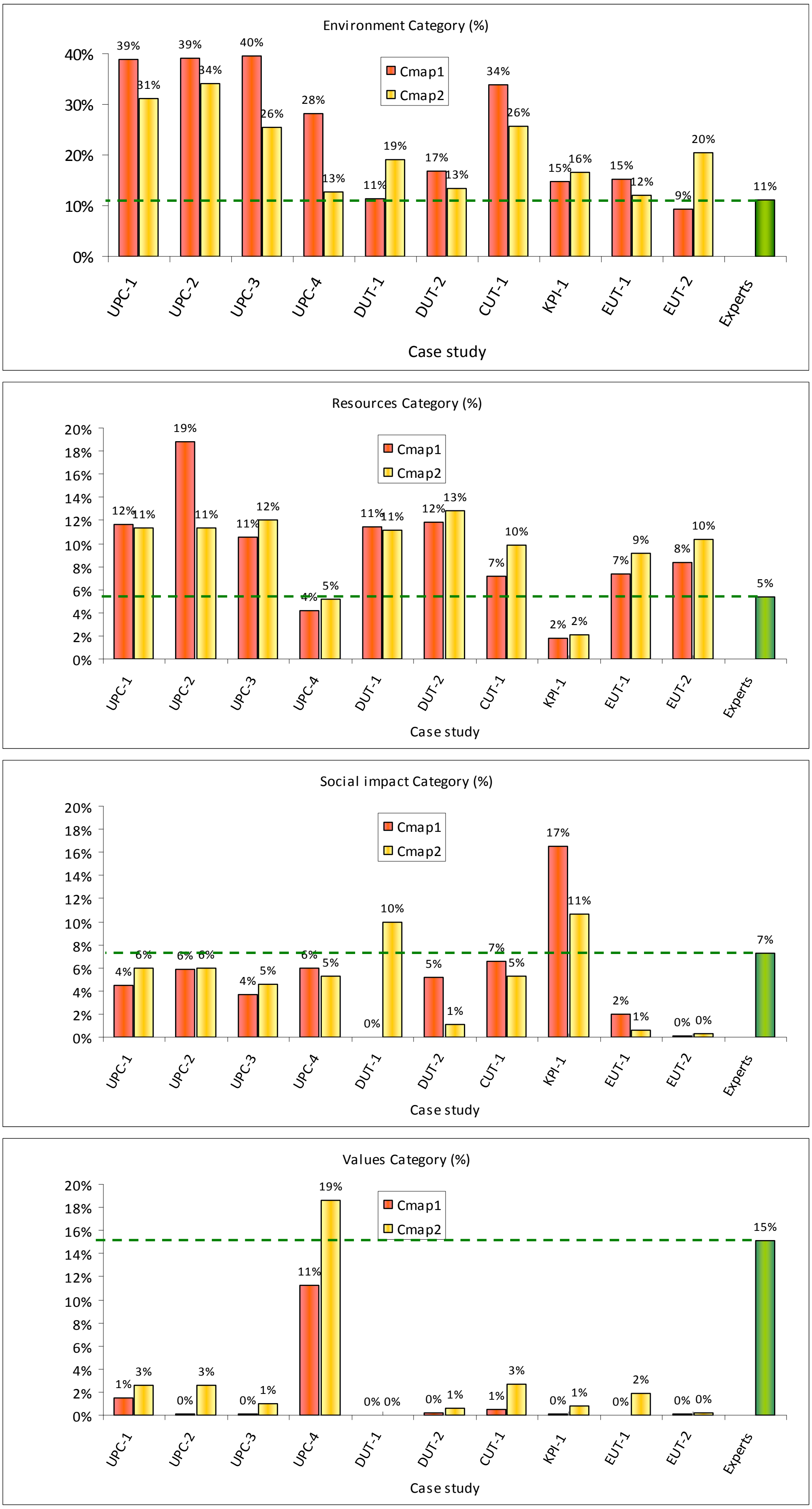


Figure 11.6(a) Category-distribution variation for all categories in each case study. 10-category taxonomy

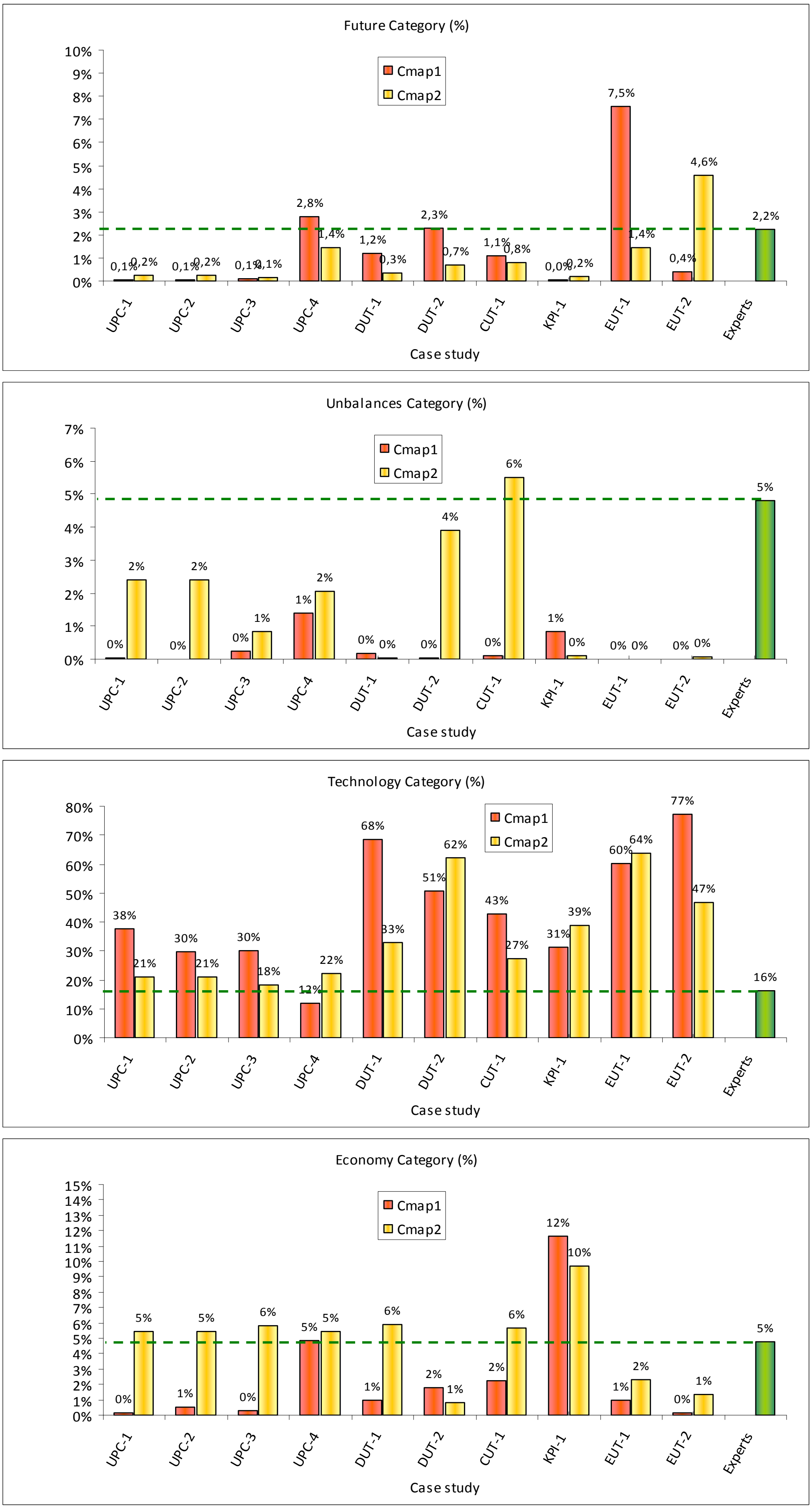
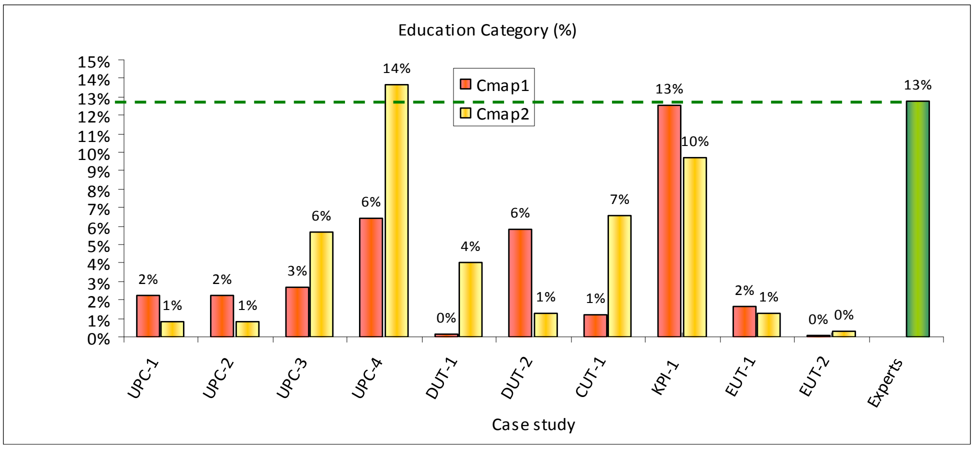


Figure 11.6(b) Category-distribution variation for all categories in each case study. 10-category taxonomy



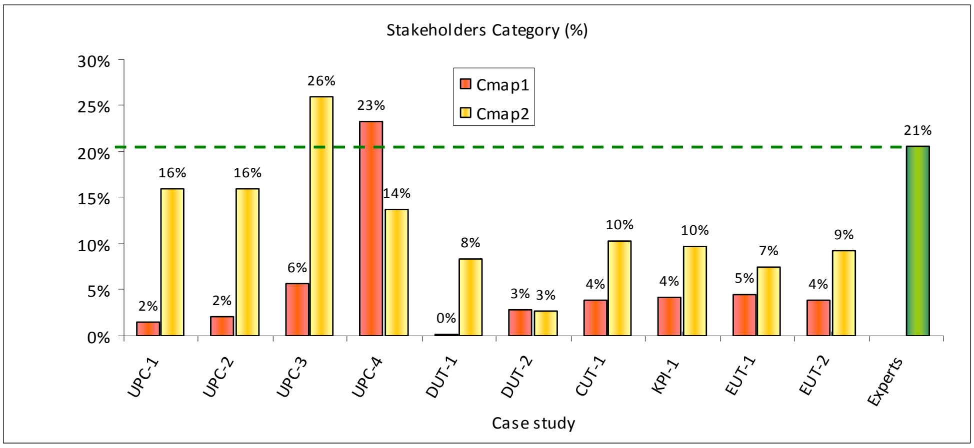


Figure 11.6(c) Category-distribution variation for all categories in each case study. 10-category taxonomy

The results of the analysis of each category shown in these figures are described in the following paragraphs.

Environment: In most of the case studies, students give too much relative relevance to *environment*. This misunderstanding is partially redressed during the course. However, the difference between the results after taking the course (Cmap2) and the experts' ones is still substantial.

Resources: Again most case studies show too much relevance for the category *resources*. Only UPC-4 and KPI-1 have lower values than the reference. In this category, courses do not seem to produce a significant change in the students' perception of the category *resources*, since the values after the courses are still high.

Social impact: Most case studies give little relevance to *social impact*. The exception is the KPI-1 case study (this could be because the Ukraine is a developing country and the social problems are considered as more important than in the western European countries). The results reveal that, after taking the course, there has not been a real improvement in this category.

Values: Only in the UPC-4 case study is importance given to the *values* category (we should recall that most students in this case study had taken Sustainability courses previously). In the other case studies very little relevance, if any, is given to the *values* category before taking the course. After the course, there is a slight improvement of the results but still very far from the 15% relevance of the expert reference.

Future: Once more, most students give little value to the *future* category both before and after taking the courses. Only UPC-4 (students with previous SD training) and, surprisingly, also the EUT-1 case studies have high values for this category. In the case studies with very low initial values, there is a little increase in category relevance after the course. But, unexpectedly, in the other case studies the final value for this category decreases.

Unbalances: Most students hardly give any relevance to the *unbalances* category, except for the UPC-4 and KPI-1 case studies. This may be due to the reasons already pointed out for these two cases (UPC-4 students have already been trained in SD and KPI-1 students belong to an Eastern European developing country). After taking the course, the values slightly improve in most case studies, but only in the CUT-1, UPC-1, UPC-2 and DUT-2 case studies is the relevance increase significant.

Technology: In all case studies, *technology* is seen as very important for Sustainability, since the values obtained are much higher than the experts. Only UPC-4 students are a bit more sceptical about the role of technology in SD. In many case studies, this misunderstanding is redressed and the relevance of technology decreases after taking the course. Nevertheless too much relevance is still given to this category.

Economy: As well as in the *unbalances* category, most students hardly give any relevance to the category *economy*, except the UPC-4 and KPI-1 case studies. Especially in KPI-1, this category is really valued. (This could be due to the feeling existing in developing countries that the economy is very necessary for development and also for sustainable development). This misunderstanding is generally redressed after taking the course in most case studies.

Education: Most students give little value to the category *education*. Only UPC-4 (students with previous SD training), DUT-2 and KPI-1 students recognize the importance of this category. No trend is perceived in the improvement of the value given to the category after taking the course.

Stakeholders: Except for UPC-4, all the case studies show little relevance of the category *stakeholders* before taking the courses. This misunderstanding is redressed in most case studies after taking the course.

<u>Analysis using the 4 category taxonomy</u>

	Before the course (Cmap1)	After the course (Cmap2)	Improvement
Case study	$\sum_{1}^{10}\frac{(CR_{EX_i}-CR_{Cm1i})}{10\cdot CR_{EX_i}}$	$\sum_{1}^{10}\frac{(CR_{EX_i}-CR_{Cm2i})}{10\cdot CR_{EX_i}}$	$\sum_{1}^{10}\frac{(CR_{Cm2i}-CR_{Cm1i})}{10\cdot CR_{EX_i}}$
UPC-4	39%	16%	23%
KPI-1	49%	61%	-12%
DUT-2	93%	107%	-14%
EUT-1	94%	101%	-6%
UPC-3	103%	56%	47%
CUT-1	105%	68%	37%
UPC-1	114%	74%	40%
EUT-2	115%	92%	23%
DUT-1	116%	74%	42%
UPC-2	116%	78%	38%

Table 11.5 Comparison of the category-relevance index of each case study: 4-category taxonomy

<u>Previous-knowledge analysis</u>

The results of this analysis are similar to the results of analysis of the 10-category taxonomy. Before taking the course, the students in the UPC-4 case study were the ones whose category-relevance index was closest to the experts. Close to UPC-4 is the KPI-1 case study, whose sample included 2nd and 3rd cycle students.

All the other case studies have similar results, but they can be classified in three groups as shown in the next figure.

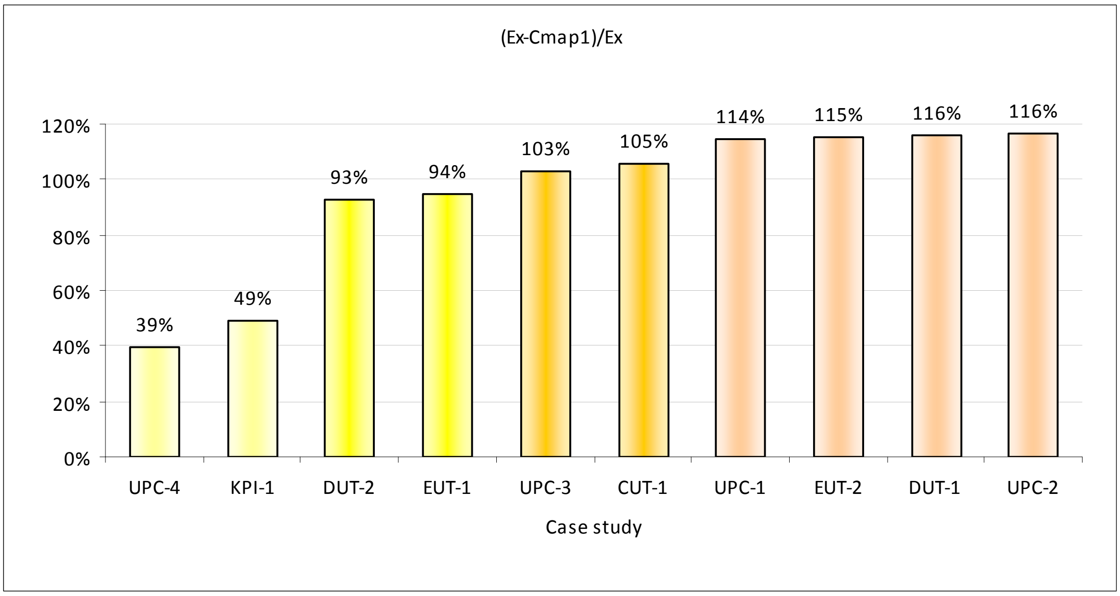


Figure 11.7 Category-relevance accumulative difference before the course: 4-category taxonomy. Sorted from the best to the worst results

<u>After-the-course knowledge analysis</u>

As shown in the next figure, after taking the course, again it is case study UPC-4 which is the one with the closest values to the experts' reference values. Case studies UPC-3, KPI-1 and CUT-1 follow with values ranging between 56% and 78%. The worst results are obtained in case studies EUT-1, EUT-2, and DUT-2.

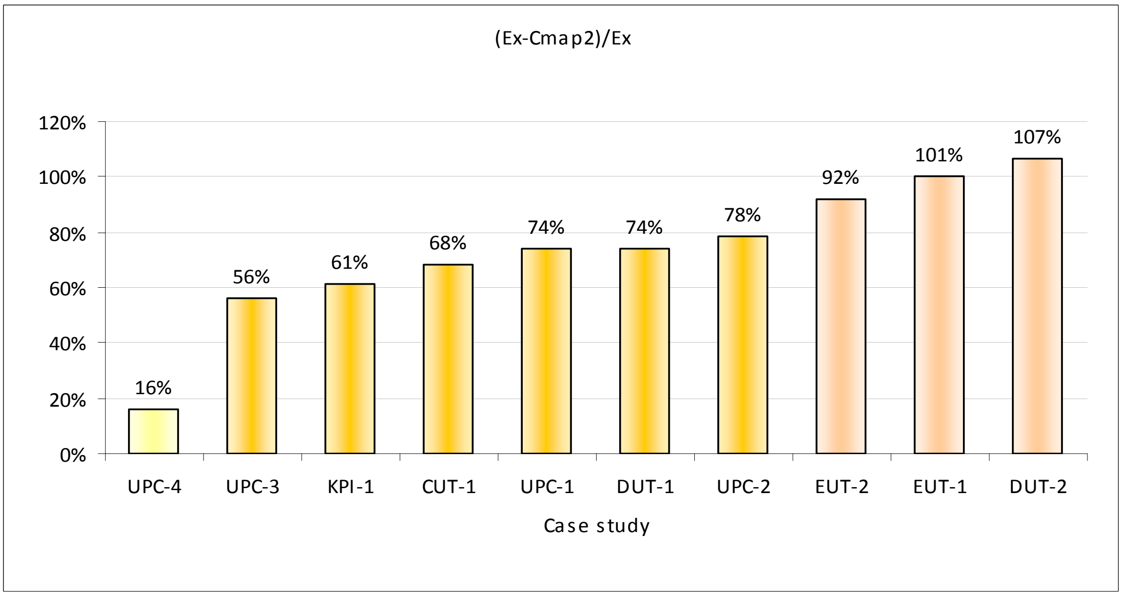


Figure 11.8 Category-relevance accumulative difference after the course: 4-category taxonomy. Sorted from the best to the worst results

Improvement

Except for the DUT-2 case study, in all the other case studies the results become closer to the experts' ones after taking the course. The results also show that the worse the initial situation, the easier it is to improve; therefore the improvement ratio is generally higher in these case studies (UPC-3, DUT-1, UPC-1, UPC-2).

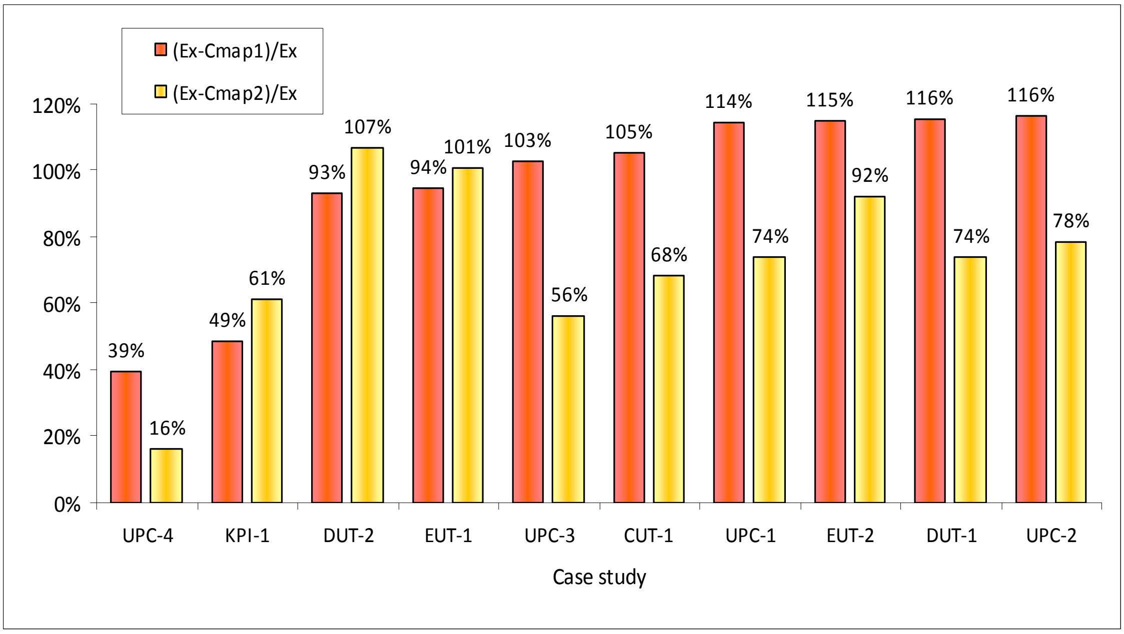


Figure 11.9 Category-relevance accumulative difference between case studies and experts: 4-category taxonomy

Each of the next figures shows the results for one category which has been analysed in all the case studies. Here we can observe the improvement achieved in each category by comparing Cmap1 (in orange) with Cmap2 (in yellow). It is also important to take into account the reference of the Experts' Cmap (in green).

The 4-category taxonomy analysis gives the big picture of the students' understanding of SD. The following paragraphs describe the results of the analysis of each category shown in these figures.

Environmental: In most of the case studies, students give too much relevance to the *environmental* category. This misunderstanding is partially redressed during the course. However, after taking the course, but there is still a lot difference between the values given by students (Cmap2) and the experts.

Social: Most case studies give little relevance to *social aspects*, except for case study UPC-4. Results from case study KPI-1 also stand out clearly from the rest. After taking the course, the results reveal that the improvement in this category is small.

Technological and Economic: Again, except for UPC-4, all the case studies give too much relevance to *technological and economic aspects* before taking the courses. This misunderstanding is partially redressed in most case studies after taking the course.

Institutional: Before the course, only case studies KPI-1 and specially UPC-4 give relevance to this category. In the other case studies, after taking the courses, this misunderstanding is partially redressed, in particular in case study UPC-3.

The results of the 4-category taxonomy analysis show that, in most cases, students relate Sustainability mainly to environmental and technological/economic issues, and they give little value to institutional and social aspects. This misunderstanding is only partially redressed by the courses. Besides, the results also show that some courses are more effective than others (See figures 8.102 and 8.103).

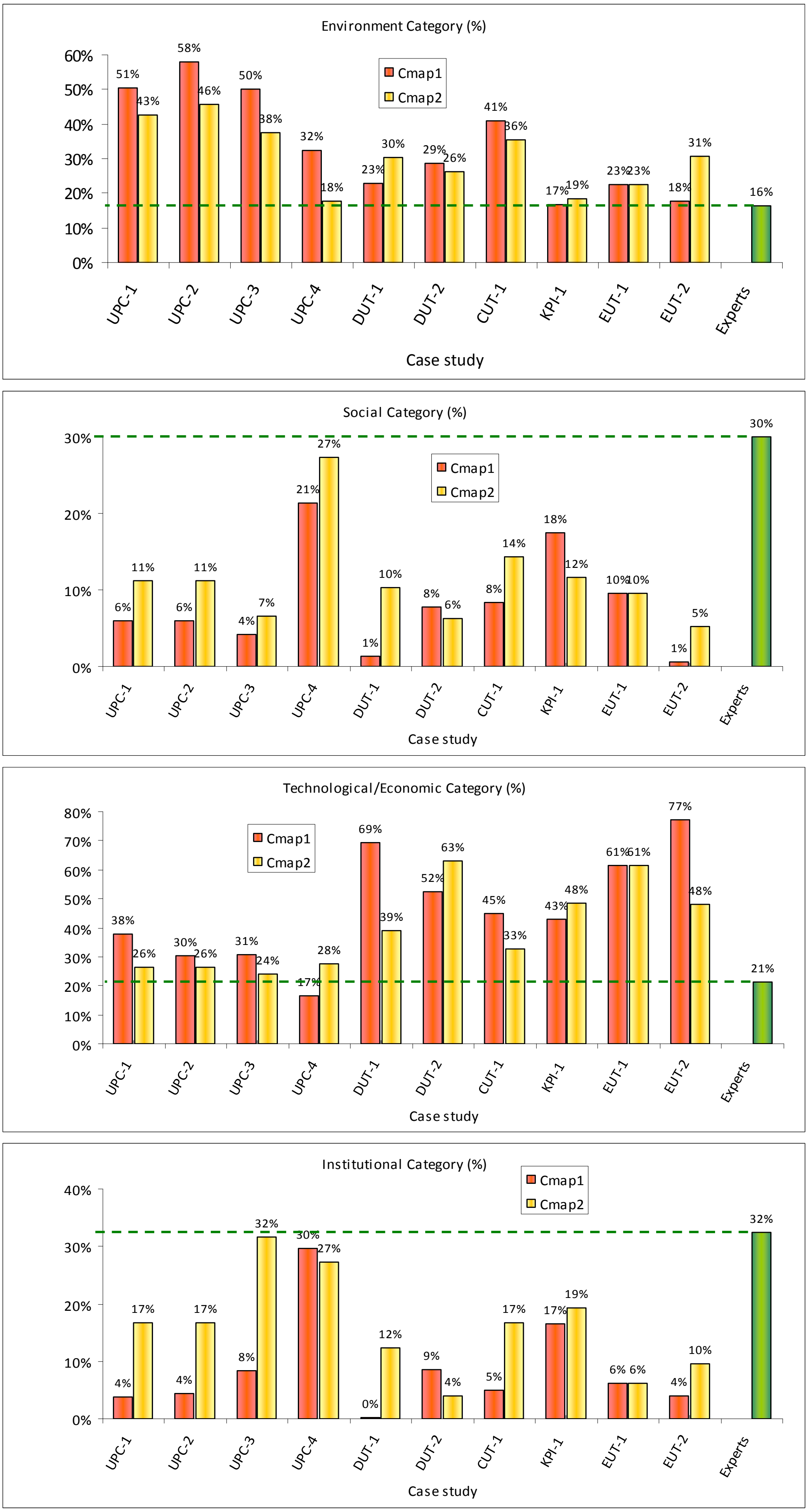


Figure 11.10 Category-distribution change in each category. 4-category taxonomy

The variability of the sample is also taken into account when analysing the results. Whenever possible, the different values of the following variables have been compared:

- **Nationality**: OECD and non-OECD students. This variable has been analysed in case studies CUT-1 and UPC-4 (see section 8.8 of this thesis).
- **Speciality**: Architecture/Civil, Chemistry, Industrial and ICT students. This variable has been analysed in case studies UPC-1, UPC-3 and UPC-4 (see section 8.9 of this thesis).
- **Gende**r: Gender has been analysed in case studies UPC-1, UPC-2, UPC-3, UPC-4, DUT-1, CUT-1, KPI-1, EUT-1 and EUT-2 (see section 8.10 of this thesis)

The results are the following:

- Regarding nationality, the analysis of the category-relevance index illustrates that non-OECD students give more relevance to the social and institutional categories, while OECD students give more relevance to the technological/economic category.
- Regarding the speciality, the speciality analysis of the three case studies shows that there are no significant differences between students from different specialities (Architecture/Civil, Chemistry, Industrial and ICT) students, neither before nor after taking the SD courses. As for case study UPC-4 (students with previous SD training), an important observation is that students taking the minor in SD Policies clearly gave more relevance to the social and institutional categories than the students of this course from other specialities. This specificity may be attributed to the background of these students taking the minor in SD Policy, which is mostly related to Humanities and Social Sciences.
- Finally, regarding the gender domain, no clearly different pattern was identified for male and female students. Thus it can be concluded that both genders distribute the concepts among the categories similarly.

11.3.4 Complexity-index analysis

The complexity-index evaluates how developed and inter-connected students see the concepts they have related to Sustainability. In other words, it measures how complex students perceive sustainability to be. To analyse the complexity-index, the value of the index is obtained for each case study before and after taking the course. Then the values of the different case studies are compared and sorted from the higher to the lower values. The reference value for the analysis is the value obtained by the experts' group.

	Before the course (Cmap1)	After the course (Cmap2)
Case study	CO Cmap1	CO Cmap2
UPC-4	20.4	15.6
CUT-1	12.4	17.1
KPI-1	4.6	26.8
UPC-3	3.3	18.8
UPC-2	2.9	12.2
DUT-2	2.5	3.4
EUT-1	1.8	1.7
UPC-1	0.9	10.3
EUT-2	0.5	3.6
DUT-1	0.3	3.1

Table 11.6 Comparison of the complexity-index in each case study

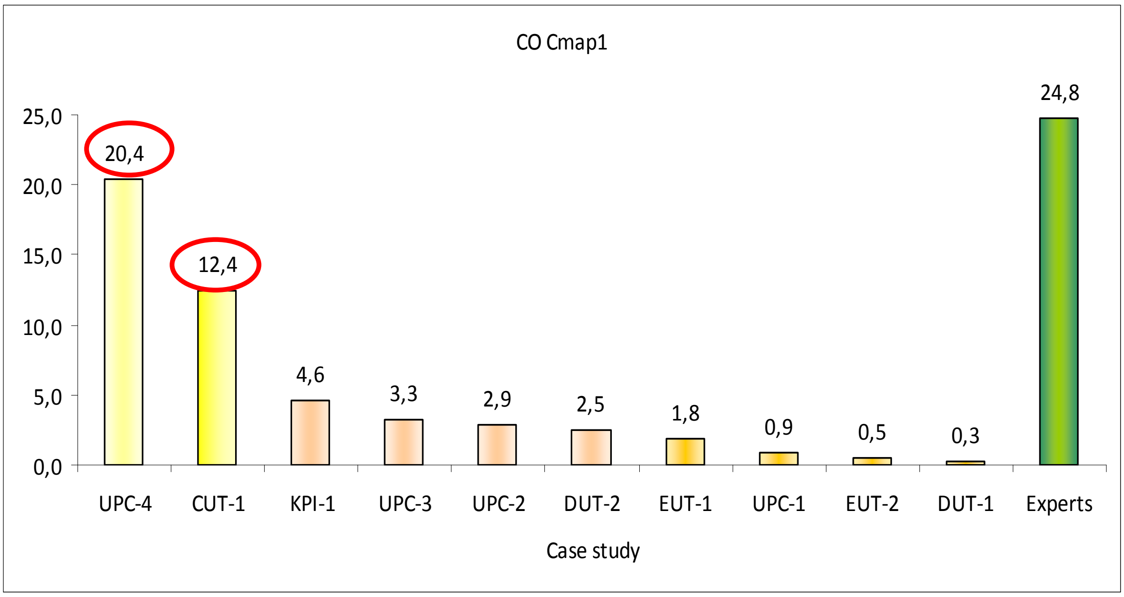


Figure 11.11 Complexity-index in each case study. Cmap1

The previous figure shows the complexity-index obtained in each case study before taking the SD course. The value of the experts' group is 24.8 and is the reference for the analysis. Students from the case studies with a high complexity-index, that is UPC-4 and CUT-1, consider Sustainability a complex issue even before taking SD. At a significant distance, follow 4 case-studies, led by KPI-1, whose complexity-index ranges from 4.6 to 2.5 with a decreasing trend. Finally, students from case studies UPC-1, EUT-2 and DUT-1 are the ones who most simplify the concept of sustainability.

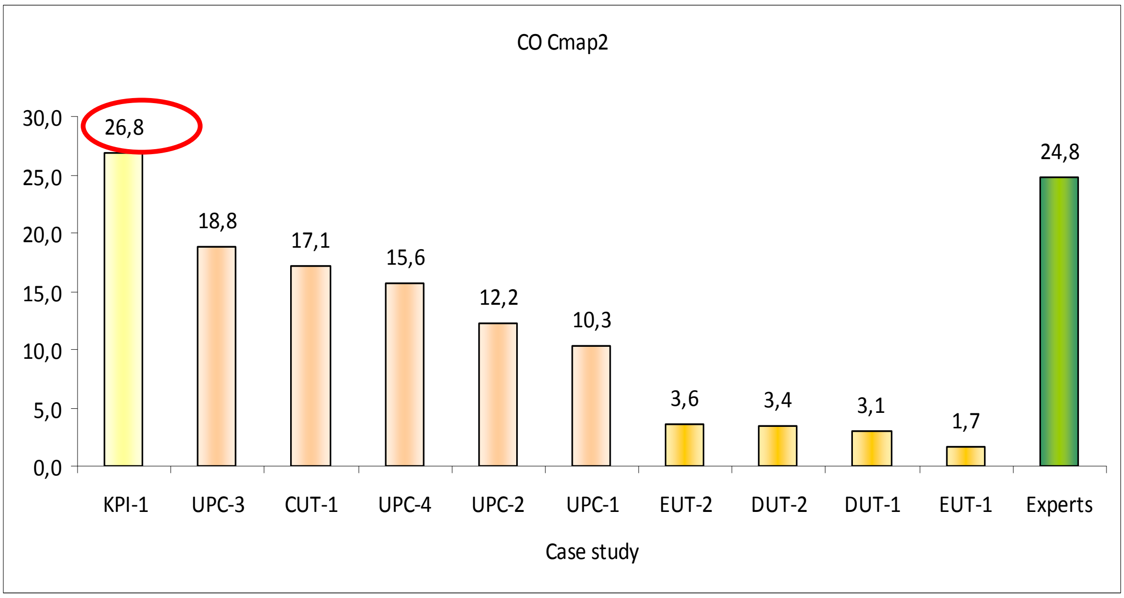


Figure 11.12 Complexity-index in each case study. Cmap2

In this last figure, the values of the complexity-index obtained in each case study after taking the SD course are shown and sorted from higher to lower values. The students from KPI-1 (26.8) are the ones who perceive sustainability as the most complex, even more than the expert reference group (24.8). At a small distance, follow case-studies UPC-3, CUT-1 and UPC-4 with values ranging from 18.8 to 16.6. A bit further on, with slightly lower values, we find case studies UPC-2 and UPC-1. Finally, the Dutch case studies are the ones with the lowest values, especially EUT-1 with a complexity index of 1.70.

The next figure shows the improvement achieved in each case-study by comparing the results of the complexity-index obtained before (Cmap1) and after (Cmap2) taking the SD course. Again, the reference value is the same, the one obtained by the experts' group.

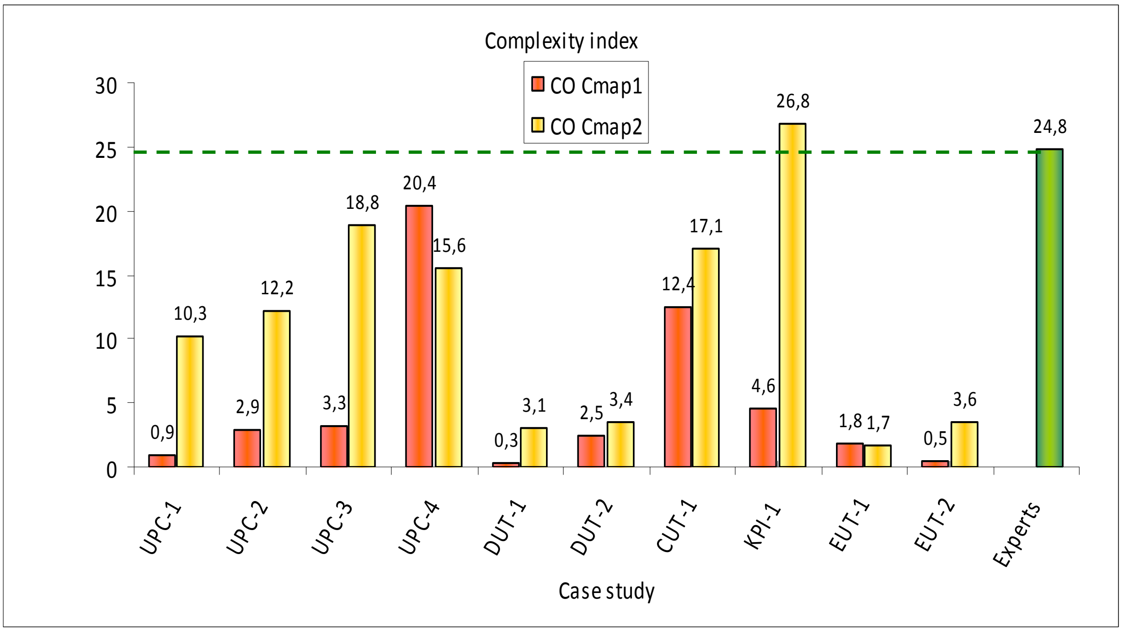


Figure 11.13 Evolution of the complexity-index in each case study

Before taking the SD course, the value of the complexity-index of most students was low. After taking the course, the value of the index increases for almost all students, but the increase is most significant in case study KPI-1. As already mentioned, the value of the index of KPI-1 is noteworthy, since it is even higher than the experts. After taking the course, the complexity-index value only decreases in two case studies, EUT-1 and UPC-4.

Again, the variability of the sample has also been taken into account when analysing the results. The same variables have been evaluated (nationality, speciality and gender of students) as in the previous analysis. In relation to the nationality of students, results showed in the analysed case studies that OECD students see Sustainability as a more complex concept than non-OECD students. However, after taking the SD course, the results get closer to the reference value for both OECD and non-OECD students. In relation to the speciality of students, no significant differences have been detected. As for gender, the analysis of the complexity-index (section 8.10) also showed similar results for both genders. Still, in three case studies (UPC-2, DUT-1, CUT-1), female students got slightly higher values after taking the SD course. Additionally, in only one case study (UPC-4), did male students get a significantly higher complexity-index.

Some considerations should be taken into account in the case study analysis. Some variables, which have not been analysed in the research methodology, may have influenced the results. These collateral variables are the following.

Students' cultural background: For instance, Spanish, Dutch and Swedish students all belong to OECD countries. However there are differences in the way the Spanish, the Dutch and the Swedish societies perceive Sustainability. Sweden is a country with a long history of environmental awareness and legislation, while in Spain environmental awareness started in the late eighties as result of the influence of European integration. This mismatch in the cultural background of students could also have affected the results obtained in this research.

Previous knowledge: Some students already had or were taking other courses about environmental or social issues.

The maturity of students: The students of two of the case studies (UPC-4 and KPI-1) were taking Masters courses. The synthesis skills for the knowledge representation of conceptual maps may be different between Bachelor and Masters students.

The duration of the case studies: The duration of the case studies is slightly different, ranging from 0.7 ECTS (case study DUT-1) to 7 ECTS (case study CUT-1).

Assessment procedure: Some of the UPC courses were distance courses. In these courses, the Cmap2 maps were submitted remotely and, therefore, there was no control of the time students took to draw the

Cmap. This could also affect the results. The kind of learning activity also affects the student's motivation to draw a conceptual map. For instance, in case study UPC-4, we detected that students were asked to draw the Cmap2 after the evaluation of a previous one-week intensive seminar in English (which was not the native language of any of the participants) after a week filled with lectures, debates in the mornings plus workshops and group work in the afternoons. After the evaluation of this seminar, they were rather exhausted. For that reason maybe the results of their Cmap2 showed a lower understanding of SD complexity than before.

11.3.5 Correlation between Category-Relevance and Complexity indexes

Two indexes to evaluate learning in SD have been defined and evaluated in 10 case studies: Category-relevance (CR) and Complexity (CO). But, is there any direct relation between them? To answer this question their correlation has been studied both before (Fig. 11.14a) and after (Fig. 11.14b) the learning action on SD. Specifically, for each case study, the absolute value of the complexity index (horizontal axis) has been correlated to the relative value of the category-relevance index in relation to the experts' reference values (vertical axis).

As was expected and is shown in figure 11.14, there is a direct correlation between both indexes. As the category-relevance distribution gets closer to the experts the complexity index increases. This correlation is kept both before and after taking the learning action on SD. However it is not enough to be capable of only using one parameter to simplify.

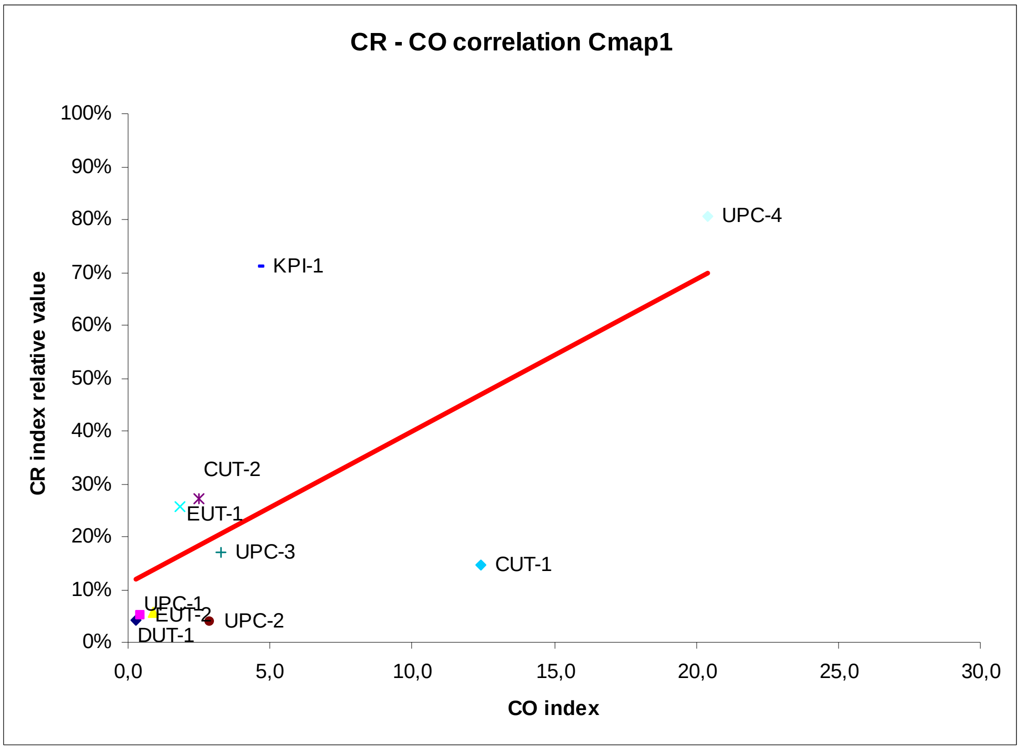


Figure 11.14(a) Correlation between category-relevance and complexity indexes

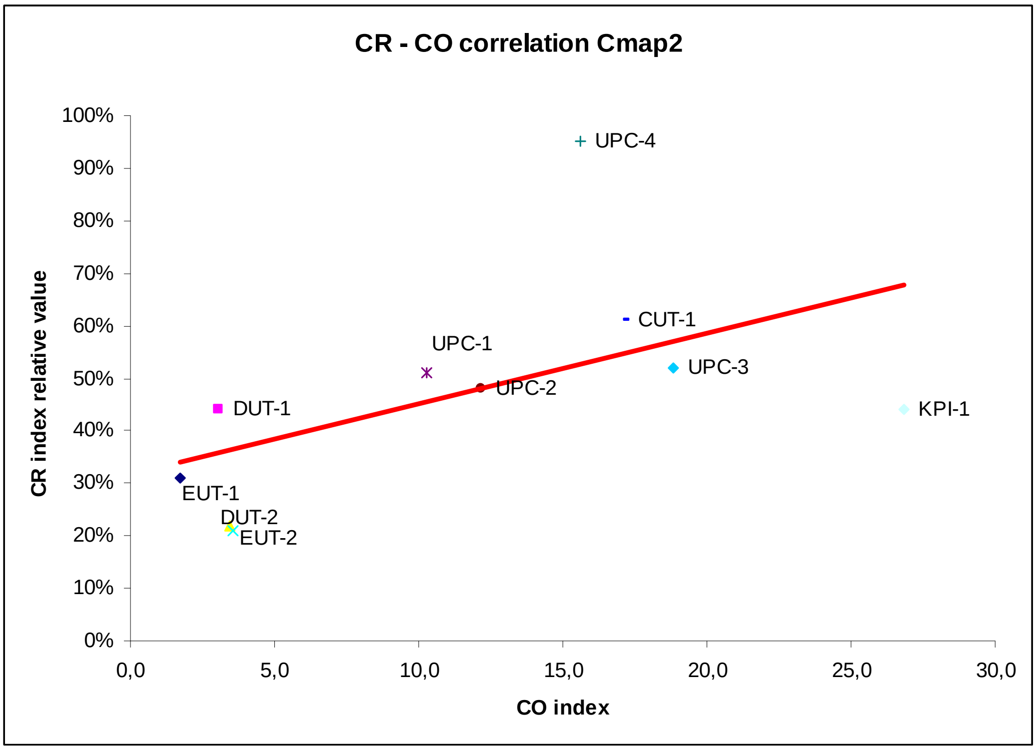


Figure 11.14(b) Correlation between category-relevance and complexity indexes

11.3.6 Analysing pedagogy versus learning

The pedagogy used in each case study, has been classified according to Horvath's topography of approaches of active learning. Figure 11.15 shows the situation of each case study on Horvath's topography as determined by the pedagogy used. The colour of case studies shows the learning achieved in each case study. Three colours have been used:

- Red: limited learning (lower category-relevance and complexity indexes).
- Yellow: medium learning
- Green: higher learning (higher category-relevance and complexity indexes).

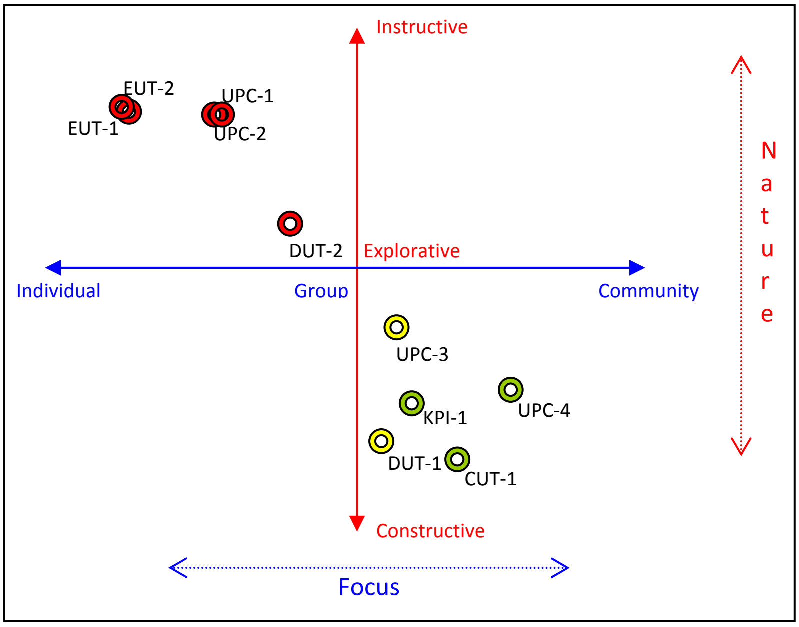


Figure 11.15 Topography of pedagogical approaches and learning of the analysed case studies

From the results shown in the figure, we may conclude that students achieve better cognitive learning as more community-oriented and constructive-learning pedagogies are applied.

In chapter 9, two enquiries are presented:

- Semi-structured interviews to 45 European EESD experts.
- A workshop on pedagogical strategies carried out during the last EESD conference held in September 2008 in Graz.

According to the experts and practitioners interviewed, Sustainability is a clear transdisciplinary concept, which asks for transdisciplinarity. Moreover experts also suggest that, taking into account that students learn in different ways, a broad range of pedagogical methodologies should be used, all of which should be based on active and cooperative-learning processes. Additionally, the enquiries analysis points out that the **role of the teacher** is essential: the "*practice what you preach*" quote is especially relevant if we want students to achieve attitudinal SD competences.

11.4 Curriculum analysis

Chapter 4 analyses the situation of curriculum engineering in terms of embedded SD. From the literature review, a SWOT scheme (see figure 11.16) is presented where the barriers and drivers to embed SD in the engineering curriculum are analysed. In the reviewed literature, four main strategies are proposed to embed SD in the engineering curriculum.

- First, a compulsory course for all 1st Cycle (Bachelor) graduates.
- Second, a minor or track on SD in both 1st Cycle and 2nd Cycle studies.
- Third, to assure the introduction of SD in the final thesis project.
- Finally, the most challenging is to intertwine sustainability in all the subjects/courses of the curriculum.

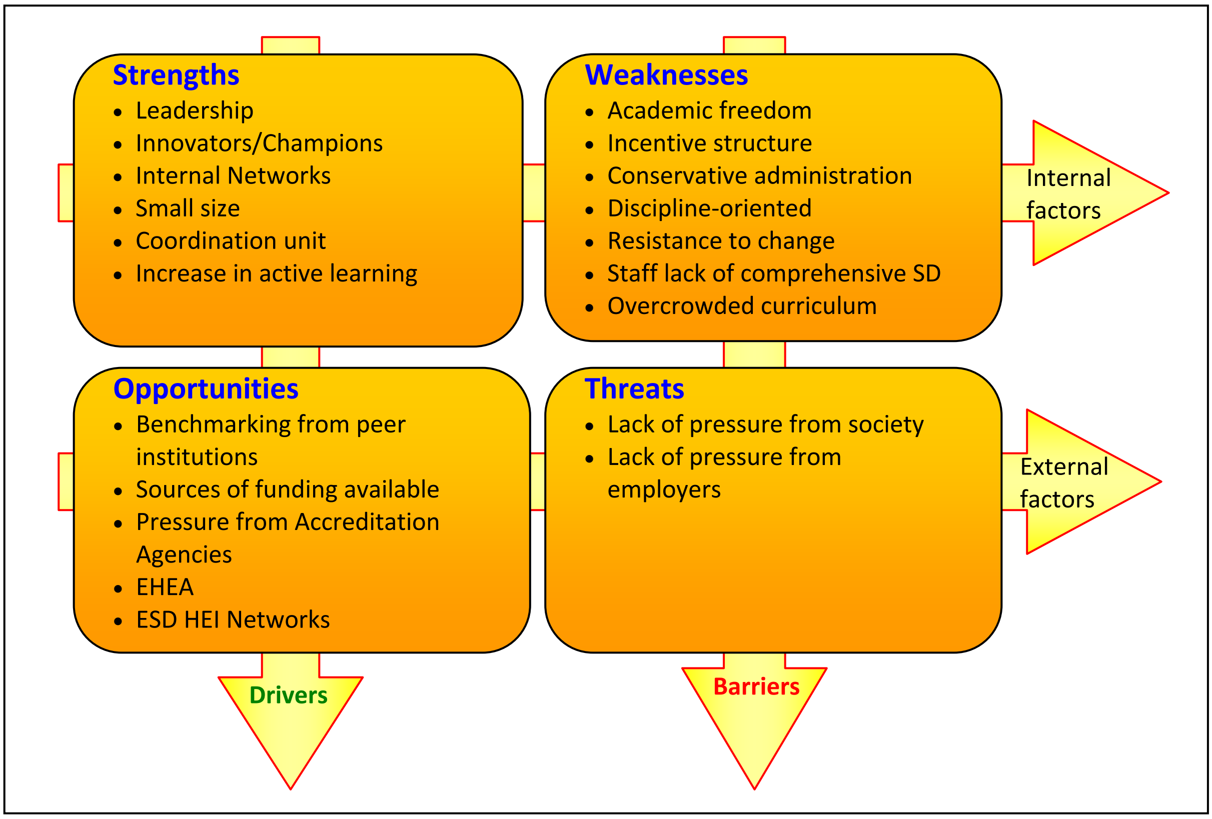


Figure 11.16 SWOT analysis of curriculum change for EESD

Up to the present, embedding SD in the entire curriculum has shown to be the most difficult strategy to achieve. The approaches applied so far (facilitating learning tools, developing learning materials, training lecturers, etc.) have shown to be necessary but insufficient. Nevertheless, individual interaction, a new avenue applied at DUT seems to open new horizons in order to increase the embedding of SD in the whole curriculum, though it is very resource demanding.

Chapter 10 includes the experts' opinions and experiences related to embedding SD in the engineering curricula. Experts confirm that the strategies used at their universities to introduce ESD correspond to the ones suggested in the literature review: to offer a specific SD course to all students; to offer the possibility of graduating with a minor or track in SD and the introduction of SD in the final thesis work.

In order to overcome faculty resistance when trying to embed SD in the entire curriculum, experts suggest the following approaches: make it clear that SD is not a threat, involve non ESD faculty to work in SD application projects with other departments, use multidisciplinary project based learning with SD-related problems and link professors to SD research.

At some universities some attempts have been made "to teach the teachers", but the results have been rather disappointing. There are several reasons for this lack of success:

- Teachers do not want to be taught, since it creates a threat to their sense of autonomy.
- Lecturers go through strong pressures to commit themselves to research. It is research that determines their careers, and education is often considered an obligation that needs to be accomplished with minimum efforts. Moreover, lecturers are also pushed to attain research money. Therefore lecturers feel an indirect pressure not to devote their time to investments in educational quality.
- Materials developed to be used by other lecturers in their teaching are not very effective. Most materials are left on the shelves.

The commitment of the university board has shown to be imperative in order to support the process of change. It is also important to have a centralized group who is responsible for developing a SD university wide policy. Moreover, it is also essential that all university departments are somehow involved in the attempts to introduce SD in the curricula. Therefore it is important to find allies in each department who will push ESD within their own department.

In conclusion, the ESD strategy should be encompassed in a broader strategy of embedding Sustainability in all university life. This is the "practice what you preach" approach which reinforces and legitimates the ESD process. Thus, the Sustainability strategy must involve all the key areas of the university: research, education, in-house management and social interaction.

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12 Conclusions and recommendations

This chapter, based on the findings of the previous ones, provides conceptual and theoretical reflections and ends with conclusions for the three areas studied in this research: SD competences, learning and pedagogy and curriculum development for ESD. Finally some recommendations and new fields of research for future development are presented.

12.1 Final Discussion and reflections

This research has been guided by three main questions.

1. Which SD competences must an engineer obtain at university?
2. How can these competences be efficiently acquired?
3. Which educational structure is more effective for the required learning processes?

The first question is a "*What*" question, which focuses on what competences (knowledge/understanding, skills/abilities and attitudes) a 21st-century graduate engineer should have in relation to SD. The second question is a "*How*" question and focuses on how can the educational processes make this learning achievable through the proper pedagogical strategies. The last question is a "*Where*" question that focuses on the favourable setting, that is the curriculum and the organizational structure which will encourage the optimal didactics to achieve the goal of graduating sustainable engineers.

12.1.1 The What: discussion and reflections on the competence analysis

What competences do engineers need to acquire in order to fulfil the sustainability demands of society? Defining these competences will improve the assessments which try to measure how well prepared engineers are to face SD challenges. The definition of these competences will also be useful to identify the overriding goals of the educational systems.

The description of competences embraces three strands which describe basic cognitive domains:

- *Knowledge and understanding*: the theoretical knowledge of an academic field, the capacity to know and understand.
- *Skills and abilities*: the practical and operational application of knowledge to certain situations.
- *Attitudes*: values as an integral element of the way of perceiving and living with others in a social context.

The question about competences has been analysed in chapters 2 and 6. Chapter 2 describes the state-of-the-art, while chapter 6 compares the SD competences of students from Delft University of Technology, Chalmers University of Technology and the Technical University of Catalonia (Figure 12.1).

A conclusion of these analyses is that the approaches have high commonalities. Most of the competences are related:

- *Critical thinking* is regularly mentioned explicitly (…is able to critically reflect…; .. "why" and "what if" reasoning…) and implicitly (…understand how their work interacts with society and the environment…) in sets of competences. The mental processes of discernment, analysis and evaluation from an open-minded point of view are often highlighted.
- Systemic thinking: Systems thinking is any process of estimating or inferring how local policies, actions, or changes influence the state of the neighbouring universe. It is an approach to problem solving that views "problems" as parts of an overall system, rather than reacting to present outcomes or events and potentially contributing to further development of the undesired issue or problem (O'Connor & McDermott, 1997)
- Inter-trans-disciplinarity is also important for SD taking into account both the participation of different professionals to solve problems and the involvement of stakeholders in processes that are seen as experts' jobs.
- Values and ethics are at the core of the meta-cognitive sets of competences. They are shown as the main force to change personal and professional attitudes for SD engagement.

In addition, the analysis of the SD-competences in the 1st cycle (Bachelor) degrees of the three universities reveals in more detail the common SD-competences clustered by key words for each cognitive domain. In this analysis, the level of achievement of the SD competences was also evaluated according to the taxonomies of Bloom and Krathwol (figures 6.1, 6.2 and 6.3 and table 11.1).

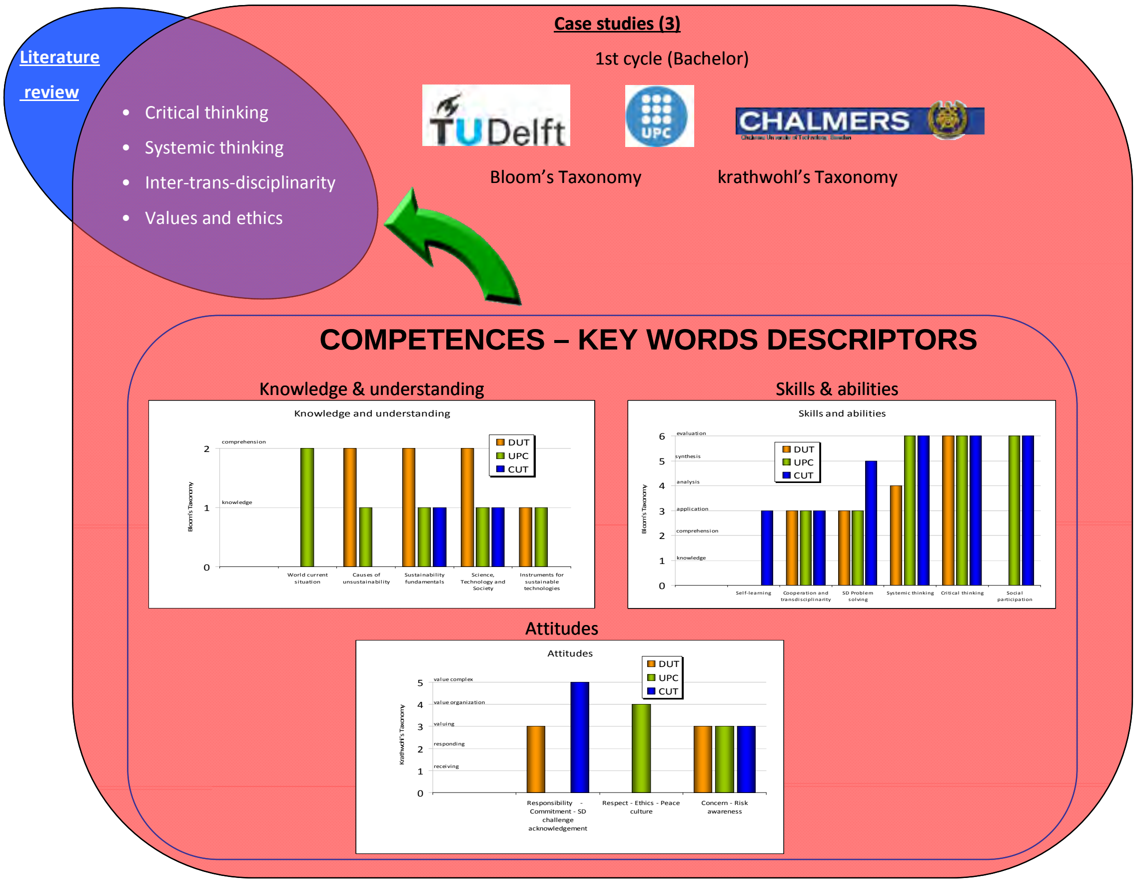

Figure 12.1 Methodological analysis of SD competences and results

The common SD-competences were grouped in the following way:

- Knowledge and understanding:
  - World current situation
  - Causes of unsustainability
  - Sustainability fundamentals
  - Science, technology and society
  - Instruments for sustainable technologies
- Skills and abilities:
  - Self-learning
  - Cooperation and transdisciplinarity
  - SD problem solving
  - Systemic thinking
  - Critical thinking
  - Social participation
- Attitudes:
  - Responsibility
  - Commitment
  - SD challenge acknowledgement
  - Respect
  - Ethical sense
  - Peace culture
  - Concern
  - Risk awareness

It is interesting to raise attention to the key words that have been chosen to describe SD-competences. In the future, these key words could be used by other universities, thus becoming a useful means for benchmarking and learning.

In the process of looking for commonalities between the three institutions, the main barrier to comparing the list of competences of the three universities was the way each institution described the competences. For instance, some competences embraced a full branch of actions and sub-competences (e.g. critical thinking), while other competences described a specific action (e.g. the ability to separate facts from values). Hence, the differences between the institutions pointed out items that should be reviewed at each of the universities, since they did not reflect different approaches (or real differences), but rather that the formulation of the competences had been different depending on the conditions (some competences might just have been forgotten) or the people involved. Some differences also reflected the culture in which they had been formulated.

These divergences, found in the description of competences by each university, complicated the classification under a common descriptor or key word and, furthermore, they revealed that the academic engineering community is not yet used to working with SD-competence descriptors. Consequently, one of the outcomes of this work is to contribute to the development of the SD-competence descriptors and to integrate them in first-cycle programmes. Thus, one of the aims of this work is to advance in the important learning process of formulating SD-competences in a comparable way. Hence, additionally, this work aims to advance how to make the required learning explicit, also for things that in a certain culture go without saying.

The competence definition is the first step to designing degree programs which ensure the acquisition of certain competences. This is why the description of the competences should be clear and unambiguous.

One key point of working with competences is their evaluation. Currently the SD competences are not easily assessed, and the difficulty lies mainly in their vague description. So, in order to facilitate their assessment, the description of SD competences should also include to what extent they should be learnt; in other words, the expected acquisition level of the competence should be made explicit. For this purpose, different learning taxonomies may be used, such as the ones used in this study: Blooms and Krathowls. One step further in the assessment of competences is to use rubrics[1] which can clearly facilitate the assessment process and make it more transparent by letting the students know what is expected from them. Nevertheless, the assessment of competences is, in itself, a whole field of research which is out of the scope of this study.

12.1.2 The How: discussion and reflections of the pedagogy analysis

The pedagogy question has been studied in chapter 3, which explains the state-of-the-art, in chapter 8, which presents 10 case studies, and in chapter 9, which describes the conclusions of the analysis of the interviews with ESD experts (Figure 12.2).

In order to achieve an effective education for SD, the reorientation of the pedagogy and the learning processes is a must; quoting the Barcelona Declaration (2004) "*teaching strategies in the classroom and teaching and learning techniques must be reviewed*". Also in this direction, experts are currently suggesting different schemes and actions to facilitate and promote this necessary pedagogical transformation in higher education institutions and, specifically, in engineering education.

The literature review in chapter 3 showed that education is an important condition but it is not a guarantee for change. In order to guarantee change, learning has to provide a deep knowledge of the basics of sustainability, and also has to capacitate students with the appropriate SD competences in relation to their future profession.

Several theories substantiate that sustainability needs systemic thinking. However, higher education is still set up on a mechanistic model that divides understanding into separate boxes. According to the experts and practitioners interviewed, we need to create a new pedagogical approach that optimizes the understanding of the flows of relationships between all kinds of concepts. Sustainability is clearly a complex and systemic subject (which includes environment, society, economy, values, the future, culture, diversity, technology, etc…) and therefore, it needs transdisciplinary teaching/learning processes. Furthermore, these processes should also be active and cooperative. Also, it should not be forgotten that the process of teaching ("the role of the teacher") is as important as the contents. Moreover, studies on learning reveal that students learn in different ways. Therefore a multi-pedagogical active methodology is needed in order to reach all students.

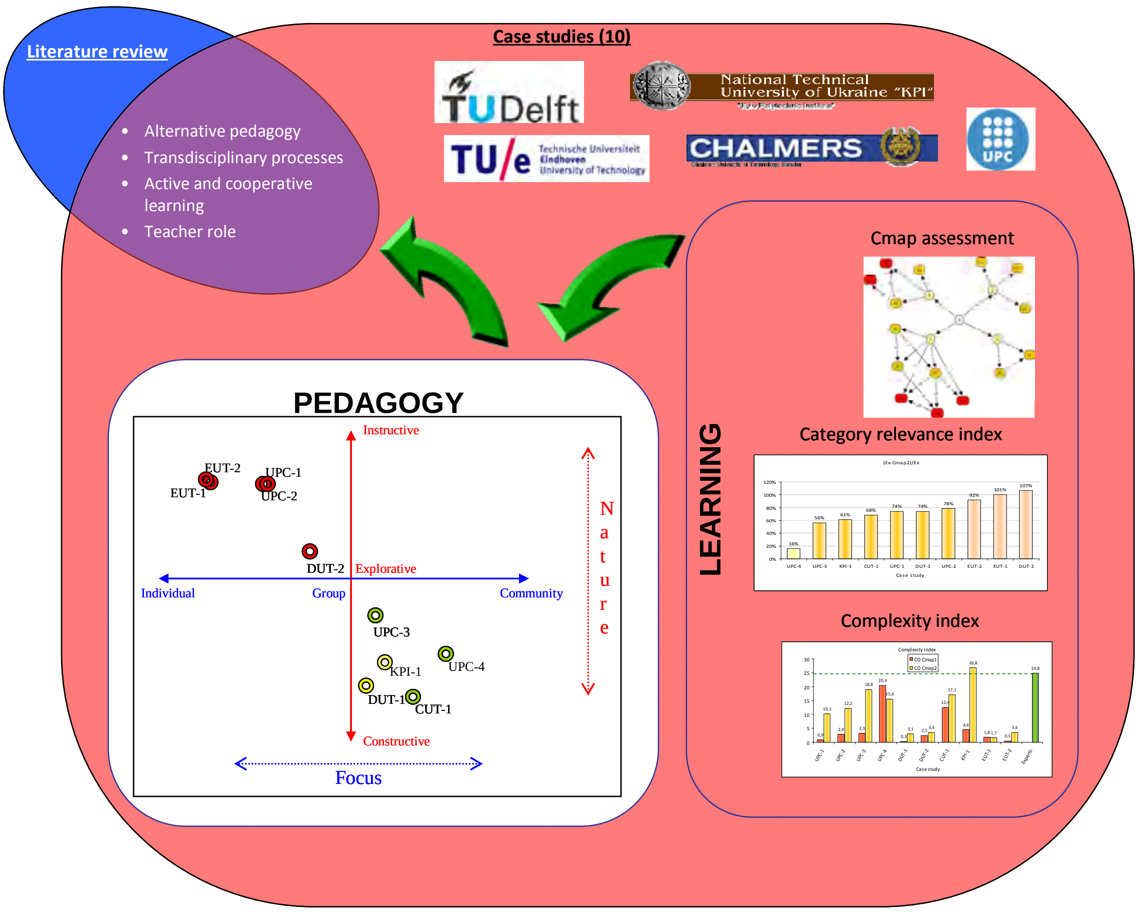

Figure 12.2 Methodological analysis of SD pedagogy and results

The following pedagogical methodologies are compiled from the interviews and literature review (see table 3.10 and figure 3.5):

- **Project-based learning** linked to real transdisciplinary projects; it is the most adequate pedagogy to learn SD competences in the three learning domains: knowledge and understanding, skills and abilities, and attitudes. However, PBL methodology embraces a set of pedagogical techniques which should also be used during the project development.
- **Lecturing** is a good method to introduce sustainability concepts in the first stages.
- **Case studies** can be used to explore specific issues such as different stakeholder perspectives, examples of actual practice, and demonstrations of where progress towards sustainability is going. Case studies can be taken from the real world and they might be useful for introducing systemic thinking (Scholz and Tietje, 2002).
- **Problem-solving** prepares students to be responsible. As a part of the problem-solving process, students must consider their own educational goal, which is likely to require introspection about their values, ethics and beliefs.
- **Role play** is an approach which simultaneously combines complexity, the setting of the situation, group work, and the student's autonomy and action. It makes students experience the stakeholders' point of view and facilitates transdisciplinary dialogue. It facilitates the introduction of critical thinking.
- **Backcasting** allows students to address long-term problems and sustainability solutions.

With the aim of validating the literature review and the experts' opinions, 10 case studies from 5 different universities in 4 different European countries have been analysed. The aim of the research on pedagogy has been to evaluate the pedagogical methodologies used when learning SD competences. This evaluation has been based on finding a correlation between the achieved SD learning and the pedagogy used. With this purpose 10 cases studies have been analysed. The 10 case studies encompass different typologies of pedagogy: from pure PBL, through a wide range of methodologies (role plays, simulation games, debates, cooperative learning) and students' interaction with the social community to a more instructional pedagogy. The case studies also cover different typologies of learning activities (distance and face-to-face courses, intensive seminaries and semester long courses). Finally they also comprise different cultural contexts: (4) Spain, (4) The Netherlands, (1) Sweden and (1) the Ukraine. The case-study analysis began with an evaluation of achieved SD-learning in the cognitive domain by students after taking a SD-learning activity (course or seminar). Then, the pedagogical methodologies used in each case study have been analysed. Finally, the correlation between the achieved learning and pedagogy used has been analysed. The characteristics of the case studies are presented in table 11.2.

Conceptual maps (Cmaps) have been the assessment tool used to evaluate student learning. With the aim of knowing the real understanding of SD by engineering students, Cmaps have been used with the lowest degree of directedness (no concepts, linking phrases or Cmap structures were provided). Due to this "open answer" possibility, the assessment of these Cmaps was more complicated. Therefore two indexes have been designed with the purpose of facilitating their assessment: the category-relevance index (CR - which provides information about what students think sustainability is most related to) and the complexity index (CO - it evaluates how complex students see sustainability). Also, a reference Cmap from SD experts has been defined. With this methodology it was possible to evaluate the cognitive domain learning or the knowledge and understanding of SD competences defined in the previous sections.

In order to define what is expected to be learnt in these kinds of specific sustainability courses and seminars, several EESD experts were also asked to draw an SD-related Cmaps. The results of the experts' Cmap analysis were taken as a reference to evaluate the results obtained by the students. Regarding the reference experts' Cmaps, experts have considerable knowledge regarding their field of knowledge and they emphasise the key sociological role of sustainability above the scientific/technological one. However, they are not neutral towards it: experts always consider their own discipline as the most important. So SD experts might also have this bias, thereby overemphasizing the specifics of SD such as transdisciplinarity, stakeholders' role, etc. Other approaches could also have been used for the research, such as using Cmaps from key professionals in the engineering fields, or even, taking into account the *post-normal science*[2] framework, which uses society stakeholders as experts. However, the evolution of the students' understanding throughout the courses, which gets closer to the experts, somehow validates the experts' reference.

Analysis of the category-relevance index: general trends

The results of the category-relevance index in the 4-category taxonomy reveal that, in most cases, students relate sustainability mainly to environmental and technological/economic issues, and they give little value to institutional and social aspects. This misunderstanding is only partially redressed by the courses. Furthermore, the results also show that some courses are more effective than others.

These results surprised some of the coordinators of the courses. Their initial goal was to raise the students' awareness of the importance of social and institutional aspects. By means of the Cmap assessment, they realised that, despite a small improvement, after taking the course, students still gave "too much" relevance to environmental and technological aspects. This is why some of the coordinators are thinking of restructuring their courses in order to increase the social and institutional relevance in the students' understanding of sustainability.

The analysis of the experts' Cmaps (see figure 12.3) shows that they relate sustainability mainly to *social* (30%) and *institutional* (32%) aspects and less to *technological* (21%) and *environmental* (16%) ones. These results reflect that they give more value to the **sociological role** in terms of how sustainability affects human-beings (social impact, unbalances, future) and how we feel that we can solve unsustainability problems (values, education and stakeholders). However, students' results before taking the SD courses show an opposing idea to the vision of the experts (see figure 12.4). Instead, they understand sustainability basically as a *technological* (46%) and *environmental* (34%) issue and they hardly relate it to *social* (8%) or *institutional* (9%) aspects. The results after taking the courses are quite similar to the previous ones: *technological* (40%), *environmental* (31%), *institutional* (16%) and *social* (11%). This reveals that students see sustainability basically as a **scientific-technological** subject in terms of the technological role to avoid and solve environmental problems.

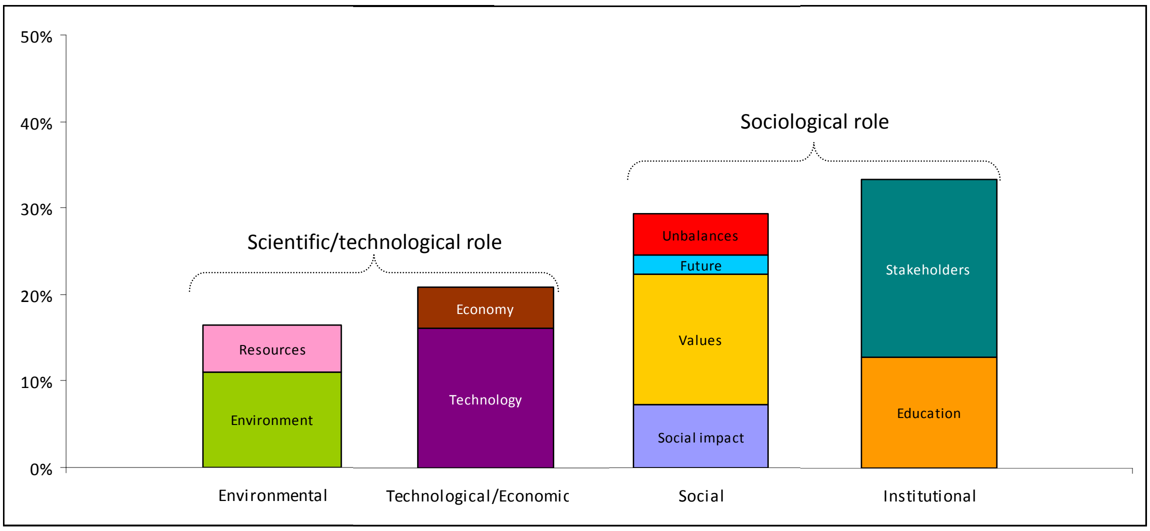

Figure 12.3 Experts category-relevance index values

The 10-category taxonomy (see figure 11.6) offers a more detailed analysis of the previous categories.

There, the more general *environmental* category is divided into two: *environment* and *resources*. The new analysis reveals that the *environmental* category values were so high in the previous analysis mostly because students relate sustainability too much to *environment* and a bit less to *resources*. Nevertheless, in all of the case studies, both categories have higher values than in the experts' reference.

The *social* category is divided into four: *social impact*, *values*, *the future* and *unbalances*. Very little importance was given to the broad *social* category in general. Even so, the distribution of its values shows that, before taking the course, most students gave almost no relevance to *values* and to *unbalances* and a little relevance to the *future,* while *social impact* was the one with the greater consideration. These trends remain the same after taking the courses, except for *unbalances* which shows a significant increase and for *values* which also increases its values a little. Nonetheless all four categories are still given too little importance after taking the course.

The *technological/economic* category is divided into two: *technology* and *economy*. Here there are large differences. While *technology* has very high values in all case studies both before and after taking the courses, *economy* has low values before taking the courses and, after the courses, its values increase and are almost equal to the ones given by the experts. Thus the category which should decrease its relevance is *technology*.

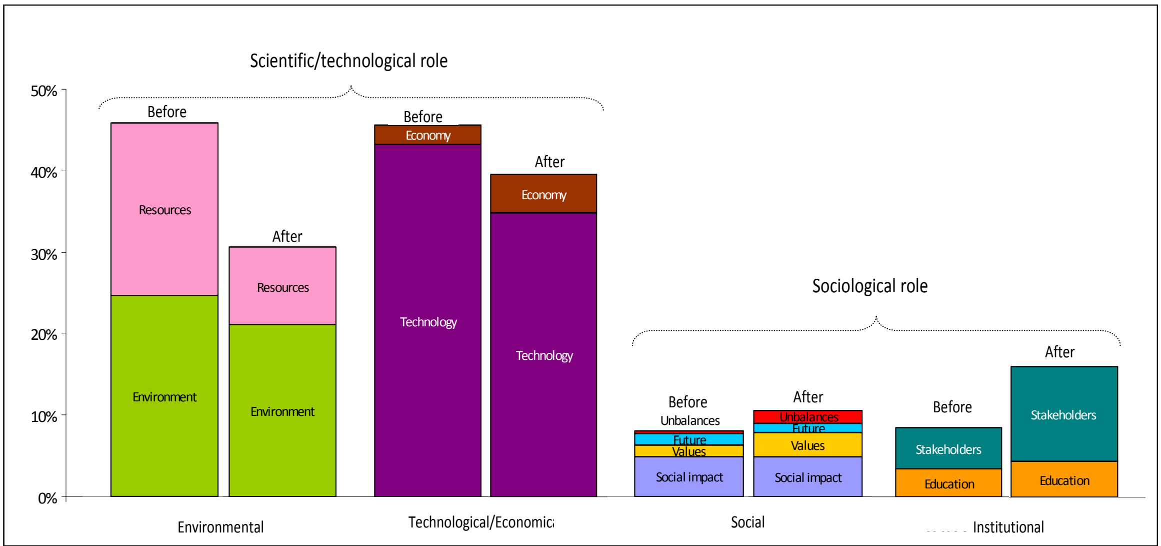

Figure 12.4 Students category-relevance index values: Cmap1 (before) and Cmap2 (after)

Finally the *institutional* category is divided into two: *education* and *stakeholders*. The *institutional* category is given almost no relevance for both *education* and *stakeholders*. Nevertheless, after taking the courses, the value of *stakeholders* shows a relative significant increase, although it does not reach the experts, while *education* hardly reveals any improvement.

<u>Analysis of the complexity-index: general trends</u>

Both before and after taking the SD course, the value of the students' complexity-index was very low in most case studies. These low results might be explained due to two reasons. The first one is that students perceive that sustainability is not very related to social and institutional aspects, and therefore they hardly included concepts in these areas. Another reason is that they see sustainability as a barely complex issue, so they mainly linked intra-category concepts and included few inter-category links (See figure 7.2). These results may be explained by the lack of SD understanding in terms of <u>systemic thinking</u> (inter-links) and <u>transdisciplinarity</u> (no *social* and *institutional* concepts). The analysis of the SD competences in the cognitive domain showed that engineering students should have both competences of systemic thinking and transdisciplinarity, when graduating. Therefore more efforts should be placed on the pedagogy and the contents of the SD courses in order to ensure the acquisition of these competences.

<u>Correlation between the category-relevance and the complexity indexes</u>

Two associations show up in the previous reasoning. First, more transdisciplinary learning is achieved in the case studies as their Cmaps get closer to the reference one. Second, more systemic thinking learning is acquired as the complexity index values become higher. Therefore, taking into account the high correlation between the category-relevance and complexity indexes (see figure 11.14), it may be concluded that there is a <u>direct relation between transdisciplinary and systemic thinking learning</u>. This relation has also been stated by some authors (Oxley & Lemon, 2003; Wadsworth, 2008).

<u>Analysis of the category-relevance index: results by case study</u>

Each case study has been analysed independently and the most relevant results are shown. Before taking the course, the results of two case studies, UPC-4 and KPI-1 (see figures 11.9 and 11.10), are close to the experts. The results that were closest to the experts correspond to case study UPC-4 which included a sample of students who were taking a Masters in SD; therefore they had already been exposed to SD contents. These results are followed by results from case KPI-I. The students of this sample had never taken any sustainability course, and nonetheless they still gave relatively high relevance to the *social* and *institutional* categories. This may be attributed to the fact that these students are from the Ukraine, where there has been a fast transition from communist planning to ‘wild west’ capitalism, which could explain that for them *social* and *institutional* aspects are considered the most relevant. This trend is also corroborated by the nationality analysis between OECD and non-OECD students included in this research. All the other case studies show the same pattern: they give a lot of relevance to *environmental* and *technological/economic* categories and little to the *social* and *institutional* ones.

After taking the courses, again it is case study UPC-4 is the one whose results are closer and almost the same as the experts. The second closest case studies closer to the reference group are UPC-3 and KPI-1. The results of the other case studies also show a tendency towards the reference, as the values of the social and institutional categories increase and those of environmental and technological/economic categories decrease. Despite this tendency, their results after taking the course are still quite far from the experts.

Analysis of the complexity index: specific case study trends

In relation to complexity (see figure 11.13), before taking the courses, UPC-4 and CUT-1 are the case studies which see sustainability as more complex than the other ones. This is attributed to the following reasons: As mentioned before the UPC-4 sample, previous to the research, had been exposed to sustainability knowledge, therefore it seems reasonable that students see sustainability as a complex issue before taking the course. The CUT-1 sample is from Sweden, a country with a long history in environmental protection and education, this is the reason why students were more aware of the inter-relationships of sustainability issues. This contextual variable is analysed in more detail in the followingparagraphs. All the other case studies have an extremely low value for complexity. It reveals that students do not relate sustainability to any complexity. This could be attributed to the educational disciplinary approach that the students, during their university studies, have been exposed to, making it difficult to inter-relate disciplines and cause-effect processes. After taking the courses, most case studies raised their complexity vision, especially for case studies UPC-3 and KPI-1.

Taking into account the category-relevance and complexity indexes it can be concluded that the case studies where the learning was most significant are UPC-4, CUT-1 and UPC-3 followed by KPI-1 and DUT 1. Finally the worst learning results are for the EUT-1, EUT-2, UPC-1, UPC-2, and DUT-1 case studies.

In relation to the sensibility of the assessment system, a comparative analysis between two evaluators has been carried out in order to raise the validity of the evaluation process. Specifically in case study CUT-1, two evaluators, with different background and from different countries, analysed the Cmaps drawn before taking the course separately. The evaluators were: Jordi Segalàs from UPC (Spain) and Magdalena Svanström from Chalmers University of Technology (Sweden). The comparison of their evaluation (section 7.4) shows that there are few differences between the results of the two evaluators. Therefore the methodology can be considered consistent and exportable. However defining a common Cmap evaluation pattern would facilitate the evaluation process and render more accurate and comparable results.

The results of the analysis showed that while experts emphasise the key sociological role (social and institutional) of SD above the science/technological one, students relate sustainability more to environment and technology than to societal aspects. Moreover, experts see sustainability as a complex subject, while students simplify their vision of SD. Nevertheless, comparing the results obtained before and after taking the courses, it is clear that the results of the students improve significantly (depending on the case study). The mismatching results between the experts and the students are attributed to the students’ lack of SD cognitive competences in systemic thinking, transdisciplinarity and the social role of sustainability. Therefore more efforts should be placed on the pedagogy and contents of the SD courses in order to ensure the acquisition of these competences. Nevertheless it is normal that the students’ results differ, to some extent, from the experts. Experts have been working and researching in the field for a long period of time, and most students have “merely” taken a course on SD.

Some considerations should be taken into account in the case study analysis. Some variables, which have not been analysed in the research methodology, may have influenced the results. These collateral variables are the following:

Students' cultural background: For instance, Spanish, Dutch and Swedish students all belong to OECD countries. However there are differences in the way the Spanish, the Dutch and the Swedish societies perceive sustainability. Sweden is a country with a long history of environmental awareness and legislation, while in Spain the environmental awareness started in the late eighties as result of the influence of the European Commission. This mismatch in the cultural background of students could also have affected the results obtained in this research.

Previous knowledge: Some students already had or were taking other courses about environmental or social issues.

The maturity of students: The students of two of the case studies (UPC-4 and KPI-1) were taking Masters courses. The synthesis skills for the knowledge representation of conceptual maps may be different between Bachelor and Masters students.

The duration of the case studies: The duration of the case studies is slightly different, ranging from 0.7 ECTS (case study DUT-1) to 7 ECTS (case study CUT-1).

Assessment procedure: Some of the UPC courses were distance learning courses. In these courses, the Cmap2 maps were submitted digitally and, therefore, there was no control of the time students took to draw the Cmap. This could also affect the results. The kind of learning activity also affects the student's motivation to draw a conceptual map. For instance, in case study UPC-4, we detected that students were asked to draw the Cmap2 after the evaluation of a previous one-week intensive seminar in English (which was not the native language of any of the participants) wiht lectures, debates in the mornings plus workshops and group work in the afternoons. After the evaluation of this seminar, they were rather exhausted. However, the results of their Cmap2 were still the best ones.

Compulsory versus elective courses: The nature of the course can affect the results. Usually students who take an elective course on SD are more motivated to learn about SD than students taking compulsory courses, as they don't need to have a predisposition to see the relationship of SD to their speciality of studies, this has been shown to be relevant specially for ICT students.

Nevertheless the results obtained from the evaluation seem to be very reasonable and confirm that Cmaps are a very useful tool to evaluate cognitive learning.

Once the case studies' learning had been evaluated, the correlation between the learning and the pedagogy used at each case study was studied. The pedagogy used in each case study is summarised in table 11.2 and has been classified according to Horvath's topography of approaches of active learning (Horvath et al., 2004). Figure 11.14 shows the situation of each case study on Horvath's topography as determined by the pedagogy used.

From the results shown in the figure 11.14, we may conclude that students achieve better cognitive learning as more community-oriented and constructive-learning pedagogies are applied:

- The philosophy of group and community-oriented approaches depend on the dynamic interaction and collaboration of multiple learners. Moreover the interaction with stakeholders increases the effect of the community approach, facilitating the introduction of transdisciplinarity.
- The theory of constructivist education explains that learning is a process of construction and confrontation of meaning, rather than of exploration and memorization of facts. In addition to the construction of meaning, it emphasizes the social aspects of learning, the interactions with the environment, the distributed cognition and the endeavour of completion. It facilitates systemic and critical thinking.

Comparing the learning results with the pedagogy used in each case study, it is demonstrated that the more active the learning, the more focused on community and the more constructive, the higher the cognitive learning achieved by students. It is important to highlight that active learning education (ALE) is not only good for SD competences, but also for all other kinds of competences, for example to train engineering students to apply knowledge in practical situations, to train communication skills, or to prepare for a career of "life long learning", etc. (De Graaff and Christensen, 2004; Raucent et al., 2005). Usually ALE increases the percentage of student success and this is especially important in engineering education where the student dropout rate is very high. Moreover, there is a growing awareness that, within a comparatively short period of time, it is no longer possible to train engineers for a long career. Therefore, and in line with the EHEA, "learning to learn" has become one of the most important learning goals in engineering education, and this has increased the popularity of active learning methods in engineering curricula (De Graaff et al., 2005).

Despite all the advantages of active learning education, Bonwell and Sutherland (1996) identified the following major barriers to implementing active learning in the classroom: the "coverage" problem (the ability to cover all or most of the syllabus); increased time of class preparation; large classes; limited or lack of skills, resources and support; and the risks of colleagues' disapproval, student dissatisfaction, and significance in promotion and tenure decisions. Perhaps the most important is the recognition that changing how we teach is more difficult than changing what we teach. Barriers to changing how we teach included a general lack of knowledge about learning among faculty and students, fear of the uncertainty that comes with change (both faculty and students), reluctance to devote the additional time that change requires, and lack of specific data in many instances to assert that change would be helpful (Hall et al., 2002). The following specific actions may help to lower these barriers to change: include the participation of all department faculty members in a careful strategic planning process that leads to a mandate for change; create an environment within the university where excellence in teaching is increasingly valued and rewarded; release faculty members from other duties to enable them to focus on these activities; facilitate learning activities on teaching (having access to workshops in the college, on the campus, or at professional conferences); authorize experimentation with new ways of teaching without initially risking low annual teaching evaluations, and get access to instructional consultants and good teachers to serve as coaches and mentors (Dee Fink et al. 2005).

12.1.3 The Where: discussion and reflections on curriculum structure

The curriculum question is introduced in chapter 4 and further developed in chapter 10 with the curriculum greening approaches carried out in ESD-leading universities and with the analysis of the interviews to ESD experts (Figure 12.5).

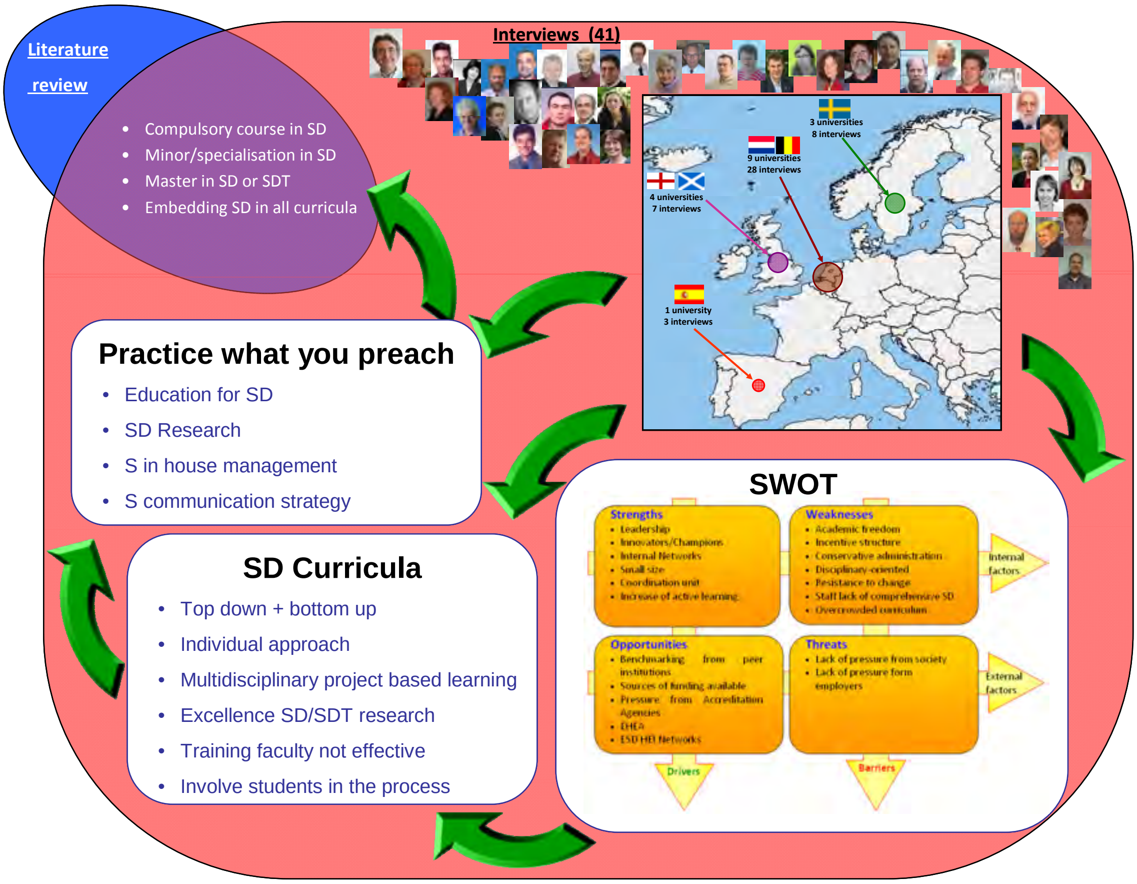

Figure 12.5 Methodological analysis of SD curriculum and results

It could be considered that the ideal curriculum is the curriculum in which SD is embedded in all the courses. This would mean that all faculty knows how its courses were related to sustainability and introduced the SD competences in terms of contents, skills and attitudes in their teaching. However, the current situation is far from ideal and some approaches have shown to be successful in order to increase the acquisition of SD competences by engineering students. These complementary approaches are:

- To offer a compulsory course for all 1st Cycle (Bachelor) graduates.
- To offer a minor or track on SD in both 1st Cycle and 2nd Cycle studies.
- To ensure the introduction of SD in the final thesis project.
- Some technological universities have chosen to offer a specific 2nd cycle degree (Masters) in SD (See section 10.2).

The major limitation for embedding sustainability in the engineering curriculum is the academic culture. Faculty lack of comprehensive SD makes it feel threatened in its autonomy. Academic staff is not used to dialogue with regard to the content of teaching or research. This prevents adequate reactions to new societal challenges like SD. Integrating SD into a course is tricky if the lecturer feels insecure regarding his/her power position in the department: it might trigger discussions regarding the credit points of his/her course, that are potentially a threat to his/her academic credibility, i.e. his/her position. Overcoming this resistance is the key point to embedding SD in the curriculum. In that direction the following approaches are proposed:

- Make it visible that SD is not a threat. Instead it should be explicitly shown that there are inherent linkages which are implicit in each discipline by illustrating that there is something to be gained and that there are opportunities emerging from SD for the faculty and for their disciplinary fields.
- The individual approach is a good way to involve lecturers (Peet et al., 2004; Holmberg et al., 2008).
- Involve non ESD faculty to work in SD application projects with other departments. This helps the faculty to better comprehend sustainability, since it is applied to their field of expertise.
- Use multidisciplinary project based learning with SD-related problems. This will raise SD awareness of non SD teachers who participate in the projects.
- Earn some respect from your colleagues, by doing a good job and then, ask them for some collaboration and join somehow.
- With excellence: by linking professors to SD research, rewarding ESD pioneers and promoting excellence in research on SD.

In order to change the faculty's attitude towards ESD, we need to create a teaching/learning arena in which reflection processes question disciplinary principles and values and enable lecturers to experience the added values of systemic thinking and transdisciplinary approaches. SD learning requires more than classroom discussion; it requires practice in real-life settings. The university campus which can serve as a useful laboratory to test ideas and methods of SD implementation may become this necessary arena. From an educational and research perspective, opportunities to learn about sustainability exist all around the campus. Some experiences of this learning environment approach have already been implemented (Steinemann, 2003; Pujadas, 2004).

A crucial aspect to success is the real commitment of the university board to support the process of change needed in the universities. This commitment has to embrace different strategies, from promotion and tenure to SD strategic plans in all the key areas of the university such research, in-house management, social interaction and of course education. In other words, the ESD strategy should be encompassed in a broader strategy of embedding sustainability in all university life. This is commonly referred to as the "practice what you preach" approach which reinforces and legitimates the ESD process.

As in any other management activity, it is also necessary to develop a quality management plan which encompasses the closed quality loop: plan, develop, assess-monitor-control, and re-plan. In this sense, indicators and external audits have shown to be useful to evaluate progress. Some institutional assessment tools of Sustainability in higher education (Shriberg, 2002) already exist and they can help to monitor the process.

It is also important to have a centralized group who is responsible for developing, ensuring and monitoring progress of SD university policy. Because it can apply the board SD planning and catalyse the SD embedding process. Moreover, all university departments should be somehow involved in the attempts of introducing SD in all their areas of influence. Therefore it is important to find allies in each department who become the committed actors that push ESD within their own department.

The ultimate goal is to transform the university itself (education, research, in-house management, urbanism, mobility, stakeholders outreach, etc.) into an SD organization, this transformation being itself an experiential learning[3] opportunity which should not be disregarded: use the university itself as a space of reflection and experimentation where new SD knowledge is created and experienced by faculty and students. Students should be taken into account to catalyse this necessary change, because they usually have been one of the driving forces of renewal in HEI (Dawe et al, 2005; Kelly, 2006). Moreover the change management process at universities should involve reforms in order to create consensus among academia but it also needs to transform somehow the faculty in order to create the real transformers, otherwise the change within the university will be superficial and ESD will be another artificial patch in the traditional education system.

Does education relevant to SD require its own protected incubating environment to survive? Otherwise, by attempting to instil it throughout the traditional curriculum and traditional disciplines, will it be swallowed up and marginalized? Given that much needed research for sustainable development has to focus on larger system changes and the fact that government and industrial support is likely to be traditional – or at the most multi-disciplinary – the necessary research for sustainability has to be incubated and protected and it has to have a long-term focus.

Even if the technical options to do so do exist, how can it be safe for courageous students to take educational paths different from traditional tracks? The insecurity of future employment also makes this a high-risk venture for them. Therefore, the establishment of government programs for sustainability research where the evaluators/"peer reviewers" of the research proposals are transdisciplinary themselves is essential. Otherwise, innovative cross-cutting research will not be encouraged or funded. In addition, governments should be committed to hiring the early graduates of the programs – and providing incentives to the private sector to hire graduates of multi- and trans-disciplinary programs. There is a need for government to "make a market" to lead this educational innovation (adapted from Ashford, 2004).

12.2 Conclusions

Conclusions of this thesis are clustered in the 3 areas of study analysed: Competences, Pedagogy and Curriculum.

In the **competence** area -the *what* question-, the conclusions of this work are the following:

- From the literature analysis and benchmarking of the three ESD active European technological institutions it is concluded that engineering students must have acquired the following SD competences when graduating: **critical thinking**, **systemic thinking**, to be able to work in **transdisciplinary** frameworks, and to have **values** consistent with the sustainability paradigm. These competences have been defined more explicitly under key words in tables 6.4, 6.5 and 6.6, where they have been sorted by the learning domains: knowledge & understanding, skills & abilities and attitudes.
- In order to fulfil the requirements of the European Higher Education Area in terms of degree comparison and student mobility, it has been proved that while the definition of competences is broadly converging a **common framework to define, describe and evaluate competences is needed**.

In the **pedagogy** area -the *how* question-, the conclusions of this work are the following:

- It has been demonstrated that **the conceptual maps-based assessment process designed for this research is adequate** to measure cognitive learning on sustainability.
- It has been empirically demonstrated, by applying Cmaps, that EESD experts highlight the sociological role of sustainability in terms of how sustainability affects human-beings and how the unsustainability problems can be solved, while most students, after taking a course on SD, highlight the technological role of sustainability in terms of technology as the solution to environmental problems. This mismatching reveals that **SD courses need to place more emphasis on the social/institutional** side of sustainability.
- It has been proven, through the category relevance and complexity indexes analysis, that **there is a direct relationship between transdisciplinary and systemic thinking learning**.
- It has been experimentally verified that students achieve better cognitive learning as more community-oriented and constructive-learning pedagogies are applied. **Multi-methodological experiential active learning education increases cognitive learning of sustainability**.
- The qualitative research, interviews and literature review have revealed that, for SD learning, the role of the teacher is very important in terms of implicit learning of sustainability values, principles and critical thinking.

In the **curriculum** area -the *where* question-, the conclusions of this work are the following:

- It has been shown that there are mainly four approaches to increase EESD in universities: a specific course, a minor/specialization in SD, a Master on SD or Sustainable Technologies and the embedment of SD in all courses.
- It has been identified that, according to the experts' interview research, **the main barrier to embedding SD in all courses is the faculty lack of SD comprehension.** The individual approach has shown to be a successful approach to overcome this barrier.
- It has been identified that there is a need of clear top-down leadership in the ESD process, which must promote the bottom-up approach. Also, that ESD processes are reinforced when they not only encompass education but also all the key areas of the university: research, management, and society outreach.

12.3 Recommendations

Based on the results of this research, recommendations can be made to various groups of actors. This section includes recommendations to (1) people in charge of competence descriptions; (2) educational researchers using conceptual map tools; (3) university managers and (4) faculty.

Recommendations to define SD competence descriptors

Through this research, it has been shown that the way competences are described complicates their understanding, and thus the comparison of different degrees and students mobility between universities (these last two are key objectives of the EHEA). Therefore a common framework for competence description could be of significant help. This framework would facilitate the understanding and assessment of competences. The CDIO[4] initiative is a first step in this direction although not all European technological universities are involved in it. This common framework is particularly critical for generic competences such as SD, which should be embedded and assessed throughout the entire curriculum.

Recommendations to educational researchers using Cmap assessment

Cmaps have shown to be an appropriate assessment tool to evaluate cognitive knowledge. During this research some aspects to be improved arose. The first aspect is that students need previous training in building their conceptual maps, since the fact that many students did not use linking words to link concepts complicated the categorisation of concepts. The second aspect refers to the evaluation process: In this research when explaining the procedure to the students on how to draw a Cmap we used the same slides to introduce the subjects and left 15 minutes for the students to draw a Cmap. To obtain comparable results from different case studies, it is important to supervise the period of time left to draw the Cmap. Finally, a third aspect is that the assessment of the conceptual maps should be systematised. In this regard, appendix 4 introduces the assessment procedures used in this study. It should also be noted that in this research, the assessment results from two different evaluators with no previous guidelines have been compared and the results obtained were considered to be sufficiently equivalent.

Recommendations to university Managers

The top-down approach has shown to be necessary to succeed in ESD. Therefore the role of university managers is crucial. The most efficient top-down strategies implemented in the analysed universities are both a strategic plan (Vision-Mission-Action Plan-Unit Tesponsible-Time Planning-Funding) and a quality plan (Plan-Implement-Measure-Evaluate-Replan). Additionally, university managers may also promote the bottom-up avenue with more participatory approaches. For example, it is important to dynamise and support the ESD activities proposed by the faculty. The individual approach is a successful methodology to embed SD in the curriculum and involve faculty in the process. Another suggestion is to identify key ESD faculty in each department and give them the resources and responsibility to spread SD within their own department, ensuring supervision and coordination processes.

Recommendations to teachers willing to introduce SD in their subjects

Teachers who are motivated for ESD should work in two directions. The first one is to learn SD and ESD. There are many learning resources in EESD, both in the broad meaning of SD and also in relation to specific engineering specialties that can be applied to their courses (see appendix 5). The second is network with colleagues within their department and university in order to share experiences and increase their voices within the university structure. Here the role of a centralised unit in the university which can catalyse the process is very important.

12.4 Further research

This thesis has opened a field of systematic study in EESD, and has shown there are many questions to be investigated when entering that new research domain. Although some answers have been given, more questions have been opened, which were not necessary there when the investigation started. Some of these are the following:

- In the competence area, the first part of this study has focused on the definition of competences and benchmarking of SD competences for 1st cycle degrees. It would be complementary and of interest to study the SD competences for 2nd cycle degrees.
- Another field of research is competence assessment. Cmaps have been used to assess cognitive learning, but more research is needed in order to evaluate meta-cognitive learning like skills, abilities and attitudes.
- In the learning area, this research has focused on evaluating the learning achieved after taking specific sustainability courses/seminars. Further research is needed to evaluate the learning of SD of students through other less formal activities which might affect in a higher manner the non-cognitive domain. In that direction, PhD research work at the UPC has already started.
- Also, it is of interest to study what happens actually after graduating and how this SD learning affects the graduates' professional activity. Follow-up of graduated and their SD perception and action is of high interest.
- In the pedagogical field, as suggested in the previous sections, an interesting development would be to use universities themselves as experimental laboratories to create ecological/alternative and learning environments and monitor their effectiveness for ESD.
- It has been proved that the main barrier to embedding SD in the engineering curricula is faculty; therefore, research into evaluating faculty comprehension of SD and ways of involving them in the ESD process is necessary. It has to be said that a PhD research on faculty comprehension of SD has already started at the UPC.
- It would be very interesting to monitor SD learning during all the university life of students in order to evaluate which learning processes are more effective. In that sense a long term research would be to evaluate SD comprehension of students arriving to higher education; followed by the continuous evaluation of their SD learning in the university and, finally, also evaluate how SD learning influences their professional live after graduating.

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[1] A rubric is a scoring tool for subjective assessments. It is a set of criteria and standards linked to learning objectives that is used to assess a student's performance on a paper, project, essay, or other assignment. Rubrics allow for standardised evaluation according to specified criteria, making grading simpler and more transparent.

[2] Post-Normal Science is a concept developed by Silvio Funtowicz and Jerome Ravetz. It is simply an extension of situations routinely faced by experts such as surgeons or senior engineers on unusual projects, where the decisions being made are of great importance but where not all the factors are necessarily knowable. Although their work is based on science, they must always cope with uncertainties, and their mistakes can be costly or lethal. Because of this, advocates of post-normal science suggest that there must be an "extended peer community" consisting of all those affected by an issue who are prepared to enter into dialogue on it. They bring their "extended facts", which will include local knowledge and materials (Funtowicz and Ravetz, 1993).

[3] Experiential learning theory defines learning as: the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience (Kolb, 1984).

[4] CDIO™ INITIATIVE, is an innovative educational framework of curricular planning and outcome–based assessment for engineering universities and schools. CDIO formed *focus groups* of industry representatives, engineering faculty and other academics, university review committees, and alumni in order to compile a list of the abilities needed by engineers. The outcome of theses groups is the CDIO Syllabus, which objectives are to create a clear, complete, and consistent set of goals for undergraduate engineering education, in sufficient detail that they could be understood and implemented by engineering faculty.

Index of tables

Index of figures

Appendix I

Transcript of the semi-structured questionnaire:

I'm Jordi Segalàs from the Technical University of Catalonia.

As you know I'm working on a UNESCO Chair in Technology and Sustainable Development, which is mainly focused on the education of SD in Engineering.

We are starting a research project on pedagogical strategies to teach SD in Engineering courses, and our goals are to identify which of these strategies are more efficient and effective.

In the first steps of our research we are mapping the way technical universities have been introducing the SD paradigm in the engineering curriculum.

For us, the key point is the way to involve non SD lectures in this process and the spread of SD into the whole curriculum.

Particularly we are interested in the following aspects:

1. ***First of all, whether your university has a specific policy in the introduction of SD or not, and the way this policy has been developed and put into practice.***

   So can you tell me something about your university policy? And how has your department/university/section implemented it?

   Do you think the policy you have put into practice is sufficient? Or in other words, if it's not good enough how would you have implemented it more effectively?

   Have you measured how much the curriculum is "Sustainabilizated"?

   How have you measured it? And which results have you obtained?

   Do you have teacher training strategy?

2. ***Curriculum design and pedagogy***

   In order to make a comparable study, we will analyse it according to the HEEA (The Bologna process). And I would like to ask you questions by separating them into two categories: Bachelors' and Masters' programs.

   Let's start with the Bachelors' programs.

   Does your university have a special Bachelor degree (minor) in Sustainable Engineering?

   Which subjects are taught related to SD on this degree?

   Can I have access to the contents of the subjects or their program?

   Let's focus on the Pedagogical Strategies: How are these subjects taught?

   I mean, do you use case studies? Problem based learning? Project based learning? Is it a distance learning subject?

Now let's focus on the Master' programs.

Does your university have a special Mastes degree (minor) in Sustainable Engineering?

Which subjects are taught related to SD on this degree?

Can I have access to the contents of the subjects or their program?

Let's focus on the Pedagogical Strategies: How are these subjects taught?

I mean, do you use case studies? Problem based learning? Project based learning? Is it a distance learning subject?

Does your Masters or Bachelor include a specific subject on SD in engineering? In that case can you let us have the objectives and the program?

Is it a compulsory or an elective subject? Why is it organized like this?

Does the subject include social and economic impacts of technology?

And engineering ethics?

Let's focus (again) on the Pedagogical Strategies: How is the subject taught?

I mean, do you use case studies or other strategies?

3. ***Have you developed any learning tools/materials for /these subjects? Which kinds of tools?***

   We are also thinking of compiling these kinds of tools and publishing them on the web, so, can your institution share these materials with other universities?

And finally, I'll like you to tell me anything else that you think is relevant. And who do you think it would be worth interviewing to obtain more information?

Appendix II Experts Interviewed

In the year 2005, the author spent three months in leading European universities on ESD:

- Delft University of Ttechnology (Delft - The Netherlands)
- Chalmers University of Technology (Goteborg - Sweden)
- Herriot-Watt University (Edinburgh - Scotland)

During the stays 50 experts from 19 European technological universities and network associations were interviewed (Segalas et al. 2007). The name, position and institution of the experts interviewed are shown in following tables:

Delft University of Technology. (Delft – The Netherlands)

Name	Position
Karel Mulder	Head of the Technology Dynamics and Sustainable Development Department
Dirk-Jan Peet	Teacher at the Technology Dynamics and Sustainable Development Department
Geerlinge Pessers-van-Reeuwijk	Policy adviser to the TUD board on Sustainability
Gertjan de Werk	Teacher at the Technology Dynamics and Sustainable Development Department President of OSIRIS-Students' association for SD
Linda Kamp	Coordinator of SD in Maths. Teacher of courses: Sustainable technology for Sustainable Molecular Science and Technology degree. And SD for civil engineers
Mariette G.G. Overschie	Teacher at the Technology Dynamics and Sustainable Development Department
Arnold Heemink	Coordinator of SD in Maths Department
Carlos Infante	Coordinator of SD in Mechanical Engineering Department
Erik De Graaff	Educational Sciences. Education and Curriculum Development. Chairof the SEFI Working Group on Curriculum
Hans Klein Woud	Educational Director of Mechanical-Maritime Department
Leo Jansen	Responsible for the implementation of SD in the curriculum at DUT. Director of the TUD board on Sustainability
Saul Lemkowitz	Coordinator of SD in Chemistry Department

Hogeschool Zeeland (Vlissingen - The Netherlands)

Name	Position
Anja de Groene	Director of the Centre of Water Sustainability
Margot Lobezno	Teacher of SD in Business degrees and researcher at the Centre of Water Sustainability

University of Twente (Enschede - The Netherlands)

Name	Position
Denie Augustijn	Water Management Department
Marten Toxopeus	Professor of Engineering Technology
Sacha Kersten	Thermo Chemical Conversion of Biomass in the Chemistry Department
Theo van der Meer	Professor of thermal engineering section in Mechanical engineering department

Fontys Eindhoven (Eindhoven – The Netherlands)

Name	Position
Hay Geraedts	Mechanical Department

Radboud University Nijmegen (Nijmegen – The Netherlands)

Name	Position
Irene Dankelman	Coordinator for Sustainable Development Copernicus Coordinator and now Coordinator of the SD program
Dorri Boekhorst	Researcher and Project Manager in Sustainable Development. Teacher of the SD program. Working on DHO platform

Eindhoven University of Technology (Eindhoven – The Netherlands)

Name	Position
Lex Lemmens	Director Eindhoven Centre for Sustainability. Managing Director of Education Institute
Ajen Kirkels	Teacher at the Eindhoven Centre for Sustainability
Dione van Noort	Teacher at the Eindhoven Centre for Sustainability

Wageningen University (Wageningen – The Netherlands)

Name	Position
Maja Slingerland	Assistant Professor. Chair Group Plant Production Systems. Sustainable Development and Systems Group.

Dutch Network for **S**ustainable Development – DHO [*Duurzaam Hoger Onderwijs*] (The Netherlands).

Name	Position
Niko Roorda	DHO Consultant. AISHE Project Coordinator - Developer of the CIRRUS project

Université catholique de Louvain (Louvain-La-Neuve – Belgium)

Name	Position
Michel Installé	Maths Engineering Department. President of Environment and Sustainable Development Group

University of Gävle (Gävle – Sweden)

Name	Position
Kaisu Sammalisto	Dean for Environmental Management and Education

Royal Institute of Technology (Stockholm – Sweden)

Name	Position
Nils Brandt	Associate Professor. Director of Studies Industrial Ecology Department

Chalmers University of Technology (Goteborg –Sweden)

Name	Position
John Holmberg	Vice President with responsibility for the Systems and Environment Initiative. Professor of Physical Resource Theory. Holder of the UNESCO Chair in Education for Sustainable Development
Anna Nyström	Teacher. Environmental Systems Analyst
Karin Andersson	Environmental Systems Analyst. Lecturer of Environmental Science, Sustainable Building and Environmental Systems Analysis
Greg Morrison	Professor of Sustainable Aquatic Systems. Head of Department for Water Environment Transport at the School of Civil Engineering
Magdalena Svanstrom	Assistant Professor at the Department of Chemical Engineering and Environmental Science
Ulrika Lundqvist	Head of Division at Physical Resource Theory

Heriot-Watt University (Edinburgh – Scotland)

Name	Position
Bob Craik	Professor of Building Acoustics and Deputy Head of Department Quality Education
Veronica Bamber	Director of Educational Development

University of Plymouth (Plymouth – England)

Name	Position
David Selby	Professor for Education in Sustainability, Faculty of Education Director of the Centre of Expertise of Teaching and Learning on SD from Plymouth University.
Alan Dyer	Associate Director of the Centre for Sustainable Futures, Faculty of Education

University of Surrey (Guildford – England)

Name	Position
Roland Clift	Distinguished Professor of Environmental Technology and Founding Director of the Centre for Environmental Strategy

University of Bristol (Bristol – England)

Name	Position
Sally Heslop	Senior Teaching Fellow Engineering Education, Environmental Management, Environmental Systems, Sustainability. Education Director & Graduate Dean of Engineering Faculty

Technical University of Catalonia (Barcelona - Spain)

Name	Position
Miquel Barceló	Vice-Rector of Sustainability at the UPC. Coordinator of PhD program on Sustainability of the UNESCO chair of Sustainability of the UPC. Long experience on teaching SD courses in the Computer Science Department.
Enric Carrera	Has been the director of the UNESCO Chair of Sustainability for 10 years. Long experience of teaching SD courses at the Technical University of Catalonia.
Antoni Grau	He has been introducing SD contents in technical courses. He is editor of the journal Sustainable Education - RCE Barcelona. Member of EDUSOST (research network on ESD). STEP (Sustainable Technology Excellence programme) coordinator.

Appendix III Experts' Interview transcripts

The semi-structured interviews[1] with experts[2] were recorded and transcribed. This appendix contains the transcription of these interviews.

Contents

A3.1 Delft University of Technology

Expert: Dirk-Jan Peet		Date: 24 January 2005	
City: Delft	Country: The Netherlands		
Institution: Delft University of Technology			
Department: Technology Dynamics and Sustainable Development			

Comments: Dirk-Jan Peet was a lecturer on SD from the section of Technology Dynamics and Sustainable Development of the Technology, Policies and Management Department. He has developed and taught courses in Technology in Sustainable Development at the faculties of Electrical Engineering, Technical Mathematics, Chemical Engineering and Technical Informatics. He is also involved in the working group Disciplinary Review and Sustainable Development as a basis for the intertwining of SD in regular disciplinary courses e.g. Technical Informatics.

Transcription: The transcription has been structured on two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewed.

Embedding SD.

- Individual approach is the best way.
- Teachers don't like people from outside interfering into the things they teach, it does not work to say that this is SD and you have to teach this and that.
- Ask them what aspects of their work are related to SD topics and then TDO writes a report for the person in charge of Curriculum development.
- So far they have seen signs that this methodology works.
- In applied mathematics, they did a workshop to lecturers on ESD and it doesn't work because lecturers were sceptical about knowledge from outside. Lecturers feel experts in their own field and they will not go for a course on SD on their own.
- Training for people from other institutions in order for them to embed SD in their curriculum.
- One isolated course on SD is not the solution.
- A SD basic course is necessary to get the overview of what SD is.
- Top down approach doesn't work in universities; maybe in polytechnics where the teachers don't do research.

Pedagogical strategies.

- First have a basic course. Give the principles of SD basic knowledge and then implement this knowledge straight away into a project
- Every time you give knowledge, use it in a case. Knowledge has to be very close in time to the application of this knowledge.
- In maths, two parts of semester. First they have lectures and then projects where students have to implement all the knowledge gained at the beginning of the semester.
- He is sceptical of what students learn by role plays.
- They use case studies to show applied concepts.
- In Delft Ethics and SD are separate: two different departments, although there's an overlap.
- Backcasting is used in a theoretical part but not in the project work.
- Most Engineering students feel that SD has nothing to do with their profession. (although they think that SD is a good thing, generally speaking) This changes when they get a job and have responsibilities. There are also some enthusiastic groups of students.

Expert: Geerlinge Pessers-van-Reeuwijk	Date: 15 February 2005
City: Delft	Country: The Netherlands
Institution: Delft University of Technology	
Department: Electrical Engineering, Mathematics and Computer Science	
Comments: Geerlinge Pessers-van-Reeuwijk was the policy adviser to the DTU board on Sustainability.	

Transcription: The transcription has been structured on two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

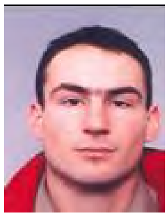
- In 1996 the board decided that SD had to be integrated in research and education.
- There was a survey on what was on the curricula but it wasn't enough.
- They set up a committee with LEO Jansen (President) and Geerlinge (Secretary), whose task it was to advise on the integration of SD in Research and Education and to supervise the implementation of the advice.
- They set up a committee with teachers, interested people, and professors who were not too busy.
- Its function was to get this accepted by the faculties.
- They visited the department directors twice.
- In 1996 the curriculum lasted one more year and they decided to fill the space with courses like SD, ethics, communication, etc not technological subjects.
- The TDO group put too much effort on organizing the attachment specialization on SD and specific course, but not on Embedding SD.
- You always need to have somebody on the board who really supports Embedding SD.
- TDO needs to switch from education to research.
- Link professor to SD research and put money there to attract PhD students.
- It's a very slow process, too slow to interest managers!!!
- SD in education is not seen as very scientific
- They have a compulsory course in all the departments.
- When defining learning goals within The Bologna Process, you should introduce SD.

Pedagogical strategies.

- Integration of SD is easy with PBL

Expert: Gertjan de Werk

Date: 2 February 2005



City: Delft

Country: The Netherlands

Institution: Delft University of Technology

Department: Technology Dynamics and Sustainable Development

Comments: He has been working at the TA Section since mid 2002 and teaches sustainable development at the department of Mechanical Engineering in the first, second and third year. He is also involved in the graduation appendix in sustainable development. During his studies, together with other students, he has founded OSIRIS, a platform for communication on sustainable development. He is Chairman of the Board of Osiris.

Transcription: The transcription has been structured on two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee

Embedding SD.

- There was a platform for SD embedding.
- Each department has a representative (reference) on the platform (chose by the dean of each department) basically professors who are working in some way on SD. The platform monitors the curriculum by the reference in each department.
- The reference checks if the students have integrated SD properly in their final thesis. And they check if the students have done enough credits to graduate with a mention of SD.
- The individual approach is good to know what teachers think but is difficult to make them move.
- In multidisciplinary PBL when introducing SD it also makes teachers who tutor the project together with the SD expert aware.
- Developing materials for teachers is not effective on its own. Most materials are left on the shelves.
- Lunch research on SD.
- Action plans for motivating teachers to SD.
  - Students questioning
  - Enthusiastic teachers who are always pressing others like the TDO people.
  - Governments, companies asking for SD solutions.

Pedagogical strategies.

- In Mechanical engineering is based on PBL (1st year- project on hybrid vehicles. 2nd year- heating systems (cogeneration) 3rd year on Sustainable enterprises.
- Backcasting
- Workshops, discussions. Give information and from their own speciality information they get more knowledge (boat experience)
- Especially not only lecturing (too passive) students don't know what to do with the SD knowledge.
- Make them think about new solutions and the impact of their solution, and the rebound effects.
- "Active group work"
- PBL is more permeable for introducing SD in practice.
- A compulsory course on SD is necessary in all the curricula.
- In PBL it is important for students not to split the knowledge they work on in parts of the group. So every student gets all the knowledge.
- In Masters' degrees students are more motivated in the learning process.
- 40-50 students year gets an attachment in SD at TUD.
- 300-400 students get some information on SD (5-10% of the TUD students)
- Students must be motivated by the teachers and might play a very important role.
- Evaluation ways: Exams, Reports, Presentations + questioning by teachers.
- Problems of PBL: students divided the workload.

<table>
<tr><td colspan="2">Expert: Linda Kamp</td><td>Date: 10 February 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Delft</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: Delft University of Technology</td></tr>
<tr><td colspan="3">Department: Technology Dynamics and Sustainable Development</td></tr>
<tr><td colspan="4">Comments: In October 2003, she joined the TDO section where she is developing a course on sustainable technology development. Furthermore, she is continuing her research into wind energy development.</td></tr>
<tr><td colspan="4">Transcription: The transcription has been structured on two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

<u>Pedagogical strategies.</u>
- For some departments the embedding SD has worked very well.
- For other not so much, for instance in civil engineering students are just given lectures on SD.
- Project work is the more permeable pedagogical strategy to SD in non specific SD courses.
- In the project work there were some lectures on SD but very close to the field of knowledge of the degree.</td></tr>
</table>

Expert: Mariëtte G.G. Overschie	Date: 26 January 2005	
City: Delft	Country: The Netherlands	
Institution: Delft University of Technology		
Department: Technology Dynamics and Sustainable Development		

Comments: She worked at The Dutch Innovation Centre (eco-design within SME's), Royal Volker Wessel Stevin and at the Netherlands Design Institute (Sustainability Coordinator). She joined the TA section in 1999. She has developed courses on Technology in Sustainable Development within Marine Technology and Geodetic Engineering, and teaches at these faculties. She also teaches in the Electrical Engineering Department, the Technology in Sustainable Development colloquium and the MSc Summer School. For two years two days a week she has also worked in the Department of Architecture, SOM group. She organizes the Rathenau TA Summer school and has coordinated several interdisciplinary projects. Her research will focus on how cooperation has dealt with societal protest in regard to their own research and development organization and strategy.

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The Following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

- To develop SD embedding you need not only top-down approach but give a lot of information to teachers.
- SD is becoming known and accepted.
- In Holland you still have to discuss with lectures about the importance of SD but there's a lot of information, enterprise examples, regulation, prove front industry, keynote speakers, etc.
- The SD embedding in TUDelft is a continuing process, and it will improve.
- It is important that each department is involved in the SD embedding. Not just a group in the university in charge of it.
- There are departments which are more permeable to SD embedding, like chemistry, architecture…
- When teaching SD you need to focus on technical choices and not on technical knowledge, it is interesting to know how PVcell works but it is more important why you want to have it.

Pedagogical strategies.

- Focal training (learn to make presentations) and report (so the students demonstrate they understand the knowledge)
- Mind maps at the beginning and at the end of electrical engineering (Natalie Lourdel method,) Students feel they are back at school and not at university.
- They also ask the firms about Sustainable entrepreneurship using conceptual maps, and this is a good initial point for further discussions.
- It is a good system to make students realise that they do not know anything at the beginning of SD and at the end they fill in a full Cmap page.
- The theory on learning says that when you listen you remember a little and when you present yourself you remember the most.
- Problem solving
- The PFC must be asked at the beginning (assignment in the beginning) for SD in an integral way. Students don't pay attention to it.
- Most people don't know about pedagogy at university, teachers do what they think is best,
- Contact student to the real fieldwork, students are sent to different stakeholders (firms, government, media organizations, and environmentalists). And they present their work.
- In general, the students when finishing Master's degree do not have enough knowledge on SD, but they are interested in knowing more.
- It's important to teach student what they choose for what reason.

<table>
<tr><td colspan="2">Expert: Arnold Heemink</td><td>Date: 26 January 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Delft</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: Delft University of Technology</td></tr>
<tr><td colspan="3">Department: Delft Institute of Applied Mathematics</td></tr>
<tr><td colspan="4">Comments: Mathematical department. Coordinator of SD in Maths</td></tr>
<tr><td colspan="4">Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

<u>Embedding SD.</u>
- There's a basic compulsory course on SD
- At bachelor level there's a minor related to SD
- At Master' level students can do an intensification in SD
- That the teachers get involved in research with other departments in SD applications, so that they can change their attitude towards SD.
<u>Pedagogical strategies.</u>
- SD is introduced in projects
- Environment modelling
- The final project is often related to environmental issues.
- They work in projects and in groups
- Students don't feel comfortable about qualitative knowledge like SD</td></tr>
</table>

<table>
<tr><td colspan="2">Expert: Carlos Infante</td><td>Date: 26 January 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Delft</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: Delft University of Technology</td></tr>
<tr><td colspan="3">Department: Process & Energy Laboratory</td></tr>
<tr><td colspan="4">Comments: Coordinator of SD in Mechanical engineering department</td></tr>
</table>

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

- Curriculum is structured in PBL
- In Masters there is an SD intensification.

Pedagogical strategies.

- In his department they implemented SD in projects. Because they think it's the best way to do it because the students see the relationship between the ideas of SD and their professional knowledge
- The PBL is more effective to get knowledge in SD because they used it so they keep it more in mind.
- The problem with PBL is that in large groups of students what happens is that students specialize in some aspects of the projects and don't see the whole concept.
- It's more expensive and intensive to teach in PBL curriculum structure.
- The PBL doesn't have much impact on student marks

Expert: Erik De Graaff

Date: 10 February 2005

City: Delft

Country: The Netherlands

Institution: Delft University of Technology

Department: Education and Didactics

Comments: In 1990 Dr. De Graaff joined TU Delft as advisor on the process of educational innovation at the Department of Architecture. In 1994 he was appointed Associate Professor in the field of Educational Innovation at the Department of Didactics in the Department of Humanities and Philosophy, a position which later shifted to the Department of Technology Policy and Management

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

- Try to find your allies in each department and start there.
- The university organization is a strange arena… the professional schools are easier, because the board fixes the path and everybody has to follow it, but at universities due to academic freedom it is very difficult.
- First you try with the ones enthusiastic about SD and they will be successful, and then reward them and finally the others should start following.
- You can use the strategy of telling them that the professional body is asking about SD knowledge.

Pedagogical strategies.

- Didactics and pedagogy is different (in one language pedagogy is working with children).
- Considers that didactics are a tool, they are important in themselves but are used to achieve a learning objective, if the objective is that students are aware of SD issues, problems, and take SD into consideration in the solution.
- The objective for SD is to change attitudes.
- The objective is that students know certain facts: lecturing to students, make students read papers,… find ways to get the information to the students
- The objective is the area of attitude you need to create a situation where they can encounter the consequences, where they can learn from experience or what the experience is really like if you are not working on something.
- The suitability of the project oriented approach to SD is tight and closer to the type of learning objectives in that specific field than the preference of a certain method.
- To change attitudes the students should learn from their own experiences.
- It is more how to use a tool than the tool itself. You should create a more specific environment to make sure that the students are working in the direction and the areas that you want them to work on. If you take away too much of their freedom, which used to happen with PBL where students had to report on their progress every week, then students can lose their capacity for independent thinking. You have to find a balance as a teacher between how much freedom to allow students and where to put the checks and balances. This is the most complicated thing.
- You need to put controls on their activities, but at the same time enough freedom so make them feel that they are responsible for the project themselves.
- The control can be done, by assessment, punishment, and reward. You have to be flexible, because the learning PBL project is unstable.

Expert: Hans Klein Woud		Date: 10 February 2005	
City: Delft	Country: The Netherlands		
Institution: Delft University of Technology			
Department: Mechanical-Maritime department			
Comments: Educational Director of Mechanical-Maritime department			

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee

Embedding SD.

- The SD introduction started with a requirement from the board.
- Although there ware some teachers before who had been already teaching SD.
- Now there's a clear place for SD in the curricula.
- SD should not be a subject but in the mind of all the teachers in all the curricula.
- There's a policy to introduce SD knowledge in the project.
- The ideal situation is that every teacher has to handle SD itself but so far help from TDO department is necessary.

Pedagogical strategies.

- SD in introduced in PBL (the year is divided into 4 quarters, and on average they have 60 PBL and 120 in courses)
- 1/3 of the curriculum is in designing a project. And connected to this project they have work on non technical subjects. (economics, reporting techniques, ethics, SD, …)
- In the projects they have to take SD issues into account in their design.
- They give 6 hours of introduction on SD (in seminars or lectures).
- Just lecturing on SD was not effective, didn't motivate students to assume SD in their profession.
- PBL is good for motivation of the students (students are more open to his kind of topic) the problem is that when working in groups it is difficult to ensure that every student gets the knowledge. Students can get the credits by avoiding some parts of the project. It's not a problem for good students but for the average students PBL is better, but you have to find ways to check the students, by tutoring, questioning them about their work.
- Within the project they also have individual parts (each part is done by every student), put examinations at the end of the PBL.

<table>
<tr><td colspan="2">Expert: Leo Jansen</td><td>Date: 8 February 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Delft</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: Delft University of Technology</td></tr>
<tr><td colspan="3">Department: Delft University of Technology</td></tr>
<tr><td colspan="4">Comments: Responsible for the implementation of SD in the curriculum at DUT. Director of the DUT board on Sustainability.</td></tr>
</table>

Transcription:

Embedding SD.

In 1992 the board of the university established an explorative committee to fix "What should the university do in Sustainability".

Chairman Marcel, a hard technical man so he could be trusted. (Non believers are necessary in the committee to make it more reliable).

In 1995 the board make a strategic choice, one of the pillars must be society and in this society pillar, sustainability would be an important aspect. (Board commitment)

In 1996 Leo Jansen became the chairman of the committee and was asked to set up a program for education.

They decided that this should not to be a top-down experience, there was support from the board, but they negotiated with every head of department or educational program:

- How do you look upon Sustainability in the university? – Discussions with them.
- Different faculties and different courses have different educational approaches (PBL, Problem BL, lectures, etc.) How to embed Sustainability into each department/course specific situation?

Members of the committee: Non believers, professors, students, short time, long time people in the university, old, young, different disciplinary dimensions, men and women.

(10 people). One believer from the Construction department.

Find out what sustainability is, and its educational dimension. You have to define everything…. It took one year.

Within the committee, after half a year, they all became believers.

Setting up the project (1 million Euros).

Back-casting to define the Policy – principles. What kind of students do we want to deliver the next 10 years?

1. We want them to be aware of Sustainability, know what it is and how it works, etc. Basic knowledge that all the university students must have.
2. Implement Sustainability into all regular courses. (Realising that it will not be possible within the 5 years but developing a methodology to do that).
3. Make the opportunity available to the students who want to specialise in SD.

For each line a program was developed.

TDO was in charge of delivering the program and working it out.

For each line the committee returned to the deans and educational officers again, and asked them their opinion how to do this in their department or educational program.

(A lot of work: interviews realized by members of the committee as near to the department as possible).

Setting up a course for all the students was successful and quite fast.

Pilot approaches in all the faculties and from them to define a methodology.

One approach was to give a course to the teachers, (didn't work)

Individual approach. (much more time consuming but it was successful)

At the same time DHO was founded. => disciplinary SD books

After five years, an Evaluation of the whole program was proposed. The conclusion was that the 70% of the work was done. The Board give 2 more years (complete the project and to prepare the post project period programs)

In the meantime the SD concept was growing (lunch readings, etc)

There was a crisis when the Dean of TBM changed and the new one did not like what was going on, because the academic world are more used to developing products (thesis, a design, …) and TDO was developing processes (not generally recognized). The new Dean had a fixation on products of excellence.

Now with a new Dean, there is no problem… he was always sustainability minded

The next job was to get the Deans of the faculties to take over the responsibility. An inventory on all faculties on what the state of Sustainability was with respect to education. We went to the Deans and told them what had to be done, and they should take care of it.

The Board defended the report to the council of Deans.

At this very moment, we have inertia to break, brokers (Board, TBM, Faculties)

In each department there were at least 1 or 2 references (teachers in charge of dealing with the specific degree in SD)

Two more questions:

- How can we build Sustainability in technology (what are the principles of doing that?) Wanted somebody (a professorship) to take that question to those demanding research.
- The embedment of Sustainability into a running educational organization is a Science (the Science of the process). Follow and evaluate the sustainability of the whole university.

It was difficult to find that person. (Who had enough time).

Chairman of the platform. (In Leo's opinion, the person has to be as independent as possible, a person from outside the university, but problem with financing)

Things occurred that Leo did not like: the division in the Masters (Minor and Majors) there's a tendency to set up a Minor in Sustainability that could prevent all students having Sustainability subjects.

Research.

They made a evaluation of research in the university and they wanted to measure ppp (people, profit (prosperity), the planet (environment and technology)) and it was found that only very little of the research was about people, mostly it is in environmental sciences and to some extent economics, this is also reflected in the education.

There's a need to bring in the regular courses the non technical and non environmental aspects (which are the easiest). The people aspects are very badly represented and it's very difficult to bring them in.

In the basic course and in the graduation course it is not difficult to introduce all the ppp because it depends on the TDO group.

We must find how technical aspects are touching people in a small circle and in a wide circle (all over the world).

In supporting technologies (mathematics, informatics…) which are neutral, (the way they are applied makes them Sustainable or not Sustainable). The way to embed Sustainability is by practical exercises (for examples creating models in mathematics like the spread of gases in a chimney …)

In fundamental technologies like nanotechnology it is very hard, because it can be applied in very different directions and you have to make people aware what the purposes of their inventions are and which directions they could be developed.

Important things to develop a good curriculum sustainabiliting:

1. The very first thing is to have support from the board. (a really important thing).
2. Build up connexions with the outside (from the university) world (chemistry world, agricultural world, construction world), people who give you support. Show that the market is asking for this kind of knowledge. We have to identify persons who are more or less representative for a certain sector, and ask them what kind of people they need, and this is very important to convince the board and to convince the professors, because this is their market.
3. The connexion between research and education. (The outside world is important again, when the outside world demands, for example, Sustainable water management, recycling material…)

Having support from the top you have to build it up bottom-up, you have to prepare a kind of vision, what it should be in ten years. The point in developing a vision, you always need a champion to take the first steps. To promote the bottom-up approach it should be done in two phases:

1. by contacts with key people
2. organize meetings. (With the influential key people to make a presentation in the meeting)

The program should be accepted from the beginning.

You should have a kind of communication philosophy in which you make yourself completely transparent for the whole of the university.

In every department, you have to find a reference, a person who may introduce you to the department. The main task of the reference is to represent the project/program in the department.

Once the attachment in SD was established in all the departments/faculties and reference was in charge of assessing the students as well as the teachers.

They have representatives of the faculties in the platform for SD. (usually the representative is the department reference)

All this was done as a 5 year project and it was funded by the board - 1.5 million Euros.

Expert: Saul Lemkowitz		Date: 10 February 2005
City: Delft	Country: The Netherlands	
Institution: Delft University of Technology		
Department: Department of Chemical Technology. Particle Technology Group		

Comments: Coordinator of SD in Chemical Technology department

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

- Embedding SD is a modern topic, but the general problem is the relationship between science and technology and society.
- One problem of the universities' structure is that it divides the knowledge into very specialized fields, and teachers are asked to research in that without paying attention to the broader picture, so it is difficult to motivate teachers to green the curriculum and teach critical thinking. The system doesn't help too much.
- Most of the SD taught in the university is done through a disciplinary point of view.

Pedagogical strategies.

- We need to train people to think critically. And technological universities don't do this.
- S&T are controversial, because in SD the relationship to society has not yet been covered.
- In modern society (capitalism & democracy) how SD fits… Students must understand what the driving forces in the world are, and what area the driving forces are producing on SD. Students must be presented with data and arguments about the general question STS. Which are the driving forces opposing SD and the opposite the driving forces for S. They have to be trained to think critically. This is not an isolated scientific phenomenon. It is very complex and very difficult to predict.
- S&T have a crucial role to play but they can also be part of the problem.
- We should question a society which is based on continuous growing. Maybe some deeper changes have to be made in our society.
- The external cost must be introduced into the curriculum. (role of economics.. death terrorism-car accidents-diseases from pollution)
- Example of course Industrial ecology
    - 1st part (critical part) to stimulate students to think that the world is getting better or worse (they look for data, facts) and the moral view point they are taking. Think critically
    - 2nd part study tools and approaches of Industrial Ecology (LCA, etc...)
    - 3rd part case study in a research institute related to car industry: pollution, accidents.
- It is essential for students to do a project because they are working with their own initiative and applying what they learn. Students must be given some basic knowledge (lectures, readings...)
- In an elective course you have more freedom to experiment because students are motivated while in compulsory course has to be very structured.
- Make the method of assessing and valuating of Sustainability very explicit to the students.
- Involve people from industry to talk about Sustainability so students perceive its importance as more real.

A3.2 Hogeschool Zeeland

Experts: Anja de Groene & Margot Lobezno		Date: 3 February 2005	 
City: Vlissingen	Country: The Netherlands		
Institution: Hogeschool Zeeland			
Department: Centre of sustainability and water			

Comments: The two experts were interviewed together.

Ms. Anja de Groene is the head of the Centre of Sustainability and Water "spring" <http://www.hz.nl/spring/> 10 people, 2 fields of research, 1-S enterprise (small and medium size enterprise) and 2- S water management

They teach courses related to SD and also work as an expert team to help other teachers to introduce SD in their courses.

Transcription:

Embedding SD.

It is very important for the process that university board makes a strategy document with vision of the university with the points which are important: sustainability, safety and internationalization. The board has to be convinced of the importance of sustainability.

The vision of SD is a tool to motivate people.

There is a week for Sustainability for 1st year students.

1 day the students work on multidisciplinary groups on the subject of Sustainability.

2 – 3 days The students work in their own departments, their teachers make a program for them so it makes teachers think about the relationship of their field of knowledge to sustainability.

4 – 5 days. Students go to organizations and firms in multidisciplinary groups and do a sustainability scan on those firms. (60-70 firms collaborate) (students learn about SD and the firms are forced to think about their own sustainability policy)

To put this week inside the curriculum, the vision statement from the board was essential because it forced them to have this week.

In the 2nd, 3rd and 4th year.

The maritime department has a large project "sustainable sort see shipping" <http://www.duurzaamschip.nl/engels.html> they have already made 60 projects (3-4 students work in the project) That course is structured on Project based learning. (Compulsory for maritime students).

It integrates theory and practice and the outside stakeholders cooperate. (Eg. a ship was going to use bio-fuel and the students are going to analyse the consequence of this)

Engineering department is focused on Sustainable energy (1 compulsory course – half theoretical and half practical)

Economic department (1 project that last two semesters, they have to set up a company, choose a product or a service and they has to formulate the business plans and they take sustainable issues into account (basically environmental ones))

All these courses are applying sustainability. In this way it makes easier for students to understand what Sustainability means in their professional lives. Sustainability as a subject itself is necessary in the beginning (week on sustainability) but afterwards it's worth teaching applied sustainability.

There is not a specific strategy to involve non SD teachers,:

There are teachers who came to the group to ask for help.

There are teachers who are asked to introduce SD in their specific courses (Eg. Projects in maritime engineering).

There are teachers who don't bother at all about SD.

The part time teachers in the group, make an individual spread of SD knowledge by talking about the necessity of the introduction of SD to their colleagues in their departments.

Publicity is a good way to spread the Sustainability (Eg. During the Sustainability week, at the end of the week there's a presentation of the project worked on the firms, all the students and the regional press come to the presentation, so the teachers read about SD week) We can call it an external legitimization.

In Hogeschool the education is more rewarded than in universities and the education pedagogical strategies are easier to apply.

There is an external evaluation of the educational system; it does not evaluate embedding of SD. They evaluate competences (knowledge, skills, aptitude).

Each department has to make sure that the competences of Sustainability are included in the courses. Because each new subject proposed for the departments has to be approved by the board who, among other competences, ensures SD competence, as well as ethics and safety. It'll help to measure the Embedding SD of the curriculum.

But there are no specific learning goals like after 4 years students must have had so many hours taught on SD.

The Embedding SD still depends too much on the teacher itself.

And it also depends on the head of the department which can help to convince new teachers.

What do students think about the importance of sustainability to their career?

The best way to motive students to SD is to relate SD to its profession. Otherwise they don't find any application and they think it has nothing to do with them.

The course (Sustainability week) will became elective next year. And they will check how many students will take it.

In the international business management studies (3rd year) there is an elective course on SD business. And they are positive about it.

For the other students, it depends on the course (if the teacher introduces it in the course).

The students must do an internship in the 3rd year and the PFC is done in the firms so this contact can spread the SD paradigm.

There is no SD attachment or specialisation, in any field either.

There are going to be major studies with a minor (1 semester) they are going to have a minor in SD and innovation (they are developing it).

Pedagogical strategies.

Use different strategies, practical work, and work in groups.

Which Pedagogical Strategies are more permeable to the introduction of SD into courses?

Depending on the starting knowledge of the students:

If they have no idea about how products are made in factories, then practical case study work.

The less knowledge the students have the better it is to start with practical PS.

The social constructivism way of teaching. As there is a difference in the starting point in knowledge of students you may use many ways of teaching.

If you give only case studies, the students are not always used to finding the theory themselves. There are not used to learning by themselves.

They use the network DHO to share case studies.

A3.3 University of Twente

<table>
<tr><td colspan="2">Expert: Denie Augustijn</td><td>Date: 11 February 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Enschede</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: University of Twente</td></tr>
<tr><td colspan="3">Department: Water Engineering & Management</td></tr>
<tr><td colspan="4">Comments: Mr Augustijn teaches environmental courses in civil engineering.</td></tr>
<tr><td colspan="4">Transcription:
<u>Pedagogical strategies.</u>
He thinks that you have to repeat in different ways: tell students what SD is but try to help them discover for themselves what SD is in different ways. If you use SD as the automatic reason why we sometimes do things then it will stick and it will became a part of their reasoning. They can always have an objective reason we want to create a better world. By challenging students to answer questions related to SD. To make them work on a project where they have to report on those questions.</td></tr>
</table>

Expert: Marten Toxopeus		Date: 11 February 2005	
City: Enschede	Country: The Netherlands		
Institution: University of Twente			
Department: Industrial Design Engineering			
Comments:			

Transcription:

Embedding SD.

- Start with courses on interaction between technology and environment and society.
- In different courses try to enforce more attention on the LCA.
- Have some short courses on design for recyclability, design for disassembling, design for modification, and use this knowledge in projects

Pedagogical strategies.

- Although there's not a PBL curriculum structure, most of the teachers do their courses with PBL strategy.
- They have the one room concept. They do theory lectures, applied lectures, drawings, computer science; write reports, exercises all in that room. It's a flexible room.
- If you want to teach the theory of SD then you should combine theory and exercises, (teach some theory, take an example product and see what this theory means for this product).
- If you only teach theory, students don't see what SD means for their professional lives.
- It is important to have guest lecturers from industry professionals.

Expert: Sacha Kersten	Date: 11 February 2005
City: Enschede	Country: The Netherlands
Institution: University of Twente	
Department: Thermo-Chemical Conversion of Biomass	

Comments: He did his Masters degree at the University of Amsterdam in the group of Prof. Dr. Ledema on 'The effect of recycle interactions on dynamics and control of complex plants'. In 1998 he started his Ph.D. work at ECN and continued later at the University of Twente with Prof. Dr. Ir. Van Swaaij and Dr. Prins on the subject of 'Biomass gasification in circulating fluidized beds'. On November 22nd, 2002, he obtained his Ph.D. degree. Since 2002 he has been working as Assistant Professor at the biomass technology group TCCB at the University of Twente

Transcription:

Embedding SD.

- He thinks it is important to have one basic course to know what's going on (now this course does not exist).
- It's difficult to offer this course, because there's no room in the curriculum and if you want to do this course you have to take another one out, and professor don't want to lose courses because it means money to have more lecturers, …
- They are trying to do a course between the chemistry department and the mechanical one in order to have two voices asking the same questions and maybe in this way it could be more effective.
-

Pedagogical strategies.

- He thinks that classical lecturers are needed in order to introduce the necessity to go from an all oil based society to a new renewable based one at the beginning of the course. But then the project and practical assessment are better, and the visit to companies is also very important.

Expert: Theo van der Meer		Date: 11 February 2005	
City: Enschede	Country: The Netherlands		
Institution: University of Twente			
Department: Laboratory of Thermal Engineering. Department of Engineering			
Comments: Chair of Thermal Engineering Laboratory of Thermal Engineering			

Transcription:

Pedagogical strategies.

- On bachelor courses they have a lot of project oriented courses (7 projects in 3 years). For instance, the students go to a factory and try to improve their processes as projects.
- They do the project and the theory in parallel; they make the students need the knowledge for their projects so the students are self motivated.
- In the Masters degrees there are mainly "normal" courses, although some teachers use cooperative learning in the classroom.
- The kind of evaluation has to be the same as the strategic pedagogy, so if you make the students work in groups, you have to evaluate them in groups.

A3.4 Fontys Eindhoven

Expert: Hay Geraedts		Date: 14 February 2005	
City: Eindhoven	Country: The Netherlands		
Institution: Fontys Eindhoven			
Department: Mechanical Engineering			
Comments:			

Transcription:

Embedding SD.

- The Board policy facilitates SD embedding.
- The board has this policy but the department themselves have to develop on their own without any funding.
- In mechanical engineering the director of the department wants to implement SD embedding very fast.
- In Fontys they have 40 minors.
- Within the topics on technology they have developed a minor on SD.
- In the mechanical department they have modules (unit of 1-2 ECTS) on SD, SD in mechanical design.
- Projects SD and mobility.
- To motivate teachers he started working on SD and because it was successful other teachers follow. He had interviews with colleges and it worked out.
- They have two Bachelor professors who work in a knowledge base centre called SD.
- Financing is very important to have people working on the topic.
- Motivating teachers on SD embedding processes is difficult because changing teachers' opinion is very difficult. The best way is to earn some respect from your colleagues, do a good job and then ask for some collaboration and join somehow. A bottom-up is better than a top-down approach. Although a policy and some finance is needed (co-finance board-department) and also facilitating networking within the university. Only Top-down or only bottom-up will not work. Networking for below and facilitating from above.

Pedagogical strategies.

- Project call SD and mobility 4th semester.
- In the 4th year Project on entrepreneurship and SD.
- Role plays.
- Project base learning.
- The teaching on one way direction (teacher-student) doesn't work any more.
- 40% of the time of the students is PBL. In order that what a student learns can be applied in the project.
- In his experience there are several types of students, types of learning skills, types of motivation. So this asks for different types of teaching.
- He uses purely cognitive strategies (students must read something and they have a short test with closed questions every week). And beside there's a project where students work in groups.
- There is no one universal way of learning.
- Games (make a SD summit by students)

A3.5 Radboud University Nijmegen

<table>
<tr><td colspan="2">Experts: Irene Dankelman & Dorri Boekhorst</td><td>Date: 14 February 2005</td><td rowspan="4"> </td></tr>
<tr><td>City: Nijmegen</td><td colspan="2">Country: The Netherlands</td></tr>
<tr><td colspan="3">Institution: Radboud University Nijmegen</td></tr>
<tr><td colspan="3">Department: Department of Natural Sciences, Mathematics and Computer Science. Institute: Institute for Science, Innovation and Society</td></tr>
<tr><td colspan="4">Comments: Irene DankelmanCopernicus Coordinator and now Coordinator of the SD program.
Dorri Boekhorst Teacher of the SD program. Working on DHO platform</td></tr>
</table>

Transcription:

Embedding SD.

- They started in 1999.
- works in the department of interdisciplinary and environmental studies
- She was in charge of stimulating and promoting SD in education and research.
- They offered training for teachers, but they found out that it doesn't work. Teachers don't want to be trained.
- They organized workshop by guest lecturers and a major conference.
- They find allies in all the faculties (see who is already working in this area), investigate the courses and the people behind the courses, because these people are the entrances towards starting any initiatives in the faculties.
- The major limitation for SD embedding is academic, they feel frighten about their own position, in their autonomy they are not use to dialogue. So they try to make it clear that SD is not a threat, that there are inherent linkages which are implicit in the discipline and by showing that there's something to be gained from it. Showing the opportunities for them, and saying why they are doing this and the responsibility as citizens in a global sense.
- They also show that SD is an academic issue (it is not fake), to give value to it.
- Put the disciplinary challenges in front.
- They interviews allies and develop workshops to see how the allies can be helped to integrate SD.
- Support from the board is important.
- From DHO they have disciplinary reviews on SD.
- Now they are trying to do something with the knowledge; they want to stimulate a real integration process: Pilot experiences of SD embedding. Promoting networking.
- The platform saves a lot of money and time and saves a lot of frustration. Every institution should build in its own way, but you can learn from each other and save a lot of effort.

Pedagogical strategies.

- Invite a guest lecturer.
- They want to have more PBL, but students ask for lectures from teachers coming from outside, because students are tired of so much project work.
- She thinks that lectures with discussions can be also a good option.
- Students have to write an essay.
- Coaching the students is crucial
- A combination of interdisciplinary problem solving work is essential
- Bring people from outside.

A3.6 Eindhoven University of Technology

Experts: Lex Lemmens, Ajen Kirkels and Dione van Noort		  
Date: 1 February 2005		
City: Eindhoven	Country: The Netherlands	
Institution: Eindhoven University of Technology		
Department: Eindhoven Centre for Sustainability		

Comments: Mr. Lemmens is the director of the Eindhoven centre for Sustainability and Mr. Kirkels and Ms. Van Noort are teachers of SD courses.

Transcription: The transcription has been structured in two fields, Embedding SD and pedagogy. The following paragraph shows the most relevant key points highlighted by the interviewee.

Embedding SD.

- Their strategy to have more students studying environmental problems together with the engineering knowledge is to offer them the possibility of getting a certificate "technology for SD" in each educational program of TU/e is possible to follow the certificate. This certificate contains about 20 ECTS of topics. It consists of courses given by TDO but also given within their own departments related to environment.
- They have 20 to 40 students every year who do this certificate program.
- Their aim is to have many more students doing something about sustainability (they have 800 students on their campus).
- So their second attempt was to introduce an introductory course in all the curricula. It's not compulsory in all the educational programs. They are trying to bring SD as close as possible to the daily routine of the students, so they adapted the course for different departments at the beginning. Dione developed the course. It has been compulsory in three departments and elective in others.
- To get more students to have more in contact with SD they organize multidisciplinary projects, and these projects combine students from several departments/faculties, when they started it was the only experience in this way in the university and it was very new for the students. They were a group or 4-6 students and they have an assignment from a company a government some of the university, the assignment combines technical aspects with SD and sometimes with economic aspect. They have to work together with people from different departments.
- Each group deals with a different project.
- In the beginning it was an optional course for all the students (they still have quite a lot of students). This really progressed because last year there was a lot of project based education from several department in the university. So that way it became an obligatory course for some educational programs. Most of these educational programs in which this project-course became compulsory, the students are also free to choose one SD projects.
- At the beginning, the idea was to have a broad choice of different subjects, and these subjects would be responsible, and also the departments are more capable of teaching the topics of SD related to their field of expertise. For several elective courses it is like this. They define the course, set the learning goals. For example in the introductory course, there is collaboration, the TDO group does the SD part and teachers from the departments do case studies that link the SD part to their department.
- To involve these lecturers, they set up some research projects and they make the contacts with these lecturers. The results depend on the faculties. In some faculties they involve teachers related to research but in others they are related to the educational process. It has a lot to do to with personal interest of lecturers; whether they think SD or environmental problems are good topics so they can see the mutual benefit.
- There has been a policy which allows 24 PhD students to be supported from different departments, but they don't see that the policy has helped them to introduce SD into education. Because of that policy, (the board signed the Copernicus declaration, but they think that was the most important thing the board did), supported them, the origin of the TDO was that seven lecturers from different department who worked on SD topics decided to work together to make it more visible, to make a stronger point to the board and get more funding from outside the university. The board did strongly

support them by giving them the chance to support these PhD projects. That meant that colleagues in the departments could speak the same language, and then it is easier to find people in the different departments which can cooperate in your educational program.

- There's a policy in the sense of broadening your field of expertise (society, philosophy ...) and they make room available for a few courses like 2-3 in the total program so it was a change for TDO to introduce a SD course.
- They haven't adopted the idea that every course should be greened, the basic courses remain basic courses, and the green of the curricula consist of offering the possibility to do a major or smaller part on SD. They have adjustably supported lectures in different departments who wanted to start by giving courses on SD.
- You can choose some of these courses without getting this certificate in SD.
- In the faculties where the introductory course is not compulsory. It's possible for students to graduate without getting any knowledge of SD.
- As a result of the cooperation between other departments in the fields of S energy last year a Masters degree started in "Sustainable Energy Technology", which is an interdepartmental course. <http://www.studieinfo.tue.nl/public/index.php?site_id=2&section_id=-2&scope_id=53>
- They think, as the economy is going badly, SD and the environment is not popular in society, it is the government and the people who decide in the university. Now what is popular is management, and it is now first on the university agenda.
- The teacher themselves must have the motivation to cooperate in SD otherwise they will not cooperate.
- There is an academic criteria for the whole university, and in this criteria there is something related to environmental impacts. It can help to introduce SD in the program, but Embedding SD is not their main preoccupation because they thing they think it is difficult to do.

Pedagogical strategies.

- On the basic course, the first introduction to SD is lecturing to give knowledge and give study material, (information, analysis methods, etc) lecturing with interaction and discussion with the students.
- Just lecturing doesn't motivate students.
- In chemical engineering they have PBL.
- In the 2nd and 3rd year students have to do a project, some choose projects from their group which is mainly focused on sustainable technology.
- Sustainability for some students is soft business and they are not interested so teachers try to do sustainable technology like high tech.
- You should make students realise that SD is important both as professionals and as citizens.
- The approach of SD has to be as close to the field of knowledge students have as possible.

A3.7 Wageningen University

Expert: Maja Slingerland		Date: 9 February 2005	
City: Wageningen	Country: The Netherlands		
Institution: Wageningen University			
Department: Chair of the group Plant Production Systems			

Comments: She is in charge of the Sustainable Development group at Wageningen University. They have a professor of Sustainability Issues. The task of the professor is to introduce SD in the education and research systems of the university.

Transcription:

Embedding SD.

- They are a small group with a leading professor of the university who looks for the common issues in SD that they can share to find a common ground to start with.
- This professor was already SD motivated from animal, food, biological sciences….
- A second group developed a document to define what SD is within the university departments' knowledge.
- With this concept they started to give courses.
- Having a PhD course on complexity.
- To have an attachment in SD is interesting.
- You need both knowledge and competences for SD.
- They define two paths at the university for promotion: one in research and the other in teaching, and you can get the same level of recognition with teaching and with research. It worked pretty well.
- She thinks that teachers must be rewarded for changing from lectures to active learning.
- Staff training is necessary, in multi-stakeholders' processes, interactive education and interactive research.

Pedagogical strategies.

- They try to reduce lectures as much as possible and use meaningful ways of acquiring knowledge.
- Essays, games, simulations, debates, any type of active learning tools.
- Joint learning in a PhD program, students learn in groups, students act as teachers to the other members of the group.
- Project based learning where students act as a consultancy for companies and they have to deal with all the problems of a consultancy (financing, decision making, etc…) trying to make the project as real as possible.
- The student has a portfolio to reflect the learning of competences, feedback, assessment, etc. The student is responsible for his own learning
- A balance between PBL and lectures is needed

A3.8 Dutch Network for Sustainable Development

Expert: Niko Roorda	Date: 28 January 2005
City: Tylburg	Country: The Netherlands
Institution: Dutch Network for Sustainable Development	
Department: Consultant	
Comments: Mr. Roorda is the Developer of the CIRRUS project and AISHE project coordinator.	

Transcription:

Embedding SD.

- SD should not be an independent module; it should be integrated.
- They started a project group of teachers who were trained. (25 teachers) and they developed new modules.
- Then they wanted to have 250 teachers to use those modules, but it didn't work. Teachers don't feel the modules were not their knowledge, teachers have to participate in the development of the project and learning materials… the magic word is learning by doing…. (this is possible in universities for professional education, this doesn't work for universities)
- They developed a basic module which is taken in the first year of all the departments of Tylburg Hogeschoollaan.
- It is important to involve students in the development of the module.
- For SD embedding you should focus on allies, teachers who are already motivated, and then you need to set up a platform for communication (AISHE) and then the enthusiasm is disseminated.
- To convince the teachers you should involve the professional field so teachers realise that SD is taken into account in companies.
- Other ways is to use the students… you should find motivated students and help them to organize and to put pressure on trying to influence the board, teachers, staff, etc…
- For SD EMBEDDING the role of the management is very important. The board is also important.

Pedagogical strategies.

- Learning by doing.
- Invite experts from companies.
- They used PBL
- Case studies.
- Problem oriented learning for 1st year (1st year student are not ready to work on PBL)
- PBL alone or lecturing alone is not good, use multiple pedagogical strategies.
- He thinks the best PE are:
- Problem BL
- PBL with lecturing incomes.
- Exercises

A3.9 Université Catholique de Louvain

<table>
<tr><td colspan="2">Expert: Michel Installe</td><td>Date: 27 January 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Louvain-La-Neuve</td><td colspan="2">Country: Belgium</td></tr>
<tr><td colspan="3">Institution: Université Catholique de Louvain</td></tr>
<tr><td colspan="3">Department: Mathematical Engineering</td></tr>
<tr><td colspan="4">Comments: Mr. Installe is the President of the Environment and Sustainable Development Group.</td></tr>
</table>

Transcription:

Embedding SD.

- He thinks that the board of the engineering department doesn't consider SD as very important.
- SD is already implemented and now there is an opposition to redefining the curriculum again because of SD.
- The problem is also the promotion and recognition of teachers, which is mainly focus on papers, publications, European projects but not much on the teaching.
- To motivate teachers it is necessary to make the good practices on SD visible in different subjects (in the university newspaper, university web…)
- Training teachers will not work, because teachers are too busy to attend courses.
- The disciplinary division of the university makes the integration of SD difficult. (The transdisciplinary aspect is not valued).

Pedagogical strategies.

- They have a course on SD (6 ECTS) in PBL.
- The engineering Dean wants to have PBL. Within this PBL they have some projects on environmental technology. (where there are some SD aspects apart from the purely technical ones)
- He thinks the best way to teach is by projects in groups, and it is also important to reduce the number of exams and increase evaluation by report assessment.
- There are still lectures because they have some big groups (400 students).

A3.10 University of Gävle

Expert: Kaisu Sammalisto		Date: 15 June 2005	
City: Gävle	Country: Sweden		
Institution: University of Gävle			
Department: Industrial Engineering and Management			

Comments: Mrs. Sammalisto is the Head of Industrial Engineering and Management. And recently she finished her PhD on "Environmental Management Systems - a Way towards Sustainable Development in Universities".

Transcription:

Embedding SD.

The board of the university decided that they have to work on SD instead of environment. They actually decided that the main role of universities is to work towards SD, increase knowledge and awareness and competences of the whole department, staff and students (this policy is from 2002).

There are objectives, targets and action plans to implement the policy. Objectives are common for the whole university and initially they also had targets for the whole university, but from this year each department has its own targets based on common objectives. Thanks to this approach, each department is working more on the implementation of SD.

Each department also has its action plans.

The main idea is that all the teachers and researchers must check and assess their courses and research projects with regard to SD. So every teacher, when a new course is taken, has to submit a form where they make an assessment according to a set of possibilities:

- Whether most of the course is related to E&SD
- Whether the course has inputs in environment and SD.
- Whether the course does not have inputs in environment and SD yet, but there is a potential to do so in the future
- Whether SD is not relevant for the course.

They have to submit the reasons why the course fits one of these possibilities.

Whether the information written in the assessment has not been checked so far.

The main thing is that you make teachers think about the introduction of SD.

They have already checked 73 % of the courses. The checking of the courses is a continuous activity; all new courses and revised courses are checked.

When a department wants to teach a new course they have to make an assessment. The EMS allowed them to ask for these assessments.

All the students get information about EMS at the university.

The President appointed Kaisu as Vice-President of Environment. And they have an environmental council which has a representative for each department (12 representatives). Some of them are lecturers and others are administrative staff. These people from the council support the head of departments and inform the staff.

There was also a project group during the first two years of EMS implementation, with two EMS teachers, an administrative member of staff representing procurement and service, a student and an industry representative.

So Kaisu was working on two fronts, in the EMS (top down in the management group and via the president) and the people from the council who support the head of departments and inform the staff (bottom up).

The department is responsible for its own resources through the environmental coordinator.

Department feelings are diverse, there are people who support it very much, and other people who are critical of this whole process.

Kaisu has done the process this way because she believes that if you have a specific goal, or a set of goals for each department, which are measurable, then you can use them as a tool. The checking of the courses was not important for the checking itself but for making teachers think about the process and their own possibilities of having inputs in environment and SD in their courses.

Using the EMS to green the curriculum (inputs in environment and SD) was the best opportunity. This EMS was promoted by the government, although there are some Swedish universities that just approved the policy but did nothing else. The main driver is the decision of the university board.

Kaisu would recommend to a university who has to start this process that it has to be a decision from the university board with a specific goal, for instance for them was to be certified an ISO 14001 by 2004. If you have a concrete goal, you could make that kind of commitment. She emphasises that external audits help to push the process.

In the curriculum there are a number of elective courses, for example "Work Science and Environmental Technology)" (7.5 ECTS). The idea is to give a wide range of knowledge on environmental technology and Sustainability.

The course is taught by lectures, study cases from companies, projects in groups, students give presentations etc.

They don't really have a specific learning tool, although they are going to start a new curriculum in project based learning structures for engineering students. Within this structure they are going to have elective environmental courses, but they are mainly going to introduce the environmental and SD issues in the project in all the relevant courses and project work. The change to PBL was because of the lack of students.

They have still not worked out the embedding of SD in all the courses, although they are doing it continuously in old, revised and new courses. In the end they have left this to the individual teacher, although they try to motive the teacher to do it.

In order to embed SD in all the courses it's better to use a wide range of pedagogical strategies.

There's no any profile of SD in the university.

Pedagogical strategies.

- Course in Environmental technology & SD
- Lectures
- Case studies
- Group projects
- Student presentations

A3.11 Royal Institute of Technology

Expert: Nils Brandt		Date: 13 June 2005	
City: Stockholm	Country: Sweden		
Institution: Royal Institute of Technology			
Department: Industrial Ecology			

Comments: Mr. Brandt is the Director of Studies of the Industrial Ecology Department. He is Associate Professor and a biologist. He's been Working as a teacher and researcher at KTH since 1991 He teaches Sustainable Development and the role of technology, as well as ecology and courses in environmental effects of technology processes and systems.

Transcription:

Embedding SD.

In KTH there are some programs with a compulsory course called "Technology and SD" <http://www.ima.kth.se/im/3c1395/frame.htm>. The main content is to analyse the role of technology in the ecosystem.

In KTH they had a compulsory course called "Technology Humanity and Society", 1.5 years ago. It was 18 ECTS. But it became elective. The industrial ecology program has this course compulsory but it's a 6 ECTS course now.

There are more elective courses.

There is a profile for some specialities (mechanical, chemical, electronics) of SD if you take some environmental courses and your final Master's thesis is related to SD.

The university has the view that the Masters have to have their core in technology courses. There has been a lot of discussion about having an environmental engineering program. But they don't have this program. From IE they have graduated engineers in their core subjects but they offer the possibility of having that SD profile.

This compulsory course has been taken away from the programs, but the environmental profile is still running. They have about 25-50 students who take this profile. In the international Master's program (1.5 years) they have a program called Sustainable Technology <http://www.ima.kth.se/ms/st/index.html> (1 year courses 0.5 year thesis) and Environmental Engineering program (1.5 years) and Sustainable Energy (more pure technology).

There's no policy to introduce SD in all the courses at the university. The policy says that all the students should have these 6 ECTS courses on Environment and SD, but this is not obligatory, although the policy says it should be compulsory, but it is not. That's because every department is very independent. Some of the programs still have this compulsory course (computer science) but others run it as an elective course and in these 6 ECTS courses (Human Technology and Society) you can have philosophy, language, etc.

In every program there is space for elective courses.

There's also an environmental profile which is different in each department.

The IE department is in charge of the education in industrial programs about environment.

There's also an environmental policy on EMS. There's an action plan for the policy which says that the students should have these 6 ECTS on environment.

Nils thinks that there must be an obligatory basic course on sustainability, the role of technology and basic knowledge of the limits of the ecosystem. And then you need advanced courses on technology for SD.

It's necessary to get support from the university board, which they don't really have in KTH.

Pedagogical strategies.

In their basic course – they use lectures to give an overview of the SD and the environmental issues and the course is divided into 3 parts: SD, ecosystems and basic environmental management. They also use one long project where students work with LCA, they do a report, a presentation and a discussion in small groups. (50% lectures + 50% project). And there's a very short examination (multiple choice test).

Advanced courses (4-5 points) are more problem oriented with projects. There are a few lectures. They work in small groups (students are used to working in groups and projects). It's important to give the students some training in working in groups, how to write a report, etc…

In international programs they can see that the students present different skills when working in project groups. (The Swedish students are more used to it)

The most important thing is to get a good discussion on the report they write, that the students develop their own thoughts and knowledge.

They have to write reports, give presentations, role plays, opposition (one group of students write a report and changes reports with another group and they have to make a constructive criticism of the other reports), and case studies.

Most of the courses are based on how to implement tools (analysis, management) and they have a lot of cooperation with companies. They have a network around their division of 150 companies, where they send their students who do a small project in these companies.

They also have field studies, nature excursions (National Park, etc) but it takes a lot of time and it's not very efficient.

Educating in another language is a problem, both for the teacher and the students; it's difficult to deepen knowledge. You get general knowledge when the students have to write a report, to give presentations….

They have developed a web course for the staff.

What Nils would do is to embed SD in all the programs; he would have a compulsory course on the role of technology in SD. And in all the courses, it is important to introduce the ecological perspective, and attitudes and values, the way to do it is to make students think what their role is as professionals in SD. The problem is that most teachers think that the values are not necessary (everything is black or white).

The way to involve lecturers is to train them in a course. You should make them discuss what SD is, and relate that discussion to what is happening in the world.

The board has to make it a priority so the lecturers may also find it a priority.

A3.12 Chalmers University of Technology

<table>
<tr><td colspan="2">Expert: John Holmberg</td><td>Date: 23 June 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Goteborg</td><td colspan="2">Country: Sweden</td></tr>
<tr><td colspan="3">Institution: Chalmers University of Technology</td></tr>
<tr><td colspan="3">Department: Physical resources</td></tr>
<tr><td colspan="4">Comments: Vice President with responsibility for the Systems and Environment Initiative. John Holmberg is Professor of Physical Resource Theory, Head of the Division of Physical Resource Theory and Vice Dean of the Centre for Environment and Sustainability, GMV. He also holds Sweden's first UNESCO Chair in Education for Sustainable Development.</td></tr>
</table>

Transcription:

Embedding SD.

- Conducted an international investigation –what are the strengths, the obstacles
- Get financial aid to invest in SD Science
- Put together a mass of scientists to make SD strong in the university
- Train the university community: deans, board members on SD.
- Analyze how to involve non-environmental teachers to relate their subjects to SD.
- Obstacles: the university too conservative
- Raise professors' awareness and commitment
- Created a 5 week course in SD
- John gives 1 hour lectures to newcomers in SD to promote high expectations in students

Pedagogical strategies.

- Understand the complexity of the challenge
- Promote critical thinking
- Need to make it structured so it can be evaluated
- First, understand the basics; orientate people, principles of SD
- Then introduce the actors involved at higher level on Environment and SD (long term aspects, social & economic aspects, system perspective)
- Nodes structure (complex topic)
- Give values (teaching method)

Expert: Anna Nyström		Date: 9 June 2005	
City: Goteborg	Country: Sweden		
Institution: Chalmers University of Technology			
Department: Energy and Environment			
Comments:			

Transcription:

Pedagogical strategies.

- Lectures
- Group activities:
- Argumentation game
- 2 Role games
- Dialogue
- Learning by doing by thinking
- She applies pedagogical studies to her teaching

Expert: Karin Andersson	Date: 9 June 2005	
City: Goteborg	Country: Sweden	
Institution: Chalmers University of Technology		
Department: Energy and Environment		

Comments: Vice President with responsibility for integrating departments at Chalmers. Karin Andersson is Assistant Professor of Environmental Systems Analysis at the Department of Energy and Environment.

Transcription:

Embedding SD.

- Policy from the Rector of the university
- Policy – action plan- funding-more teachers- more lecturers (in theory)
- Networking with people working at traditional schools
- Compulsory and elective courses integrated in E & SD
- Motivated from outside the university (Central Agency of Higher Edu.)-specific program for integrating environment In ordinary courses
- Time process to assimilate the importance of SD for teachers
- Shift to teaching & research on SD
- Change of knowledge in traditional teaching
- Grant funding for courses
- Measure SD embedding: asking teachers how much integration (not structured yet)
- Change of concepts from environment to SD
- 10 year process
- Doing research on SD and promoting SD at scientist's level (hard task).

Pedagogical strategies.

- Open to new teaching
- Problem based projects
- Lectures
- Problem discussion & analysis
- Class discussion
- Promote the use of the teacher as a resource

Expert: Gregory Morrison		Date: 17 June 2005	
City: Goteborg	Country: Sweden		
Institution: Chalmers University of Technology			
Department: Water Environment Transport			

Comments: Gregory Morrison is Director of Chalmers International Master's Programme in Applied Environmental Measurement Techniques and Vice Dean of the School for Environmental Sciences. With responsibility for new environmental profiles in Chalmers undergraduate education, he also wrote Chalmers Environmental Initiative (six new environmental professorships funded by the Chalmers Foundation). Since January 1 2000 he has been Head of Department for Water Environment Transport at the School of Civil Engineering.

Transcription:

Embedding SD.

- Political agenda (raise awareness of SD)
- University authorities commitment
- New demand for sustainable technology
- Private sector involvement/ funding/show new needs
- System shift to sustainability
- Academic migration
- Complexity approach
- Emphasis on course

Expert: Magdalena Svanström		Date: 20 June 2005
City: Goteborg	Country: Sweden	
Institution: Chalmers University of Technology		
Department: Energy and Environment		

Comments: Magdalena Svanström since Postdoc support time at MIT in 2001, she has been especially concerned with mud and waste management, among others, oxidation critical water, but also continued to engage in heating supply, which was the focus of graduate student time. Magdalena teaches environmental science and sustainable development and is very involved in learning for sustainable development.

Transcription:

Embedding SD.

- Progressive changes in curricula over the years
- Necessity to put every subject into SD context
- Education system centrally planned, centrally organized, they order the courses
- No action plan taken
- Renewing the courses by introducing SD
- Hard to have a top down approach, need to have some teacher interest to generate change
- Teachers working on education and research mix

Pedagogical strategies.

- Lectures
- Case study
- Exercises
- Small projects
- Discussion
- Although in Chalmers there's mostly very traditional teaching

Expert: Ulrika Lundqvist	Date: 17 June 2005	
City: Goteborg	Country: Sweden	
Institution: Chalmers University of Technology		
Department: Physical Resource Theory		
Comments: Head of the Division at Physical Resource Theory.		

Transcription:

Embedding SD.

- There is a general policy at Chalmers towards SD
- No action plan towards Embedding SD implemented yet
- Each department offers a SD compulsory course to the university board for approval
- It is a 5 credit course compulsory for each department in environment & SD
- Each department has a working group of teachers that works on SD:
    1. The aim is to increase quality of SD teaching
    2. They meet to share experiences, invite experts on values + discussion after.
    3. Everyone agrees on SD involvement
    4. Wrote a document that intends to be a structure on what the student must learn (not how, but content, knowledge and skills): SD definition, the problems of SD and possible solutions or strategies to avoid them.
    5. The meetings are useful for SD knowledge that teachers must have (not environmental but SD)

Pedagogical strategies.

For basic courses:

- Work in groups + exercises
- Small exam
- Class discussion

For advanced courses:

- Lectures + exercises
- Working in groups + exercises + student presentations
- Seminars (students are responsible for seminars)
- Students get to choose a topic, play role, debate on the topic chosen
- Not evaluated on knowledge but on participation

A3.13 Heriot-Watt University

<table>
<tr><td colspan="2">Expert: Bob Craik</td><td>Date: 5 September 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Edinburgh</td><td colspan="2">Country: Scotland</td></tr>
<tr><td colspan="3">Institution: Heriot-Watt University</td></tr>
<tr><td colspan="3">Department: Building Acoustics</td></tr>
<tr><td colspan="4">Comments: Bob Craik is professor of Building Acoustics. From 2003 he was appointed as Director of Quality Development and then Deputy Principal (Learning and Teaching) with responsibility for developing and implementing the university strategy for learning and teaching and for quality assurance of academic activities.</td></tr>
<tr><td colspan="4">Transcription:
<u>Embedding SD.</u>
- There’s not a policy on the introduction of SD to the curriculum, but it’s being discussed.
- There is not a SD EMBEDDING strategy or people in charge of that.
- He thinks that SD is not necessary.
- There will be individual modules on SD.
<u>Pedagogical strategies.</u>
- Projects</td></tr>
</table>

Expert: Veronica Bamber	Date: 8 September 2005	
City: Edinburgh	Country: Scotland	
Institution: Heriot-Watt University		
Department: Educational Development Unit		

Comments: Veronica Bamber is the director of the Educational Development Unit

Transcription:

Embedding SD.

- There are different Scottish and English HE agencies.
- Lecturers don't want interference in their contents
- It needs long term strategies to change opposition from non SD teachers.
- Because of the pressure on research the teaching is not given any value

Pedagogical strategies.

- The university has a Learning-Teaching strategy:
  - Sharing good practice and innovation.
  - Introducing a virtual environment of learning at H-W.
- It depends on the philosophy of the module: there're hard modules which are more impermeable than other soft modules.
- The majority of teachers just lecture but there is a small group of teachers working on PBL, active learning.
- You can't teach values or ethics by telling them. Students should explore these values for themselves.

A3.14 University of Plymouth

Expert: David Selby		Date: 19 September 2005	
City: Plymouth	Country: England		
Institution: University of Plymouth			
Department: Centre for Sustainable Futures			

Comments: David Selby is Professor for Education in Sustainability. The Centre for Sustainable Futures is funded for a five year period and tasked with transforming 'the University of Plymouth from an institution characterized by significant areas of excellence in Education for Sustainable Development (ESD) to an institution modelling university-wide excellence and, hence, able to make a major contribution to ESD regionally, nationally and internationally'.

Transcription:

Embedding SD.

- There was already a culture of transdisciplinary courses, and modules among different faculties so this facilitates the SD embedding of the curriculum.
- The introduction of a module on SD was an individual approach. But they succeed in showing the quality of the module. The sustainability agenda will be embedded through the whole agenda. For that purpose, the CETLSD was created.
- There are some allies who are developing new modules on SD adapted to each department.
- They are looking at the idea of a generic module with a frame which can be used in different department. (3 ECTS).
- They will start a Masters on Education for SD.
- In building technology and architecture there are intensifications of SD.

Pedagogical strategies.

- Centre of Expertise of Teaching and Learning (CETL) on SD is about the campus-curriculum interface.
- Pedagogy means practical action on campus for CETL. (like the real laboratory at the UPC)
- How a university in partnership with sustainable learning communities can drive a Sustainability agenda?
- Curriculum should be action orientated with real live situations and students not sitting in a room learning about SD they should learn for or through SD by engagement to action oriented projects.
- Pedagogy is about the principles on SD (equity, future orientation, participation, e….) those concepts have an implication not only for what has to be on the curriculum but also for the pedagogical process, so the learning process itself must be sustainable: participatory, etc.. So it involves the lecturers' role as a lecturer.
- Traditional HE curriculum is about vertical relationships and you have to move to explore horizontal relationships in the learning approach.
- He feels that pedagogy on SD exists.
- HEI also need to rethink their attitude to emotional learning.
- Socio-affective learning, learning which concerns relationships, emotional responses to things, the dynamic flows between emotion, commitment understanding inside, and so on.
- example: Do an interactive presentation
- Sustainability is systemic thinking; a lot of pictures are still in a mechanistic mode, understanding dividing in boxes… etc. How do you create pedagogical approaches that optimise the understanding of flows of relationships between things of all kinds? We need that. Sustainability is a clear potpourri (environmental, social, economic, etc…) so we need different ways of teaching to do that.

Expert: Alan Dyer		Date: 20 September 2005	
City: Plymouth	Country: England		
Institution: University of Plymouth			
Department: Centre for Sustainable Futures			
Comments: Alan Dyer is Associate Director of the Centre for Sustainable Futures. Centre of Excellence for Teaching and Learning - Education for Sustainable Development.			

Transcription:

Embedding SD.

- Worked for SD embedding at Plymouth University.
- The highest constraint on SD embedding is the traditional system itself.
- Before CETL started, the process was a bottom-up one.
- It's important to find allies in each department and start from this point. They can produce their programs. CETL is just a facilitator; the SD embedding has to come from inside the departments.

Pedagogical strategies.

- Experiential education is the best pedagogy strategy.
- Take the students out of the classroom and put them in the real world and challenge students. Although it is difficult to include in the engineering curriculum and action is not directly related to engineering.
- PBL is a good way for the experiential learning required.

A3.15 University of Surrey

<table>
<tr><td colspan="2">Expert: Roland Clift</td><td>Date: 15 September 2005</td><td rowspan="4"></td></tr>
<tr><td>City: Guildford</td><td colspan="2">Country: England</td></tr>
<tr><td colspan="3">Institution: University of Surrey</td></tr>
<tr><td colspan="3">Department: Centre of Environmental Research</td></tr>
<tr><td colspan="4">Comments: Roland Clift is Distinguished Professor of Environmental Technology and Founding Director of the Centre for Environmental Strategy (CES). His research specialisation is in the broad field of Environmental System Analysis, including Life Cycle Assessment, Industrial Ecology and Sustainable Energy Systems..</td></tr>
<tr><td colspan="4">Transcription:

<u>Embedding SD.</u>
- Higher Education Academy has produced the policy that encourages teaching of SD.
- Since 1996, Surrey University has had an environmental policy- with talks and seminars on SD.
- They started to work on these modules for the reason that they were interesting not because of the university policy but because the market was asking for it.
- They have developed an SD module (6ECTS)
- The introduction of environmental knowledge started at the management school. His experience is that the SD EMBEDDING can start without the commitment of the board.
<u>Pedagogical strategies.</u>
- Project Based Learning.
- Case studies.</td></tr>
</table>

A3.16 University of Bristol

Expert: Sally Heslop		Date: 19 September 2005	
City: Bristol	Country: England		
Institution: University of Bristol			
Department: Engineering Department			

Comments: Engineering Education, Environmental Management, Environmental Systems, Sustainability, Education Director & Graduate Dean of Engineering Department

Transcription:

Embedding SD.

- SD is well embedded in Civil Engineering curriculum.
- Bristol is a general university. Engineering is one of six faculties. (Within engineering they have: civil, aerospace, electrical, mechanical engineering)
- The Policy didn't make any changes. In civil eng. they have been trying to introduce environment and SD inside the curriculum mainly because it was the professional body who asked for it.
- They have two subjects (5 ECTS) on SD for all students in two different student years (they meet the UK Engineering Council criteria which state SD is important for engineers to know about).
- The civil professional body has the power to give accreditation to engineers once they have graduated. And as a professional body which asks for SD knowledge it helps. In other professions without this vision from the body it is not so easy.
- To convince teachers, they have to see how important SD is for their speciality and get them engaged.
- Their policy is to engage allies from each department and start working with them.
- Reward teachers when they introduce SD and develop learning materials for SD, by giving less teaching hours. Sally's long term strategy is working on staff more than on students.
- SD Embedding started because she thought it was important, now it is reinforced by the department.
- They are audited by an exterior team and when they ask for SD it will make real changes.
- They will open a new course (elective) with no prerequisites called SD (10ECTS) for all university students.
- The environmental management of the campus is working quite well.

Pedagogical strategies.

- Students do assignments
- Lectures from professor on SD
- Case studies
- Lectures from experts from the companies are very effective both for students and sceptic teachers.
- Formal lecture
- Assignment
- PBL
- Visits
- Talk to stakeholders of the project
- Presentations
- Reporting
- For large groups, use lecturing to raise the awareness and then split into small groups and apply PBL.
- Students are used to working in PBL in UK.

A3.17 Technical University of Catalonia

Expert: Miquel Barceló	Date: 23 December 2008	
City: Barcelona	Country: Spain	
Institution: Technical University of Catalonia		
Department: Computer Science		

Comments: Vice-Rector of Sustainability at the UPC. Coordinator of PhD program on Sustainability of the UNESCO chair of Sustainability of the UPC. Long experience on teaching SD courses in the Computer Science Department.

Transcription:

Embedding SD.

- The ideal situation is that SD is embedded in all courses.
- He thinks that this ideal situation is far from reality and difficult to achieve so proposes having a compulsory course on SD as a first approach for all engineers to introduce the basics of SD, but not forgetting the embedding in all the other courses.
- He thinks SD courses should be in later courses, when students know what their engineering speciality is about.
- SD has to be clearly related to the engineering speciality.
- All the Bachelors' and Masters' final theses must include SD contents or reflections.

Pedagogical strategies.

- The role of the teacher is essential, both in the sense of his/her skills and attitudes towards teaching, and to motivate students to learn.
- Pedagogical methodologies are just tools whose efficacy in the learning process depends more on teacher's attitudes and student motivation than on the kind of methodology.
- Methodologies should be practical.
- Case studies with real and practical cases with open solutions related to the engineering speciality of the students.
- Cooperative learning.
- Student presentations.
- Debates, films, role play.
- He lectures about 20%.

Expert: Enric Carrera		Date: 20 January 2009	
City: Barcelona	Country: Spain		
Institution: Technical University of Catalonia			
Department: UNESCO Chair of Sustainability - UPC			
Comments: Has been the director of the UNESCO Chair of Sustainability for 10 years. Long experience of teaching SD courses at the Technical University of Catalonia.			

Transcription:

Embedding SD.

- A compulsory course about basics to set up a common SD language for all students is necessary
- Embedding in all courses.
- Offer a minor/track on SD (with courses related to the engineering specialities)
- All the Bachelors' and Masters' final theses must include SD contents or reflections. This SD content must be compulsory in order to graduate.
- The main barrier is the low incentive for educational activities versus research. Therefore it is difficult to involve lecturers and professors in the process of embedding SD in their courses.

Pedagogical strategies.

- Experiential/emotional learning
- Real projects.
- Lectures from professors on SD is necessary to learn the concepts of SD
- Workshops
- Exercises.
- Debates, Role play.
- Active learning activities.
- Use many learning methodologies.

Expert: Antoni Grau	Date: 20 January 2009	
City: Barcelona	Country: Spain	
Institution: Technical University of Catalonia		
Department: Automatic Control Department		
Comments: He has been introducing SD contents in technical courses. He is editor of the journal Sustainable Education - RCE Barcelona. Member of EDUSOST (research network on ESD). STEP (Sustainable Technology Excellence programme) coordinator.		

Transcription:

Embedding SD.

- A compulsory course about basics to set up a common SD language for all students is necessary and relate it to the engineering speciality of the students. This course should be done in the middle of the degree.
- Embedding in all courses, especially in the last year speciality courses rather than in the basic (algebra, calculus, physics, etc) ones.
- All theBachelors' and Masters' final theses must include SD contents or reflections. This SD content must be compulsory in order to graduate.

Pedagogical strategies.

- In the first years he advocates instructional learning.
- In the later years apply constructive learning:
  - Real projects.
  - Case studies.
  - Active learning.
  - Debates.
- Lectures are necessary to learn the concepts of SD at the beginning of a SD course.

[1] Appendix 1 contents the semi-structured interview.
[2] Appendix 2 shows the list of experts on EESD.

Appendix IV Cmaps data collection process

The data collection process followed in all 10 case studies is divided in two steps:

Before the learning activity (Cmap1).

First, the research project to the students is introduced, then students are explained how to draw a conceptual map with one example and finally they are asked to fulfil a questionnaire and to draw a Cmap (see figure A-IV.5). This process is applied during the first session of the learning activity before any learning process has started. Students are given 15 minutes to draw the Cmap.

After the learning activity (Cmap2).

The last activity of the learning activity is to draw the Cmap2. Students are given 15 minutes to draw the Cmap.

The slides used to introduced the project and explain how to draw a conceptual map were the same in all case studies. (See figures A-IV 1 to 4)

Figure A-IV.1 Slide 1. Introduction of the research project

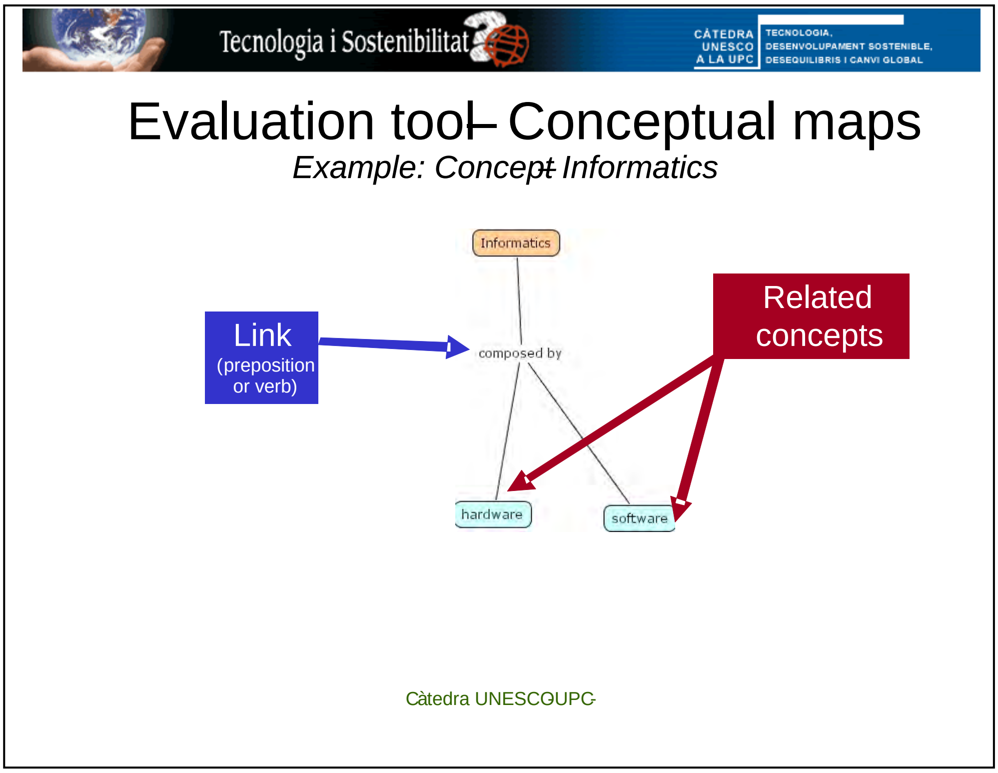


Figure A-IV.2 Slide 2. Explanation of how to draw a Cmap

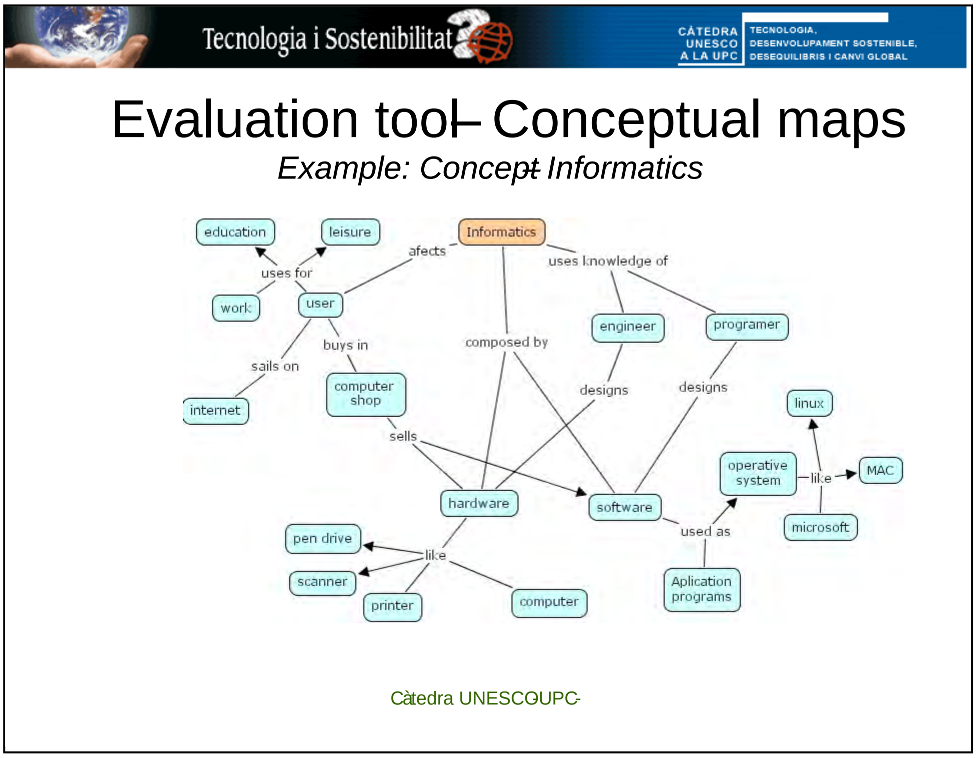


Figure A-IV.3 Slide 3. Example of Cmap

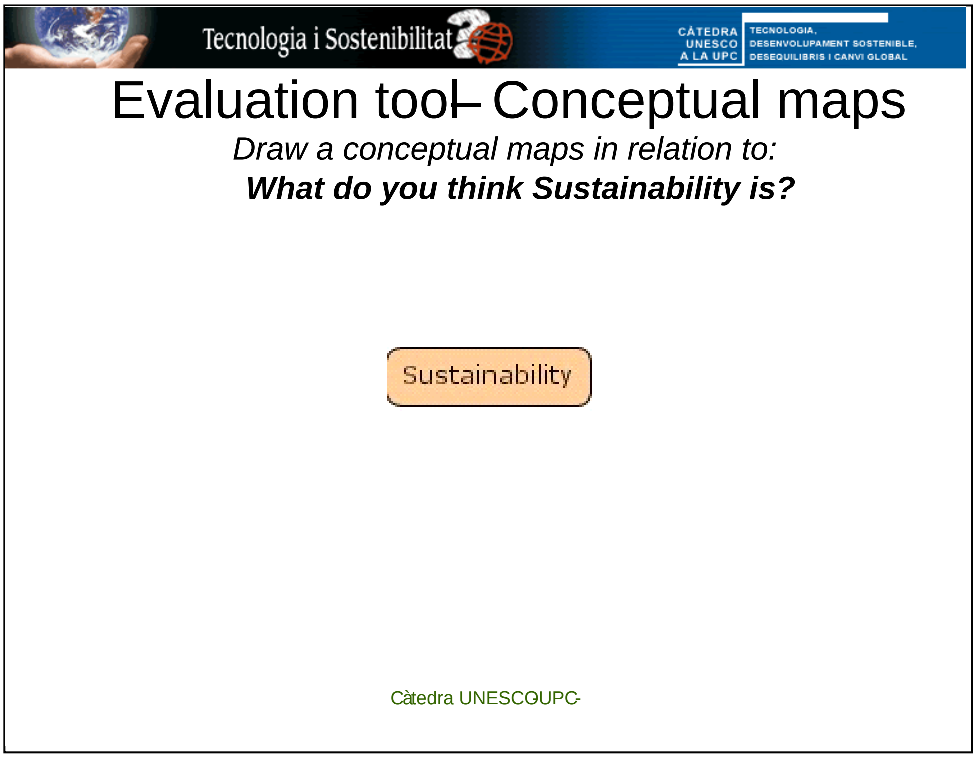


Figure A-IV.4 Slide 4. Cmap question asked to the students.

Finally students are given the next questionnaire where their data and Cmap are collected.

CONCEPTUAL MAP

Date: __/___/______ Name: ____

Nationality: ________________________ Gender: ______ Age: __________

University: ____

Studies speciality: ____

Course: ____

Which is your academic year of studies? ☐ 1st ☐ 2nd ☐ 3rd ☐ 4th ☐ 5th

Have you already done any environmental or social courses before? ____________________________

Which ones? ____

Are you doing simultaneously to this course any other environmental or social courses? ____________

Which ones? ____

SUSTAINABILITY

If you don't have enough space on this side of the paper, please, use de backside.

Figure A-IV.5 Cmap questionnaire.

Appendix V ESD Resources

This appendix of ESD resources contains the next sections:

ESD centres that has participated in this research.

Bibliography resources.

- Sustainable Education.
- Education for Sustainable Development.
- Sustainable Development in Higher Education

Web Resources

- Official organisations and programs
- Education for Sustainability
- Searchers
- Journals
- ESD Conferences
- Learning Tools

ESD centres that has participated in this research

- Centre for Environment and Sustainability (GMV). Chalmers University of Technology. Goteborg. Sweden.
  <http://www.chalmers.se/gmv/EN/>
- Centre for Environmental Strategy (CES). University of Surrey. Guildford. England
  http://www.ces-surrey.org.uk/
- Centre for Sustainable Futures (CSF). University of Plymouth. Plymouth. England.
  <http://csf.plymouth.ac.uk/>
- Centre for sustainability (Cities). UPC. Barcelona. Spain.
  <https://www.upc.edu/centresostenibilitat>
- Centre of Sustainability and Water (Spring). Hogeschool Zeeland, Vlissingen. The Netherlands
  http://www.hz.nl/spring/
- Commission de l'environnement et du développement durable. Université Catholique de Louvain. Louvain la Neuve. Belgium.
  http://www.uclouvain.be/cenv
- Eindhoven centre for Sustainability. Eindhoven University of Technology. Endhoven. The Netherlands.
  http://w3.ieis.tue.nl/en/technology_for_sustainable_energy/
- Industrial Ecology. Science for Sustainable Development. Royal Institute of Technology. Stockholm. Sweden.
  <http://www.ima.kth.se/eng/>
- Institute for Science, Innovation and Society. Radboud University. Nijmegen. The Netherlands
  <http://www.ru.nl/science/isis/>
- International Centre for Environment. University of Bath. England.
  <http://www.bath.ac.uk/ice/>
- Scottish Institute of Sustainable Technology. Heriot-Watt University. Edinburg. Scotland.
  <http://www.sistech.co.uk/>
- Technology Dynamics and Sustainable Development (TDO). Delft University of Technology. Delft. The Netherlands.
  <http://www.tbm.tudelft.nl/live/pagina.jsp?id=0ad3e4b4-cf09-48f4-b739-fe1fa56e878b&lang=en>
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- GOUGH, S.; SCOTT, W. Higher Education and Sustainable Development: Paradox and Possibility. London etc.: Routledge, 2007. 194 p. ISBN 9780415416528
- HOLMBERG, J.; SAMUELSSON, B. E. (ed.). Drivers and Barriers for Implementing Sustainable Development in Higher Education: Göteborg Workshop December 7-9, 2005. Paris: Unesco, 2006. 130 p. Available at: <http://unesdoc.unesco.org/images/0014/001484/148466E.pdf>
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- M'GONIGLE, M.; STARKE, J. Planet U: Sustaining the World, Reinventing the University. Gabriola Island: New Society Publishers, 2006. 288 p. ISBN 9780865715578
- MULDER, K. (ed.). Sustainable Development for Engineers. Greenleaf Publishing, 2006. 288 p. ISBN 1874719195
- SCOTT, W.; GOUGH, S. (ed.). Key Issues in Sustainable Development and Learning: a Critical Review. London: RoutledgeFalmer, 2003. 272 p. ISBN 0415276500

- SCOTT, W. & GOUGH, S. Sustainable Development and Learning. Framing the issues. Routledge. 2003. 173 p. ISBN 0415276489
- SEMINARI INTERNACIONAL D'AMBIENTALITZACIÓ CURRICULAR (2001: BARCELONA). Introduir la sostenibilitat en els estudis universitaris tecnològics: 29 i 30 de novembre de 2001. Barcelona: UPC; Departament de Medi Ambient de la Generalitat de Catalunya, 2002. 247 p. (Seminaris d'ambientalització curricular). Available at: <http://mediambient.gencat.cat/Images/43_8069.pdf>

Web Resources

Official organisations and programs

- Association for the Advancement of Sustainability in Higher Education
  <http://www.aashe.org/>
- Alliance for Global Sustainability.
  <http://globalsustainability.org/>
- DHO. Duurzaam Hoger Onderwijs (Dutch network for SD in HE curricula)
  <http://www.dho.nl/>
- Integrated Research System for Sustainability Science (IR3S)
  <http://www.ir3s.u-tokyo.ac.jp/en/>
- Organización de Estados Iberoamericanos para la Educación, la Ciencia y la Cultura. Programa Década por una Educación para la Sostenibilidad
  <http://www.oei.es/decada>
- SADC Regional Environmental Education Programme.
  <http://www.sadc-reep.org.za>
- United Nation Environment Programme
  <http://www.unep.org/>
- UN Decade of Education for Sustainable Development (2005-2014)
  <http://portal.unesco.org/education/en/ev.php-URL_ID=27234&URL_DO=DO_TOPIC&URL_SECTION=201.html>
- World Bank , Development Education Program (DEP)DEPWEB
  <http://www.worldbank.org/depweb/>

Education for Sustainability

- Engineering Education for Sustainable Development Observatory.
  <https://www.upc.edu/eesd-observatory>
- European Foundation for Education and Sustainable Development.
  <http://www.european-esd.net/index.htm>
- Forum on Science and Innovation for Sustainable Development.
  <http://sustainabilityscience.org/Global Development Research Center>
- North American Association for Environmental Education
  <http://www.naaee.org/>
- Regional Centre of Expertise on Education for Sustainable Development (RCE Barcelona)
  <http://rce-barcelona.net>
- SDPROMO - Promoting European Education in Sustainable Development
  <http://www.sdpromo.info>
- UNESCO Chair of Sustainability - UPC
  <http://www.catunesco.upc.es/>
- UNESCO Chair in training of sustainable development professionals- Université Michel de Montaigne
  <http://www.u-bordeaux3.fr/en/index.html>
- UNESCO Chair R I I F A D E L / International Network in engineering of training applied to local Development / Human Resources - Executive Training - University of Toulouse
  <http://www.riifadel.fr/>
- UNESCO Chair in Higher Education for Sustainable Development - the University of Lueneburg
  <http://kuntikum.uni-lueneburg.de/homepage/chair/index.htm>

- University Leader for a Sustainable Future
  <http://www.ulsf.org>
- Catalan Network of Research in Education for Sustainability.
  <http://edusost.cat/>

Searchers

- EElink: Environmental Education on the Internet
  <http://eelink.net>
- Enviroeducation. The environmental School Directory
  <http://www.enviroeducation.com/>
- SDPROMO - Searcher of SD masters in Europe.
  <http://www.sdpromo.info/web/page.aspx?refid=28>

Journals

- Environment, development and sustainability. Nath, B. (ed.) European Centre for Pollution Research ISSN: 1573-2975
  <http://www.springer.com/environment/environmental+management/journal/10668>
- Environmental Education research. Reid, A. (ed.) University of Bath. ISSN 1350-4622
  <http://www.tandf.co.uk/journals/titles/13504622.asp >
- European Journal of Engineering Education. De Graaff, E. (ed.) SEFI (European Society for Engineering Education). ISSN 1469-5898
  <www.tandf.co.uk/journals/titles/03043797.asp>
- International Journal of Engineering Education. Ibrahim, A. (ed.) ISSN 0742-0269
  <http://www.ijee.dit.ie/>
- International Journal of Sustainability in Higher Education. Filho, W.L. (Ed.) ULSF (Association of university leaders for a sustainable future. ISSN 1467-6370
  <http://www.emeraldinsight.com/info/journals/ijshe/ijshe.jsp >
- Journal of Cleaner Production. Huisingh, D. (ed.) ISSN: 0959-6526
  <http://www.elsevier.com/locate/jclepro>
- Revista internacional de Sostenibilidad, Tecnología y humanismo. Barcelo, M. (Ed.).
  <https://www.catunesco.upc.edu/publicacions/periodiques/revistaiSTH>
- Sostenible? Carrera, E. (Ed.) ISNN: 1139-966X
  <https://upcommons.upc.edu/revistes/handle/2099/1208>
- Sustainability Science. Takeuchi, K. Integrated Research System for Sustainability Science (IR3S).The University of Tokyo ISSN: 1862-4057
  <http://www.springerlink.com/content/120154/>
- Sustainability: science, practice, & policy. Cohen, M. (ed.) New Jersey Institute of Technology. ISSN: 1548-7733
  <http://ejournal.nbii.org/>

ESD Conferences

- EMSU - Environmental Management for Sustainable Universities.
  <http://www.emsu.org>
- EESD - Engineering Education in Sustainable Development
  <http://eesd08.tugraz.at/>
- WEEC World Environmental Education Congress
  <http://www.5weec.uqam.ca/EN/>
- UNESCO World Conference on Education for Sustainable Development
  <http://www.esd-world-conference-2009.org/>

Learning Tools.

- Sustain.no. Educational tool for sustainable development.
  <http://sustain.no>
- Agustí Pérez-Foguet A. & Lobera, J. (eds.) (2008). El desarrollo humano Sostenible en las aulas politécnicas.
  < http://upcommons.upc.edu/e-prints/handle/2117/1979>
- Mulder, K. Desarrollo Sostenible para ingenieros
  <http://bibliotecnica.upc.es/edupc/locate4.asp?codi=CT017XXX>
- Buckland H. (ed.) Magazin Education and Sustainability.
  <http://rce-barcelona.net/index.php?option=com_content&task=view&id=87&Itemid=124&lang=en>
- Forum for the Future. (2005). Learning and skills for sustainable development: developing a sustainability literate society.
  <http://www.forumforthefuture.org/files/learningandskills.pdf>
- UPC Sostenible 2015. SD learning resources data base.
  <http://www.upc.edu/sostenible2015/ambits/la-formacio/recursos-per-introduir-la-sostenibilitat-als-programes-formatius>
- Portal Sostenibilidad. UNESCO Chair of Sustainability UPC.
  <http://portalsostenibilidad.upc.edu/index.php>

Appendix VI Publications

The work developed during this research has been published in journals, conferences and also has produced two guides. This appendix shows the most relevant.

Research journals

- Segalàs, J.; Ferrer-Balas, D.; Svanström, M.; Lundqvist, U. & Mulder K.F. (2009). What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities. Sustainability Science, (ISSN: 1862-4057). Vol. 4, Nº 1, pp. 17-27. <http://www.springerlink.com/content/251j43864n2736x4/fulltext.pdf>
- Segalàs, J. (2009) Educating engineers for sustainability: Why? What? How? Sostenible? Sostenibilitat I Educació. (ISNN: 1139-966X). Vol. 10, pp. 117-138. <https://upcommons.upc.edu/revistes/bitstream/2099/7109/1/010_09.pdf>.
- Segalàs, J.; Ferrer-Balas, D. & Mulder, K.F. (2008). Conceptual maps: measuring learning processes of engineering students concerning sustainable development. European journal of engineering education, (ISSN 0304-3797), Vol, 33, Nº 3, pp. 297-306. <http://www.informaworld.com/smpp/content~content=a794476057~db=all~order=page>
- Holmberg, J, Svanstrom, M, Peet, DJ, Mulder, KF, Ferrer-Balas, D & Segalàs, J (2008). Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities. European journal of engineering education, (ISSN 0304-3797), Vol. 33, Nº 3, pp. 271-282. <http://www.informaworld.com/smpp/content~content=a794475740~db=all~order=page>.

Conferences

- Segalàs, J. (2009). Teaching engineers for a sustainable future. International Conference on Sustainability Science (ICSS2009). University of Tokyo. Tokyo. February 2009.
- Segalàs, J.; Ferrer-Balas, D. & Esbri, M.E. (2008). University's role in sustainable development. Konferencija Industrijska ekologija i održivi razvoj u visokom obrazovanju. Mašinski fakultet Sarajevo. Sarajevo. Bosnia & Herzegovina. 18 December 2008.
- Segalàs, J. (2008). SD-Promo project. International Conference Promoting Research & Education on Sustainable Development in China. Shandong University. Jinan. China. 30-31 d'octubre de 2008.
- Segalàs, J. & Ferrer-Balas, D. (2008). UPC Sostenible 2015: La Sostenibilidad en la universidad. Jornadas sobre educación para el desarrollo sostenible y la ciudadanía Global. Burgos University. Burgos. Spain. 21-23 October 2008.
- Segalàs, J. & Esbrí M.E. (2008). European Project Semester: 30 ECTS of PBL in Sustainability with multicultural and multidisciplinary bachelor students groups". International conference Environmental Management for Sustainable Universities (EMSU'08). A new knowledge culture. Universities facing global changes for sustainability. Universitat Politècnica de Catalunya. Barcelona. Spain. 15-17 October 2008.

- Segalàs, J.; Ferrer-Balas, D. & Mulder, K.F. (2008). Evaluación de competencias transversales mediante Mapas Conceptuales: Sostenibilidad en estudiantes de ingeniería. Congreso Universitario de Innovación Educativa en las Enseñanzas Técnicas (XVI CUIEET). Cadiz university. Cadiz. Spain. 23-26 September 2008.
- Segalàs, J.; Ferrer-Balas, D. & Mulder, K. (2008). Pedagogical strategies for learning Sustainability by engineering students. International Conference Engineering Education in Sustainable Development. Graz. Austria. 22-24 September 2008.
- Segalàs, J.; Mulder, K.F.; Kordas, O.; Wennersten, R. & Nikiforovich, E. (2008). Sustainable Development course at the National Technical University of Ukraine: a joint venture of 4 European Universities. International Conference Engineering Education in Sustainable Development. Graz. Austria. 22-24 September 2008.
- Gallón, L.; Motrel, A.P.; Lobera, J.; Segalàs, J. & Ferrer-Balas, D. (2008). Demand of education for sustainable development in latin america". International Conference Engineering Education in Sustainable Development. Graz. Austria. 22-24 September 2008.
- Segalàs, J.; Ferrer-Balas, D.; Pujadas, M. & Mulder, K.F. (2008). Learning evaluation from an international seminar on Sustainable Technology Development using Conceptual Maps". International Conference Engineering Education in Sustainable Development. Graz. Austria. 22-24 September 2008.
- Segalàs, J. (2008). Educação para o desenvolvimento sustentável na Europa. I Encontro Latino Americano de Universidades Sustentáveis. Universidades Sustentáveis, Possibilidades e Desafios. Universidade de Passo Fundo. Passo Fundo. Brasil. 1-3 September 2008.
- Segalàs, J. (2008). EESD-Observatory: Status of engineering education for sustainable development in European higher education. I Encontro Latino Americano de Universidades Sustentáveis. Universidades Sustentáveis, Possibilidades e Desafios. Universidade de Passo Fundo. Passo Fundo. Brasil. 1-3 September 2008.
- Segalàs, J.; Esbri, M.E. & Trullols, E. (2008). Diseño y organización del European Project Semester: 30 créditos de aprendizaje basado en proyectos en sostenibilidad con grupos multiculturales y multidisciplinares para estudiantes de grado". I Encontro Latino Americano de Universidades Sustentáveis. Universidades Sustentáveis, Possibilidades e Desafios. Universidad de Passo Fundo. Passo Fundo. Brasil. 1-3 September 2008.
- Segalàs, J. (2008). "Teaching SD to Engineers: From Edu-cation to Edu-action". Conferência Desenvolvimento Sustentável uma visão Global". Conselho de Engenharia, Arquitetura e Agronomia do Rio de Janeiro. Rio de Janeiro. Brasil. 29 August 2008.
- Segalàs, J. & Carrera, E. (2008). La experiencia Europea de educación para la sustentabilidad. El caso de la Universitat Politècnica de Catalunya (España). Congreso Internacional: Gestión Sostenible del Agua: Reutilización, Tratamiento y Evaluación de la Calidad. Universidad de Antioquia. Medellín. Colombia. 16-18 July 2008.
- Segalàs, J. (2008). Sustainable Development indicators. SDPromo-2008 Conference: "Екологія. Людина. Суспільство". Kiev Polytechnic Institute. Kiev. Ukraine. 13-18 May 2008.
- Mulder, K.F.; Segalàs, J. & Ferrer-Balas, D. (2008). Engineering Education in Sustainable Development in Europe. An overview of processes, networks, barriers methods, pedagogy and strategies. 4th African Regional Conference on Engineering Education (ARCEE–2008). Dar es Salaam. Tanzania. 22-25 April 2008.
- Segalas, J. (2007). EESD-Observatory. "Status of engineering education for sustainable development in European higher education. 2nd International Colloquium 2007 Education and Sustainable Development. Capacity Building for the 21st Century. Tokyo. Japan. 9-10 October 2007.
- Segalàs, J. (2007). Universitats innovadores davant dels nous reptes socials. I congrés UPC SOSTENIBLE 2015. UPC. Barcelona. Spain. 12-13 July 2007.
- Segalàs, J.; Ferrer-Balas, D. & Mulder, K.F. (2007). Estratègies didàctiques per integrar la sostenibilitat al currículum acadèmic de les universitats tecnològiques". Seminar "L'estat de la recerca en l'educació per a la sostenibilitat a Catalunya". Barcelona. Spain. 28 June 2007.

- Segalàs, J.; Ferrer-Balas, D. & Mulder, K.F. (2007). Pedagogical strategies for integrating sustainability in technological universities curriculum”. AGS annual meeting 2007. Barcelona. Spain. 18-21 March 2007.
- Segalàs, J.; Ferrer-Balas, D. & Carrera, E. (2006). Educación en Sostenibilidad en la Universidad Politècnica de Catalunya. II Congreso de Educación Ambiental en espacios protegidos. Bermeo. Spain. 23-25 October 2006.
- Segalàs, J.; Mulder, K.F. & Ferrer-Balas, D. (2006). Conceptual Maps: Measuring learning processes of engineering students concerning sustainable development. SEFI 34th Annual Conference. Uppsala. Sweden. 28 June - 1 July 2006.
- Segalàs, J.; Mulder, K.F. & Ferrer-Balas, D. (2006). Using Conceptual Maps to measure learning on Sustainable Development: case studies from European technological Universities. IV EMSU Conference. Steves Point. Wisconsin. USA. 26-30 June 2006.
- Segalas, J. & Carrera, E. (2006). La experiencia Europea de educación para la sostenibilidad. El caso de la Universidad Politécnica de Cataluña. Seminario Iberoamericano de educación superior para la sustentabilidad SIESS. Mérida. Venezuela, 19-20 June 2006.
- Segalàs, J.; Ferrer-Balas, Mulder, K.F. (2005). Embedding sustainability in engineering education. Experiences form Dutch and Spanish technological universities. Conference New Challenges from a Global Perspective. Luneburg. Germany. 25-27 September 2005.
- Segalàs, J.; Ferrer-Balas, D. & Mulder, K.F. (2005). Curriculum greening in engineering education. Experiences from Dutch and Spanish technological universities. 3rd World Environment Education Congress. Torino. 1-5 July 2005.
- Segalàs, J.; Ferrer-Balas, D. & Carrillo, A. (2004). Sustainability Evaluation of Engineering Student Projects: A Guideline for the Sustainability Award by CETIB-UPC. International Conference on Engineering Education in Sustainable Development EESD2004. Barcelona. Spain. 27-29 October 2004.
- Mulder, K.F.; Segalas, J. & Cruz, Y. (2004). What professionals should know about Sustainable Development? Results of SD teaching experiences at engineering institutions as starting point for a course design. 1st European Networks Conference on Sustainability in Practice. Berlin. Germany. 1-4 April 2004.
- Segalàs, J.; Jorge, J.; Ferrer-Balas, D. & Pujadas, M. (2002). e-AmbiT. A virtual resources site on curriculum greening for technological studies. International Conference Engineering Education in Sustainable Development. Delft. The Netherlands. 24-25 October 2002.

Guides

- Segalàs, J. (2009). Guide to introduce Sustainability and Social Commitment competences in the new engineering degrees at UPC. [In revision].
- Segalàs. J. (2002). Guide to evaluate Sustainability of the final thesis project of Bachelors degrees. Col·legi d’Enginyers Tècnics Industrials de Barcelona. Barcelona. October 2002.

Abbreviations

AASHE - Association for the Advancement of Sustainability in Higher Education

ABET - Accreditation Board for Engineering and Technology

AGS - Alliance for Global Sustainability

BT - Bloom's taxonomy

CDIO - Conceive-Design-Implement-Operate

Cmap – Conceptual map

CO – Complexity Index

CR – Category Relevance Index

CRUE – Conferencia de Rectores de Universidades Españolas (Spanish Universities Rectors Committee)

CUK - Engineering Council of United Kingdom

CUT – Chalmers University of Technology

DESD - Decade of Education for Sustainable Development

DHO – Duurzaam Hoger Onderwijs (Dutch network for SD in HE curricula)

DIDE - Dirección de Investigación y Desarrollo Educativo

DUT – Delft University of Technology

ECTS - European Credit Transfer System

EESD - Engineering Education in Sustainable Development

EHEA - European Higher Education Area

EMSU - Environmental Management for Sustainable Universities

ENCOS - European Networks Conference on Sustainability in Practice

ESD - Education in Sustainable Development

EUT – Eindhoven University of Technology

GHESP - Global Higher Education for Sustainability Partnership

HE – Higher Education

HEI - Higher Education Institutions

HU2 - Hållbar Utveckling i Högre Utbildning (SD for Higher Education)

IAU - International Association for Universities

IE - Industrial Ecology

IR3S - Integrated Research System for Sustainability Science

JQI - Joint Quality Initiative

KPI – Kiev Polytechnic Institute

KT - Krathwohl’s taxonomy

KTH – Kungliga Tekniska högskolan (Royal Institute of Technology)

LA - Learning Activity

LCA - Life Cycle Assessment

NEPP - National Environmental Policy Plan

OECD - Organisation for Economic Co-operation and Development

PBL – Project Based Learning

R&D – Research & Development

SD - Sustainable Development

SDE - Sustainable Development Education

SIDA - Swedish International Development Cooperation Agency

SWEDESD - Swedish International Centre of Education for Sustainable Development

SWOT – Strengths, Weaknesses, Opportunities, and Threats

TDO - Technologiedynamica en Duurzame Ontwikkeling (Technology Dynamics and Sustainable Development)

UN - United Nations

UNCED - United Nations Conference on Environment and Development

UPC - Technical University of Catalonia

USLF - University Leaders for Sustainable Future

VHU – Vetenskap för Hållbar Utveckling (Swedish Research Association for SD)