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PROBLEM BASED LEARNING AND SUSTAINABLE ENGINEERING EDUCATION

CHALLENGES FOR 21ST CENTURY



AIDA GUERRA

Monograph

PROBLEM BASED LEARNING AND SUSTAINABLE ENGINEERING EDUCATION

CHALLENGES FOR 21ST CENTURY

Monograph

Volume I

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This thesis has been submitted doctoral school of Faculty of Engineering and Science, Aalborg University, for assessment in partial fulfillment of the PhD degree. The thesis a monograph composed by two volumes: monograph (volume I) and appendices (volume II).

Aalborg University

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Problem Based Learning and Sustainable Engineering
Education: Challenges for 21st century

Volume I: PhD monograph

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in Engineering Science and Sustainability
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English summary

Fast science knowledge production and technological breakthroughs form the ground for modern society's development and ways of living. Modern society's life standards and behaviours lead to sustainability problems, such as environment degradation, climate change, poverty, army conflicts, etc. Engineers play an important role in addressing sustainability crises. To address sustainability problems, engineers need new kinds of knowledge, competencies and skills, calling for a new type of engineering education able to support the development of the mentioned knowledge, skills and competencies. Furthermore, integration of sustainable development has been emphasised by engineering education research, accreditation boards and organisations.

Education for sustainable development (ESD) aims to educate critical, creative, ecological aware citizens, capable to participate and act responsibly in a sustainable society. ESD is characterised as interdisciplinary, contextual, critical, purposive, integrative, holistic, participatory, ethical and lifelong. Learning environments should enclose these characteristics in the learning processes to support the development of knowledge, skills and competencies for ESD. To integrate ESD, engineering education systems need to align their vision, missions, provisions and practices with sustainable education. Changing towards sustainable education involves the entire organisation, its structures, frameworks and actors. Higher Education Institutes (HEIs) have been developing strategies and approaches to integrate ESD throughout the entire organisation. The strategies involve, for example, greening campus operations, integration of sustainable development in formal curricula, developing innovative learning strategies, establishing new partnerships with external identities, among others.

Problem Based Learning (PBL) is one of the learning strategies used to integrate sustainable development and to address engineering education challenges. In PBL, the learning process starts with analysis and formulation of a problem, from real and ill-structured problem scenarios. PBL is based on learning principles such as contextual, self-directed, experiential and collaborative learning. Such principles enable students to develop high reasoning skills (e.g. metacognitive knowledge), critical thinking, interdisciplinary knowledge, problem solving skills and communication skills.

Most of ESD research documents that PBL pedagogies can provide a framework for developing ESD learning outcomes. However, there is lack of research on how PBL can actually support integration of ESD in engineering education from a process perspec-

tive. This study investigates in which ways PBL can support the integration of ESD in engineering education. It aims to take a comprehensive approach by carrying out the research through three perspectives: theoretical, experts and practice.

The theoretical perspective aims to comprehend the similarities between PBL and ESD for engineering education. To fulfil this research goal, PBL and ESD learning principles are outlined and defined through literature review. Furthermore, the literature review allows identifying analytical variables that can be used to investigate the practice perspective. The analytical variables are: problems, knowledge, disciplinarity, criticality, process competencies, EESD principles, SD aspects and curriculum organisation. The experts' perspective aims to investigate different strategies, drivers and challenges in integrating ESD in engineering education. The perspectives are gathered through interviews. The practice perspective is carried out through case study and it aims to analyse different PBL practices in engineering education and their support to integrate ESD. The case study is conducted in Faculty of Engineering and Science, Aalborg University (Denmark) and investigates two master programmes: M.Sc. Urban Planning and Management (UPM) and M.Sc. Structural and Civil Engineering (SCE). The research design includes: documentary analysis of formal curricula and students' reports, interviews with students and educators, non-participatory observation of students' presentations and lectures.

The study points that PBL can support the integration of ESD in engineering education by: promoting system thinking and interdisciplinary collaboration, fostering transformative holistic problem solving approach, enhancing the relations between theory and practice for ESD stress a comprehensive curricular integration of sustainable development content. The study outcomes allow to make recommendations regarding to top management level, practitioners, students and external partners involvement, academic staff development programmes for ESD, promotion of cross disciplinary cooperation between academic staff and students.

Dansk resumé

Videnssamfundet og den teknologiske udvikling danner grundlaget for moderne samfunds udvikling og levevilkår. Den livsstil og den levestandard, som kendetegner det moderne samfund, er dog ikke uproblematisk i mødet med menneske og natur. Miljøproblemer, klimaændringer og væbnede konflikter om ressourcer er nogle af eksemplerne herpå. Ingeniører spiller en vigtig rolle i adresseringen af disse udfordringer, men det kræver at de har den rette viden og de rette færdigheder og kompetencer, hvilket stiller nye krav til ingeniøruddannelserne. Både forskningen og internationale standarder for akkreditering indenfor ingeniøruddannelse peger i retning af en større integrering af bæredygtighed i ingeniøruddannelserne.

Uddannelse for bæredygtig udvikling (UBU) har til formål at uddanne kritiske, kreative og økologisk bevidste borgere, der er i stand til at udvise deltagelse og handle ansvarligt i et bæredygtigt samfund. UBU kan karakteres som værende tværfaglig, kontekstuel, målrettet, integrativ og holistisk, og hertil kommer at UBU indbefatter et kritisk, etisk og livslangt læringsperspektiv. For læringsmiljøerne kræver dette en nytænkning af viden, færdigheder og kompetencer, som traditionelt er knyttet til ingeniøruddannelserne. For at integrere UBU er der behov for en helhedsorienteret indsats, hvor UBU er gennemgående i visioner og missioner, procedurer og daglig praksis – det er dermed en forandring, der involverer hele organisation, dens strukturer, rammer og aktører. Universiteter og andre organisationer, der udbyder længerevarende uddannelser, har udviklet strategier og metoder til at integrere UBU i organisationen. Strategierne kan for eksempel involvere en grøn campus indsats, integration af bæredygtig udvikling i studieordninger, udvikling af innovative læringsstrategier eller etablering af nye partnerskaber.

Problem Baseret Learning (PBL) er en af de læringsstrategier, der anvendes til at integrere bæredygtig udvikling og nytænke ingeniøruddannelserne. I PBL starter læringsprocessen med analyse og formulering af et autentisk og komplekst problem, hvor løsningen ikke er umiddelbar. PBL er baseret på læringsprincipper, som foreskriver at de studerende skal lære i samarbejde og igennem egne erfaringer, at problemet skal ses i sin kontekst og at studerende skal tage ansvar for egen læring. Disse principper giver de studerende mulighed for at udvikle, højere ordens færdigheder, herunder metakognition, kritisk og tværfaglig tænkning samt strategier for problemløsning og kommunikation.

UBU forskning dokumenterer, at PBL er en anbefalelsesværdig pædagogisk ramme for integrering af bæredygtighed i uddannelserne. Forskningen er dog begrænset i forhold til at uddybe, hvordan PBL i praksis kan understøtte integrationen af UBU i ingeniøruddannelserne ud fra et procesperspektiv. Denne afhandling er et bidrag til denne type

forskning, idet der fokuseres på at dokumentere de måder, hvorpå PBL har vist sig at kunne understøtte integrationen af UBU i ingeniøruddannelserne. Dette undersøges både i et teoretisk, ekspertbaseret og praksis perspektiv.

Det teoretiske perspektiv har til formål at undersøge lighederne i en PBL og UBU tilgang til ingeniøruddannelse. Igennem et litteraturstudie kortlægges principperne indenfor henholdsvis PBL og UBU med henblik på at påpege potentiel synergi samt udpege analyseparametre til den videre undersøgelse. Som analytiske variable indgår: problemforståelsen, vidensformer, graden af tværfaglighed, kritisk tilgang, proceskompetencer, UBU principper, bæredygtighedsforståelse samt tilgangen i selve opbygningen af uddannelsen. Ekspertperspektivet har til formål, via interviews, at undersøge forskellige strategier, drivkræfter og udfordringer i at integrere UBU i ingeniøruddannelserne i forskellige institutioner og i forskellige lande. I det efterfølgende praksisperspektiv fokuseres der i et case-studie på to engelsksprogede kandidatuddannelser på Aalborg Universitet: "Urban Planning and Management" (UPM) og "Structural and Civil Engineering" (SCE). Forskningsdesignet for dette casestudie inkluderer tekstanalyse af studieordninger og projektrapporter; interviews med studienævnsrepræsentanter, undervisere og studerende samt observationer af studerendes fremlæggelser.

Undersøgelsen peger på, at PBL kan støtte integrationen af UBU i ingeniøruddannelserne ved at fremme systemtænkning og tværfagligt samarbejde, en transformativ og holistisk tilgang til problemløsning, relationer imellem UBU teori og praksis samt en helhedsorienteret og relevant integration af bæredygtighed i uddannelserne. Undersøgelsen peger endvidere på en række anbefalinger, som indebærer at både universitets ledelse, studieledelsen, underviserne og de studerende inddrages aktivt i integrationen af UBU, ligesom det er vigtigt at skabe uddannelsesmuligheder indenfor UBU specifikt samtidigt med at tværfagligt samarbejde fremmes på alle niveauer.

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List of Abbreviations

AAU	Aalborg University
ABET	Accreditation Board for Engineering and Technology
AGS	Alliance for Global Sustainability
AISHE	Auditing Instrument for Sustainability in Higher Education
CBA	Cost Benefits Analysis
CRS	Corporate Social Responsibility
DESD	United Nation Decade of Education Sustainable Development (DESD)
ECTS	European Credits Transfer System
EHEA	European Higher Education Area
EMS	Environmental Management Systems
ENAAE	European Network for Accreditation of Engineering Education
ESAQ	Environment Sustainability Assessment Questionnaire
EESD	Engineering Education for Sustainable Development
ESD	Education for Sustainable Development
GASU	Graphical Assessment of Sustainability
GRI	Global Reporting Initiatives
HEI	Higher Education Institution
ILO	Intended Learning Outcomes
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCT	Life Cycle Thinking
OCED	Organisation for Economic Co-operation and Development
PBL	Project Based Learning
SADP	School of Architecture, Design and Planning
SCE	Structural and Civil Engineering
SD	Sustainable Development
SEFI	Société Européenne pour la Formation du Ingénieurs (European Society for Engineering Education)
SES	School of Engineering and Science
SR	Social Responsibility
STAUNCH©	Sustainability Tool for Assessing University's Curricula Holistically
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPM	Urban Planning and Management
ULSF	University Leaders for a Sustainable Future

1 Introduction

The knowledge society is characterised by a fast knowledge production and technological breakthroughs, where economic growth also resettles in technologic and scientific innovations (OECD, 2000). For the last 150 years, the scientific and technological development has been contributing to environment degradation, increasing energy supply, resources scarcity, poverty and inequality, leading to a sustainability crisis. For the last 30 years, international conferences have been gathering politicians from around the world and join efforts framing policies and guidelines to direct society to more sustainable patterns of development, where the needs of today are met without compromising the needs of future generations (United Nations, 1987; OECD, 2012; UNESCO, 2005, 2009).

The role of education to construct a sustainable future is widely recognised, and while some areas of education have achieved much in integrating sustainability in education, framing visions, principles and theories (see for example, Huckle & Sterling, 1996; Cocoran & Wals, 2004; Gough & Scott, 2007), others have been developing strategies to integrate them in their educational programmes, such as engineering education, in order to build a new professional profile (see for example Ferrer-Balas & Mulder, 2005; Caeiro, Filho, Jabbour, & Azeiteiro, 2013).

This study investigates some of the challenges posed to engineering education by a knowledge society, which demands new technological innovations and at a fast rate (Felder, Woods, Stice, & Rugarcia, 2000; National Academy of Engineering, 2004; Duderstadt, 2010). But the same technological innovations developed should also address sustainable concerns and contribute to a more fair and sustainable future (Doods & Venables, 2005; Bourn & Neal, 2008).

These challenges call for a transformation of the traditional learning paradigm in engineering education, calling for innovative, student centred, and active learning environments (Shepard, Macatangy, Colby, & Sullivan, 2009). Problem Based Learning (PBL) is an example of a learning approach that addresses engineering education challenges mentioned. However there is a need to understand the alignment between PBL

and ESD principles, and how the PBL different principles can support the integration of ESD in engineering education.

This study reports the research carried out within the areas of Problem Based Learning (PBL), Education for Sustainable Development (ESD) and engineering education to face sustainable crises in contemporary society.

1.1 Engineering education challenges

The *Global Engineer* (Bourn & Neal, 2008) report defines engineering as a global industry which is undergoing a period of unprecedented change, where its future is framed by forces such as the impact of globalisation, rapid technology advances, climate change and inequality. To face such global challenges, future engineers need new kinds of knowledge, skills and competencies (such as problem solving skills, project management, communication, teamwork, lifelong learning, entrepreneurship, ethics, etc.) (Bourn & Neal, 2008; Duderstadt, 2010). Figure 1-1 exemplifies the engineer profile needed for profession, knowledge and education.

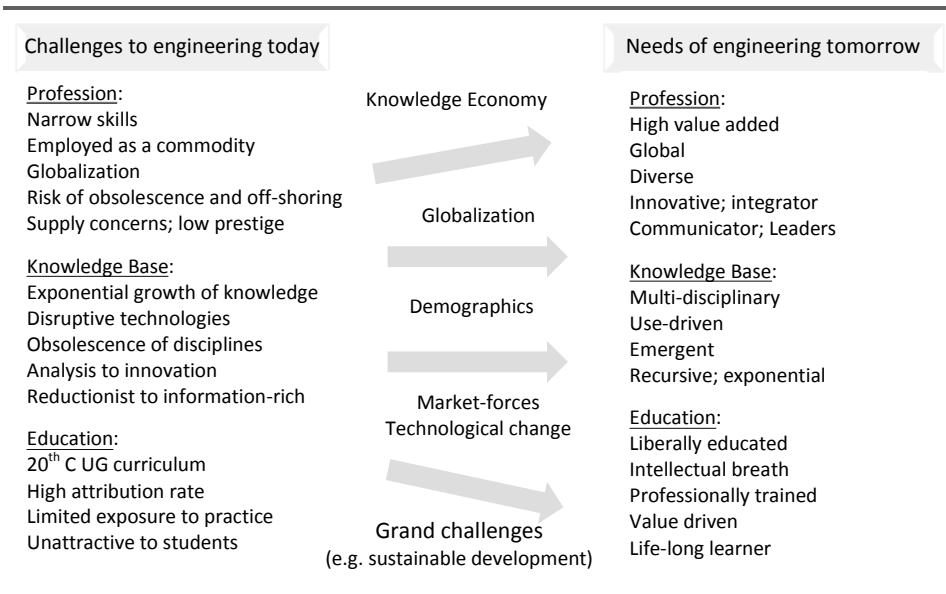


Figure 1-1 Road map regarding engineering education: today and tomorrow needs (adapted from Duderstadt, 2010, p. 34)

An education with focus on accumulation of theoretical knowledge, and problem solving skills based on “observing, and doing” do not fulfil the purposes that corporations, economy and society call for (Felder, Woods, Stice, & Rugarcia, 2000; de Graaff & Ravesteijn, 2001; Shepard, Macatangy, Colby, & Sullivan, 2009). Several documents, reports and studies have been published claiming for changes in the teaching and learning paradigm for engineering education (National Academy of Engineering, 2004; Bourn & Neal, 2008; Graham, 2012). A high level of expertise of graduates within the engineering science fundamentals is needed, but also other types of competencies that prepare them to navigate in the present complex and innovative society (National Academy of Engineering, 2004).

National Academy of Engineering (2004) characterises engineering as a creative process that occurs when a need or opportunity is presented, moving beyond the simple application of pure science knowledge. Technological innovations shape, change and improve human life. For a long time, engineering education could pace and follow the technology and society needs and changes. For example, disciplines were added to the field of engineering, or new programmes were created based on technological breakthroughs (e.g. bioengineering) (Jamison, Christensen, & Botin, 2011). The continuing technological breakthroughs increase the need for natural resources (e.g. energy supply and raw materials) putting pressure on the natural ecosystems. Furthermore, general public starts questioning and reflecting on the role and impacts of technology in overall society (Felder, Woods, Stice, & Rugarcia, 2000; Shepard, Macatangy, Colby, & Sullivan, 2009). Nowadays, it seems that traditional learning paradigms and approaches are no longer enough and it is necessary to create a workforce capable to develop and integrate new and sustainable technologies in our societies. The question is whether young engineers are able to address the challenges posed to their profession?

There is a need for a new type of engineering education that is capable of graduating engineers for the unpredictability of the future rather than for the certainties of the present (de Graaff & Ravesteijn, 2001; National Academy of Engineering, 2004).

Based on the above, de Graaff & Ravesteijn (2001: 420) argued that non-technical aspects of education should be taken into consideration concerning the grand challenges of:

- Social-responsibility (e.g. ethics, sustainability)
- Social skills (e.g. communication, collaboration)
- Humanities and social sciences (e.g. history, psychology, etc.)

Accreditation bodies and professional associations integrate such dimensions as part of their criteria to assure an engineering education of quality (Engineering Council, 2004; ENAEE, 2008; Washington Accord , 2009; ABET, 2010).

Another example is the TUNING-AHELO conceptual framework (OECD, 2009) which presents the desired learning outcomes for engineering education. These are based on framework standards for the accreditation of engineering programmes in Europe and the United States of America (ENAEE, 2008; ABET, 2010).

Furthermore, the TUNING-AHELO framework encloses 21 desired learning outcomes clustered in the following:

- Basic and engineering sciences (e.g. knowledge in STEM disciplines)
- Engineering analysis (e.g. identify and formulate problems)
- Engineering design (e.g. design methodologies to specific requirements)
- Engineering practice (e.g. solve engineering problems; project management and business practices; professional ethics and responsibility)
- Generic skills (e.g. teamwork; communication; lifelong learning; awareness of multidisciplinary context of engineering)

These point to the need of bringing more “real engineering” into education and creating a more student-centred environment, promoting collaboration, critical thinking, responsibility and ethics, problem analysis and solving skills, etc. along with depth knowledge in STEM disciplines (Felder, Woods, Stice, & Rugarcia, 2000; de Graaff & Ravesteijn, 2001; OECD, 2009).

Traditionally, engineering education focuses on acquisition of concepts, principles, theories, methods and tools within engineering fundamentals (STEM disciplines). The curriculum objectives are mainly acquisition and reproduction of knowledge; course lectured based, are confined to single subjects of STEM core disciplines (Shepard, Macatangy, Colby, & Sullivan, 2009). The complexity of reality is removed from the learning environment and promotes a culture of individual learning (Felder, Woods, Stice, & Rugarcia, 2000).

Engineering education needs to develop new learning visions and approaches, and its institutions need to reflect on their values, organisational management, teaching and learning approaches, and outcomes to address the challenges mentioned above (Shepard, Macatangy, Colby, & Sullivan, 2009).

Several engineering education institutions are changing their curriculum objectives and practice towards more active and student centred learning approaches. See for

example reports published by “*The Gordon-MIT Engineering Leadership Program*”, US (Graham, 2010), and “*The Royal Academy of Engineering*”, UK (Graham, 2012) which presents cases of engineering education systems incorporating change towards a more active learning approach, focus on developing knowledge, skills and competencies mentioned in, for example, the TUNING-AHELO framework.

1.2 Engineering education for sustainable development

Engineering education and engineering education for sustainable development (EESD) research (see for example de Graaff & Ravesteijn, 2001; Engineering Education for Sustainable Development, 2004; Ferrer-Balas & Mulder, 2005; Duderstadt, 2010; Svanström & Gröndahl, 2012), accreditation bodies (see for example Engineering Council, 2004; ENAEE, 2008; Washington Accord, 2009; ABET, 2010) and organisations (see for example National Academy of Engineering, 2004; Doods & Venables, 2005; OECD, 2009) point at integration of sustainable development in engineering programmes. To fulfil these purposes, engineering education systems need to revise and change their learning practices in order to meet their visions to address the contemporary society challenges and sustainability crisis.

Education for sustainable development (ESD) underlies sustainability principles such as responsibility, equity, social justice, democracy, diversity, etc. ESD aims educating critical, creative citizens with ecological awareness capable of acting responsibly by making part in decision processes (Sterling, 2001; UNESCO, 2005).

In order to promote sustainable education, educational systems need to revise and change their world views, visions and missions, provisions, and practices. A sustainable education calls for organisations to engage in transformative and social learning processes in order to fulfil their roles to construct a sustainable society (Huckle & Sterling, 1996; Sterling, 2001; Sterling, 2004; Gough & Scott, 2007).

Several declarations and charts along the years have been providing guidelines to promote and foster integration of ESD in higher education (Wright, 2004). Specifically for engineering education, the Declaration of Barcelona (Engineering Education for Sustainable Development, 2004) provides characteristics and learning outcomes for an engineering education for sustainable development (EESD). Furthermore, *The Royal Academy of Engineering* (Doods & Venables, 2005) published twelve guiding principles for EESD. This guide addresses all those involved in engineering and stresses the vital

role of engineering practice to contribute to a more sustainable society through product responsibility, environmental protection, contribution to high quality and sustainable lifestyles. These require engineering to be able to work with other professions, and disciplines, calling for an expert, interdisciplinary and pluralist education. This follows the same vision, theories and principles of ESD.

ESD research advocates student centred learning processes based on principles like contextual, self-directed, and transformative learning. It encompasses characteristics such as interdisciplinarity; collaborative; systemic; critical; problem oriented; and lifelong learning. In sum, ESD is linking the development of competencies to the “head” (e.g. knowledge, interdisciplinarity, critical thinking), “heart” (e.g. emotions, feelings and beliefs), and “hands” (e.g. actions, change agents) (Capra, 2007; Sipos, Battisti, & Grimm, 2008).

ESD envisions a continuous re-creation, transformation and co-evolution of higher education institutions (HEIs) and society to face sustainability challenges. While in the societal context, the sustainability challenges encompass ideology and political forces which push for cultural changes and changes of world views. In education, these change processes are still slow. Slow changes are partly due to the resistance of HEIs dominant culture, which is seen as a form of replication and assures continuity of the organisation (Wals & Jickling, 2002; O'Sullivan, 2004).

Integration of ESD claims deep change and transformation of education systems tradition, culture to provide an authentic education (Sterling, 2004; Tilbury, 2007; Dyball, Brown, & Keen, 2007). These encompass all levels of the educational systems, from top level (e.g. paradigm, vision and mission), middle level (e.g. management, relations with surrounding organisations, and communities) and bottom level (e.g. at provision level such as research and educational programmes) (Sterling, 2001; Sterling, 2004).

Regarding learning process and outcomes, ESD claims for participatory and transformative learning approaches to foster development of higher order reasoning, interdisciplinary communication and collaboration, critical thinking, adaptability and flexibility, lifelong learning, problem solving skills, creativity and innovation (Sterling, 1996; UNESCO, 2005; Steiner & Posch, 2006; Bourn & Neal, 2008; Sipos, Battisti, & Grimm, 2008). Looking back at engineering education research, accreditation bodies and organisations, the 21st engineer profile requires such abilities in order to fulfil the challenges posed by society.

1.3 The role of Problem Based Learning

In PBL, learning starts with a formulation of a problem, from real and ill-structured situations (also called problem scenarios), which drives the learning process. PBL is based on principles such as contextual, self-directed, experiential, and collaborative learning. Such principles enable students to develop high reasoning skills (e.g. meta-cognitive knowledge), critical thinking (e.g. analysis, assessment, monitor, mobilise, apply knowledge), problem solving skills and meaningful learning. In this, students are responsible for their knowledge construction and cognitive development (Borrows & Tamblin, 1980; Biggs, 2003; Savin-Baden & Howell, 2004; Kolmos, de Graaff, & Du, 2009). PBL is also interdisciplinary, and relates theory with practice. By using real problems, the disciplinary boundaries become blurred which enables students to develop knowledge from several disciplines. Furthermore, PBL allows students to develop analysis, learning and solving strategies capable to be transferred to other contexts (Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005).

PBL based learning is more than learning pedagogy or model, it can be interpreted in terms of educational philosophy rooted in most innovative learning theories (e.g. constructivism, experiential learning), in which different problem scenarios combine, for example, different knowledge, disciplines, and learning goals leading to different practices, curriculum organisations and learning outcomes (Savin-Baden & Howell, 2004; Savin-Baden, 2007).

PBL is widely recognised as suitable to develop the aimed 21st century engineer profile due to, for example, relation between theory and practice and the development of competencies such as problem solving skills, communication, collaboration, (de Graaff & Ravesteijn, 2001; Graham, 2010; Graham, 2012).

This learning approach is also used to educate for sustainable development. Similar to engineering education, PBL is used due to its characteristics to promote, for example, metacognition, interdisciplinarity, contextual and self-directed learning, critical thinking and problem solving skills (Mogensen, 1997; Steiner & Posch, 2006; Bourn & Neal, 2008; Segalàs, 2009).

1.4 Motivation and research question

Integration of sustainable development in engineering education poses challenges at different levels. It poses challenges related with profession, such as technological breakthrough at fast rate and need of sustainable ways of developing such technolo-

gies. It also poses challenges to engineering education practices and educational culture, such as the need to transform learning paradigm and teaching strategies to address the former challenge. In sum, the problem of engineering education relates with addressing societal needs (e.g. technological breakthroughs, water and energy supply) in a sustainable way.

Engineering education for sustainable development (EESD) calls for innovative learning philosophy which allows developing and transferring knowledge, skills and competencies in the field of technology, innovation, education and sustainable development (Fokkema, Jansen, & Mulder, 2005). Education for sustainable development (ESD) can work as a catalyst for innovation in practice; unifying themes across different educations; integrator of different social systems as it is claimed above for engineering education (Wals, 2012).

ESD integration is approached and supported through several researched themes, such as greening campus initiatives, integration of sustainable development in educational programmes, pedagogies, philosophy and principles, competencies and professional development, research (Wals, 2012).

From a theoretical perspective, ESD claims for transformative, holistic and integrative change throughout all levels of the institution (Sterling, 2004). ESD is also characterised as process oriented and empowering rather than product oriented, with emphasis on critical reflection and experiential learning cycles of change (Sterling, 1996). The main EESD research reported focus mainly integration of ESD from a product perspective. Also the main object of research for EESD is greening campus operations and less in learning philosophy, principles, and pedagogies (Wals, 2012). Therefore, the question is whether ESD research is not encoring the danger of clustering itself in "boxes", missing the implications that ESD principles have for organisation change and teaching practices. And, if by mainly focus on greening campus operations, HEIs contributions to sustainable development become reduced to management practices neglecting sustainable education from a learning process perspective.

From a management perspective, these activities are relevant and are taken as part of overall strategies to integrate but also it is also important to relate them with the different provisions, role and processes of HEIs for ESD.

From a practice point of view, several pedagogies have been used to educate for sustainable development, but they do not necessarily secure a holistic and integrative education towards sustainable development. In this sense, it is necessary to re-think

which learning theories, and principles support an holistic and transformative education for sustainable development, and in which ways they are practiced in engineering curricula. Furthermore, these pedagogies also need to point out who are the learners and what is their role. For example, Sterling (Sterling, 2004) claims that organisations experiment different levels of awareness and learning processes to integrate sustainable development.

Problem based learning pedagogies have been used to address engineering education challenges and integration of ESD in HEIs. Most of the research document that PBL pedagogies can in fact provide a framework for developing ESD learning outcomes but there is a lack of research on how PBL actually supports integration of ESD from a process perspective. Therefore, the following research question is formulated:

In which ways can PBL support the integration of ESD in engineering education?

Due to the above discussed, the research question is investigated through three perspectives:

- Theoretical perspective;
- Expert perspective;
- Practice perspective.

The theoretical perspective investigates the PBL learning principles, and their similarities with ESD vision for higher education, with special emphasis on engineering education. The expert perspective investigates the integration of ESD from an organisational point of view, and in which aspects PBL supports it. The practice perspective investigates different PBL practices in engineering education and in which ways they relate with previous perspectives.

In the following section, I present the research design, strategies and methods carried out to investigate the research question through three perspectives.

1.5 Research design

The research question and its goals allow placing the investigation in the landscape of possible paradigms, characterising the nature of methods to collect and analyse data

(Creswell, 2009). This study aims to analyse and comprehend in which ways PBL can support the integration of ESD in engineering education. Education is a human, and social activity. And each specific educational field and area has its own characteristics, values, cultures and vision towards how education should look like, and what purposes it serves. Education towards sustainable development argues for a paradigm shift. And the pace of the paradigm shift is somehow determined on how fast an educational system is capable of re-learning, and changing its values, traditions and cultures (Sterling, 2004). In the three perspectives: theoretical, expert and practice, the object of research encounters social interactions and constructions as the ones taking place in higher education institutions (with multi actors, structures and frameworks). This study also discusses the roles of higher education and engineering education to a sustainable future society. Relying on this assumption, the study seeks to comprehend and gather experiences, in specific contexts (PBL and engineering education), how the individuals (main actors) construct their vision and definition of ESD for future engineering practice (Creswell, 2009). According to Creswell (2009: 8), this type of research falls under a social constructivist paradigm.

The research design is qualitative due to the following reasons:

- Holistic account of the research - the overall research aims to provide a complex picture, by integrating different perspectives in investigating the problem;
- Use of different theoretical lens, such as the concept of PBL, ESD, learning principles, organisation change, etc., to comprehend, relate and analyse PBL and ESD in engineering education;
- Nature of research question and specific goals (Creswell, 2009).

The three perspectives have different research goals, approaches and methodologies, as presented as follows.

Theoretical perspective

The theoretical perspective aims to address the main goals:

- Comprehend PBL in its learning theories, principles, and their relations with learning processes;
- Comprehend ESD vision and principles for Higher Education Institutions (HEIs), and engineering education;
- Discuss similarities between PBL and ESD learning principles in order to identify and define analytical variables to investigate PBL support in integrating ESD in engineering education.

The theoretical perspective is carried out through literature review. The ESD literature review is presented in the next chapter (p. 25), while PBL is presented in chapter 3 (p. 47). In chapter 4 (p. 69), similarities between PBL and ESD principles are discussed and presented, resulting in the identification of analytical variables. The analytical variables are used to investigate PBL practice in engineering education and its support to integrate ESD.

Experts' perspective

The expert perspective aims to investigate the integration of ESD in HEIs in general, and in engineering education in particular. The expert perspective has the following research goals:

- Identify strategies, challenges and perspectives to integrate ESD in HEIs, and engineering education;
- Comprehend the role of PBL principles in the strategies, challenges and perspectives.

The experts are identified along the literature review in ESD, they are contacted and interviewed. Most of the experts interviewed have an active role in research and in integrating ESD in engineering education at organisational and educational level.

The interviews are content analysed, summarised and approved by experts interviewed. The experts' perspective is presented in details in chapter 5 (p. 81) of this report.

Practice perspective

The practice perspective has the following research goals:

- Analyse the PBL practices in engineering education and their support to integrate ESD;
- Relate different PBL practices in engineering education with different levels of ESD;
- Comprehend the limitations and strengths of PBL practices to integrate ESD in engineering education;

- Discuss and synthesise the role of PBL learning principles to support a holistic and transformative integration of sustainable development in engineering education.

The research methodology used to investigate the practice perspective is case study.

Other qualitative strategies of inquiries ought to be used to investigate practice perspective. Ethnography, grounded theory, phenomenological research, participatory action research, discourse analysis, narrative research are examples of such inquiries (Cohen, Manion, & Morrison, 2007; Creswell, 2009). For example, in ethnography research, the aim is to investigate, for example, an intact cultural group in a natural setting over time. In this study, the aim is to investigate teaching and learning practices which may enclose academic and disciplinary culture, but this is not the object of research. Another example, the narrative research focuses on investigating lives of individuals by asking about their life stories. Once again, this is not the aim of research even though teaching and learning practices involve individuals (e.g. students, or lecturers), their stories are limited or centred around teaching practices. In sum, the research purposes underlying the above mentioned inquiries do not address the aim of this research. On the other hand, case studies aim to explore in depth programmes, events, activities, or processes, which appear more suitable for investigating PBL practice to support the integration of ESD in engineering education (Creswell, 2009).

Corcoran *et al* (2004) argues that a case study is a suitable research methodology to investigate integration of sustainability in higher education, because it allows not only describing and explaining the specificities of a certain context, but also to problematize the practice and point potentialities towards changes (Corcoran, Walker, & Wals, 2004).

Different research methods, instruments and sources of evidence are used to collect data in the case study, as it is illustrated in figure 1-2 in the following page.

The case study takes its point of departure in the selection of a case. The case selection is carried out through an explorative study which points out relevant institutions that combine PBL and ESD in engineering education. The case selection is presented in chapter 6 (p. 105). Once the case is selected, a case research methodology is developed which constitutes the methodological procedures for data collection, analysis and reporting. The case study research methodology is addressed in chapter 7 (p. 121). The case stories, i.e. results, are presented in chapters 8 (p. 147) and 9 (p. 183).

Methods	Documentary analysis	Interview	Observations
Sources of evidence	HEIs webpages Curricula Students' Reports	Students Facilitators Lecturers Study board	Lectures Group work

Figure 1-2 Methods and sources of evidence used in case study research

The last two chapters of this report enclose the discussion of the results (chapter 10, p. 213), and conclusions (chapter 11, p. 237) of the study.

1.6 Thesis overview

The PhD thesis is organised in two volumes. The present volume, volume I, with eleven chapters, reports the three years of research to complete my PhD studies. The second volume, volume II, encloses the appendices which support the main report.

Figure 1-3 provides an overview of the thesis chapters, excluding appendices and reference list.

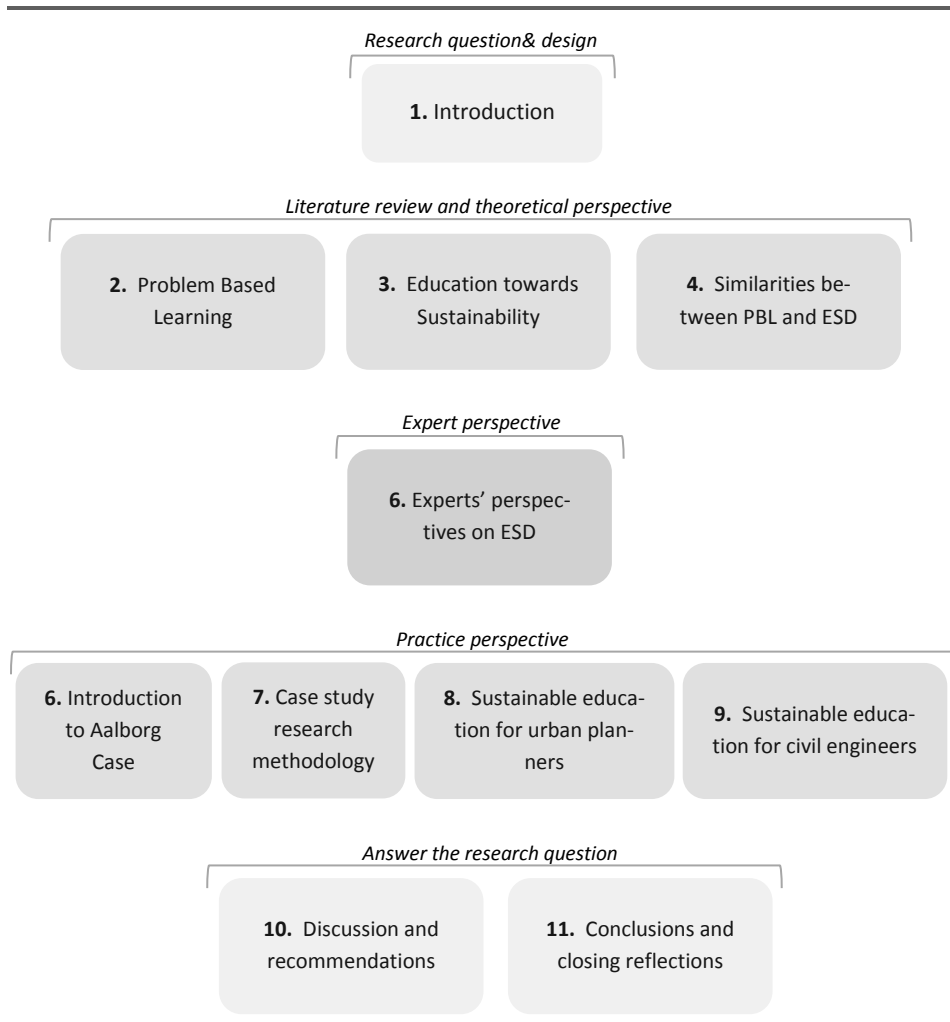


Figure 1-3 Overview of PhD thesis chapters, including brief reference of what is addressed in the chapters

In the above figure, the chapters are grouped and it is given a brief reference of which perspective is reported.

2 Education towards Sustainability

This chapter presents the state of the art of Education for Sustainable Development (ESD). The literature is divided in five subchapters. Subchapter 2.1 presents the historical background of sustainability, definition and distinction from sustainable development, followed by an introduction to ESD (2.2), different levels of organisation change and learning (2.3), and closes with institutional strategies to integrate ESD (2.4) as well as with learning and teaching for ESD (2.5)

2.1 Sustainability and Sustainable Development

Sustainability evolved from the environment protection movements from the 1960s due to a growing awareness of human impacts such as: overpopulation, water pollution, loss of biodiversity, resources depletion, poverty, army conflicts, etc. Examples such as “The silent spring” (Carson, 1962), or “Limits of growth” (Meadows, Meadows, Randers, & Behrens, 1972) lead to a global political consciousness of the dangerous societies may face in the future (Dresner, 2008).

Sustainability is an integrative and inclusive concept; it encloses not only environmental concerns, but also social and economic systems and their interdependencies (Yanarella & Levine, 1992; Dresner, 2008; Roosa, 2010). Sustainability is an ideal, a vision, oriented by principles aiming to build a more fair, democratic and responsible society with respect and care for the community of life (Roosa, 2010; The earth charter initiative, 2012).

In 1984, the United Nations established an independent group, composed by members from all over the world, with aim to formulate long-term strategies for environmental protection. And, in 1987, in the World Conference on Environment and Development published their report entitled “Report of the World Commission on Environment and Development: Our Common Future” (United Nations, 1987; Elliott, 2006).

“We needed a mandate for change” were the words of Gro Harlem Brundtland in the forward of the Report of the World Commission on Environment and Development: *Our Common Future* (United Nations, 1987).

In 1992, The Earth Charter was created by the independent Earth Charter Commission as a follow-up to the 1992 Earth Summit held in Rio de Janeiro, Brazil. The aim was to produce a global consensus statement of values and principles for sustainability. The document was developed through an extensive process of international consultation, to which over five thousand people contributed, and has been formally endorsed by thousands of organisations (such as UNESCO and World Conservation Union - IUCN). The charter includes four main cluster principles addressing the three pillars of sustainability, such as respect and care for community of life; ecological integrity; social and economic justice; and democracy, nonviolence and peace (The earth charter initiative, 2012). These can be summarised in the core values of: sufficiency; efficiency; community; locality; health; democracy; equity; justice, and diversity (Sterling, 2001: 16).

As Stephen Wheeler (cited by Dresner, 2008: 38) observes:

*The birth of **sustainability** concept in the 70s can be seen as the logical outgrowth of a new consciousness about global problems related to **environment** and **development** [...]*

The concept of sustainability does not exclude “development” but rather redirects and defines new directions and visions towards human development. However, frequently, sustainability and sustainable development appear in the literature as synonymous, but they are not (Yanarella & Levine, 1992).

In point 27 of the Brundtland Report, **sustainable development** is stated as:

*[...] the **ability** to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. (United Nations, 1987)*

In this concept, development should take into consideration the limits imposed by the current state of technology, social organisation, environmental resources and the bearing capacity of earth systems to absorb the effects of human activities (United Nations, 1987).

According to Samir Amin (referred by Yanarella & Levine, 1992), growth is not the same as development. Growth and, consequently, economic growth imply a quantitative expansion to meet the current human needs. This may not be aligned with the

ecosystem conditions and limitations to support it, making it unsustainable. Development implies a qualitative change of the growing economic systems within equilibrium with environment and social systems (Yanarella & Levine, 1992). Sustainable development underlies, and is moved by sustainability principles. The concept of development means to protect, sustain a planet for the coming generations, and lead to economic prosperity and a social equity (Yanarella & Levine, 1992; Ekins, 1993; Roosa, 2010).

While sustainability provides us with an enlightened vision for the future through its principles, sustainable development frames social, economic, political and technologic policies to fulfil and move towards sustainability (Roosa, 2010).

The distinction between sustainability and sustainable development is crucial to limit the multiple understandings, interpretations and definitions of sustainability. This has been one of the main criticisms towards sustainability and sustainable development (Elliott, 2006). Furthermore, the heterogenic nations of world (in terms of e.g. biodiversity, population, energy needs, water, pollution, equity, human rights, society, etc.) enclose also different frames, policies and actions to develop a sustainable society at a local level. Therefore, sustainable development can be seen as local actions, while sustainability is a global worldview (Ekins, 1993; Elliot, 2006; Banerjee, 2003; Roosa, 2010).

Sustainability and sustainable development calls for deep changes in the values and norms on which we build our society. Earth is the ultimate system where other sub-systems are enclosed, and each sub-system encloses sub-subsystems. According to a systems thinking approach, healthy systems are capable to maintain, organise and sustain themselves through time. This defines the continuity and integrity of a system, and it is possible when their subsystems perform in the same way (Meadows, 2008). Looking to earth as a system, its continuity and integrity depends upon its subsystems maintenance and organisation trough time (nesting principle). In the past, environment was understood as a sub-system of economic systems and its existent for and to provide resources for economic growth. In present times, the approach encloses an awareness of the interdependencies of the environment, social and economic systems. For the future, the vision takes into consideration a nesting system in which environment encloses social, and social encloses economics as subsystem as illustrated in the following figure 2-1 (Ekins, 1993; Mebratu, 1998).

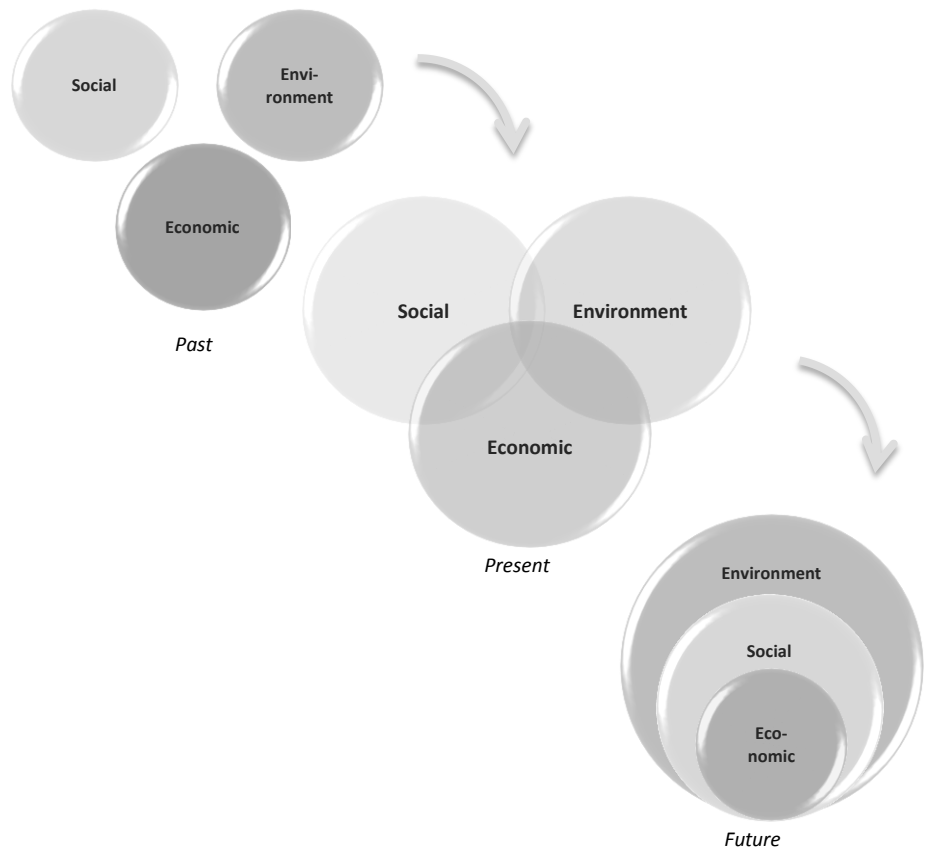


Figure 2-1 Sustainable development nesting systems (according to Mebratu, 1998: 513)

Sustainable development should not be faced as part of policies or public debate without reaching the bottom level of every employee, profession, research area or citizen. There is a need to develop frameworks, tools and approaches to bring sustainable development “to action” and part of everyday life. Figure 2-2 exemplifies different articulations for sustainable development, pillars, frameworks and tools (Life Cycle Thinking - LCT, Life Cycle Assessment - LCA, etc.) and design strategies. In the bellow figure the top down conceptualisation of sustainable development is also emphasised (Kørnov, Thrane, Remmen, & Lund, 2007).

Different frameworks and tools can be used in by different institutions, organisations or professions, such as corporate social responsibility, environmental management or sustainable technology development processes (Duckworth & Moore, 2010; Mulder, Ferrer, & van Lente, 2011).

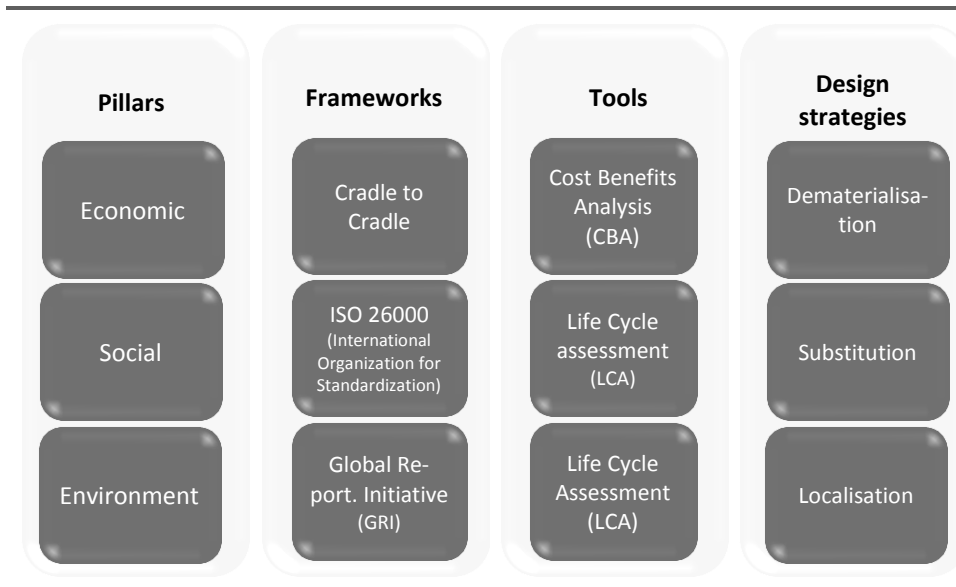


Figure 2-2 Examples of sustainable development principles, frameworks, tools and design strategies (based on (Robèrt, et al., 2002)

The above define and distinguish sustainability and sustainable development. Education is considered one of the most valuable resources to build a sustainable society. Both education towards sustainability and sustainable development underlies the principles of sustainability. This is widely recognised by international organisations, research communities and declarations (Wright, 2004; UN-Decade of Education for Sustainable Development, 2009).

2.2 Education towards Sustainable Development

In 1992, through Agenda 21, chapter 36, the United Nations “Earth Summit” conference highlighted the role of education to achieve, and contribute to a more sustainable world. Chapter 36 emphasises education, public awareness and training as the ground role of education for a sustainable society (United Nations). It also defines education as the process:

- *“in which human beings and societies can reach their fullest potential”;*

- *“critical for promoting sustainable development and improving the capacity of the people to address environment and development issues”;*
 - *“critical for achieving environmental and ethical awareness, values and attitudes, skills and behaviour consistent with sustainable development and for effective public participation in decision-making”*
-

In 2002, UNESCO was designated to lead the United Nations Decade of Education for Sustainable Development (DESD) 2005-2014, and has as its basic vision to provide to all the opportunity to learn values, behaviours and lifestyle required for a sustainable development and for positive societal transformation (Elliott, 2006; Roosa, 2010; UNESCO, 2005).

An education towards sustainability extends itself to all levels of education, from elementary to adult and continuing education, from formal to non-formal education (United Nations; Huckle & Sterling, 1996; UNESCO, 2005). And it also underlies the principles of sustainability such as responsibility, equity, social justice, democracy, diversity, community, etc. Furthermore; it aims to educate critical, creative citizens with ecological awareness capable of acting responsibly by taking part in decision processes (Huckle & Sterling, 1996; Sterling, 2001; UNESCO, 2005).

In order to promote sustainable education, educational systems need to revise and change their worldviews, visions and missions, provisions, and practices. A sustainable education calls for organisations to engage in transformative and social learning processes in order to fulfil their roles to construct a sustainable society (Huckle & Sterling, 1996; Sterling, 2001; Sterling, 2004; Gough & Scott, 2007; Dyball, Brown, & Keen, 2007).

Higher education institutions (HEIs) change towards sustainable education still far beyond the needs. In general, they still: i) enclose a mechanistic view of the world and learning; ii) are largely ignorant about sustainability aspects that affect people’s lives; iii) miss an integrative awareness of the systems influencing society progression and environment. HEIs need to fulfil the education for sustainable development (ESD) vision based on the principles discussed above (Sterling, 2004).

Education for sustainable development (ESD) envisions a continuous re-creation, transformation and co-evolution of HEIs and society to face sustainability challenges. While in the societal context, the sustainability challenges enclose ideology and political forces which push for cultural and worldview changes, in HEIs, the change processes are still considered slow. Slow changes are partly due the resistance of HEIs dominant culture, which is seen as a form of replication and assure continuity of the organisation (Wals & Jickling, 2002; O’Sullivan, 2004).

For a transformative process towards a sustainable education, HEIs need to behave as open systems, permeable to society, economic and environment needs, and provide an authentic education to address these challenges (Sterling, 2004). Furthermore, they should reach all levels of the educational systems, from top level (e.g. educational paradigm, organisation’s vision and mission), middle level (e.g. management, relations with surrounding communities, evaluation and assessment, curriculum design) and bottom level (e.g. research and educational practices) (figure 2-3) (Sterling, 2001; Sterling, 2004).

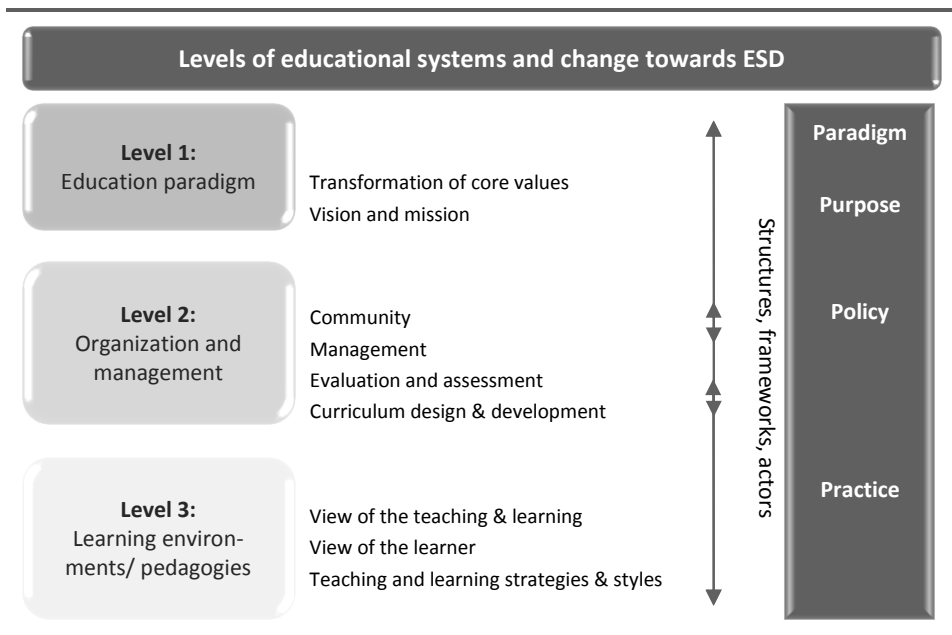


Figure 2-3 Simplified representation of higher education systems’ levels and change towards sustainability (based on Sterling, 2001; Sterling, 2004)

Figure 2-3 provides a systemic, holistic and integrative overview of higher education systems. The transformation should involve all levels through the different structures, frameworks and actors, culminating with emergence of a new paradigm (Sterling, 2004).

For example, top level, or level one, calls for a new educational paradigm, influencing an organisation’s values, vision and mission. Middle level, or level two, calls for institution’s strategies to integrate ESD at management level. The bottom level, or level three, calls for learning and teaching practices for ESD. In the following three subchapters, I approach ESD through the three levels mentioned.

2.3 Sustainable education as new paradigm

Much has been discussed regarding the role of higher education institutions (HEIs) in a broader society. One of the purposes of university is to help society to meet the needed skills for the future through, for example, research and teaching (Gough & Scott, 2007).

HEIs are places of learning, research and business; and they are also key community players (Scott & Gough, 2004; Moore, 2005). Nevertheless, HEIs enclose traditions and cultures which determine the nature of education carried out (Scott & Gough, 2004; Gough & Scott, 2007; Jamison, Christensen, & Botin, 2011). Universities enclose two main views: real world and the ivory tower view. In the real world view, the purpose of universities is to transmit knowledge, understanding and competences for profession. This view emphasises an instrumental and pragmatic value to education. In opposition, from the ivory tower point of view, education should be personal and intrinsic; removing it's social and practice value. These two views are attributed to HEIs enclosed limitations regarding ESD (Gough & Scott, 2007). For example, how and what kind of skills and competencies are needed for the future, or what are specific educational fields' needs for real life, for a mass-participation, and high-valued-added society. Furthermore, ESD claims an integration of theory (ivory tower perspective) and practice (real world view) into a systemic praxis (Wals & Jickling, 2002; Gough & Scott, 2007). Notice that this claim points for the kind of education needed, such as an education capable of developing self-directed learning skills and lifelong learning. However, to step further, HEIs need to break old "habits" and dominant cultures and visions and embrace a more ecological and transformative view of education. This pushes for a paradigm shift from a mechanistic and reductionist paradigm to a more transformative and ecological one (table 2-1) (Sterling, 2001; Moore, 2005; Wals & Jickling, 2002; Lozano, 2011a).

Table 2-1 Summary and comparison of two education paradigms: current one and towards sustainable education (adapted from Sterling, 2001: 58)

Mechanistic view	Ecological View
Level 1: Educational paradigm – core values	
Preparation for economic life Selection or exclusion Formal education Knowing as instrumental value Competition	Participation in all dimensions of sustainability transition Inclusion and valuing of all people Learning through life Being/ becoming Cooperation/ collaboration

Mechanistic view	Ecological View
Specialisation	Integrative understanding
Socialisation, integrating to fit	Autonomy-in-relation
Developing institutional profiles	Developing learning communities
Effective learning	Transformative learning
Standardisation	Diversity with coherence
Accountability	Responsibility
Faith in 'the system'	Faith in people
Modernity	Ecological sustainability

This calls for transformative learning processes at the organisational level, culminating in a paradigm shift towards sustainable education (Lozano, 2011a; Sterling, 2004).

Organisational learning for sustainable development

Transformative learning processes imply revision of current assumptions and perspectives in order to change them. From a learning point of view, these processes are triggered by finding the current assumptions invalid in relation to recent experiences, which may lead to their revision and change. Transformative learning empowers learners, presents alternative options and ways to look into the world (Cranton, 1996; O'Sullivan, 2004; Moore, 2005). The change of HEIs' assumptions for a sustainable education implies a transformative learning process at an organisational level (Pittman, 2004; Lozano, 2011a).

As organisations, HEIs are purposeful social systems enclosing structures, members and stakeholders. Furthermore, they comprise three main interrelated tasks such as: the development of the organisation; development of its members; and development of the larger system in which they are inserted (i.e. community, country and world) (Dixon, 1999). This is related to a nesting system's principle, illustrated in figure 2-1 (p. 28), in which HEIs are subsystems of economic and social systems (Pittman, 2004).

It is through intentional and planned learning processes that HEIs are able to develop themselves, their members and the surrounding environment. This process, known as organisational learning, follows the same learning principles as individual learning. The organisation learns through its members' learning ability, constructs and shares meanings, giving emphasis to the potential of the collective (i.e. members) within a unity (i.e. organisation) (Dixon, 1999). Through collaborative learning we are capable of learning our way to provide answers to more complex problems, but also to transform the organisations created by us (Dixon, 1999; Sterling, 2001; Pittman, 2004; Lozano, 2011a).

Organisational learning theory does not only emphasise the ability to transform itself and the surrounding environment through learning, but also the ability to do it continuously. Through learning cycles, the organisation learning encloses the following steps: 1) generate/acquire information (acquisition); 2) to collectively integrate the information in the existent structures (integration); 3) collectively interpret information and construct meaning (interpretation); 4) collectively take action, apply or experiment (action). It is from the last step (action) that new information/knowledge is generated/gathered to start a new learning cycle with the aim to gain new understanding and meaning out of new information/knowledge gathering (figure 2-4) (Dixon, 1999).

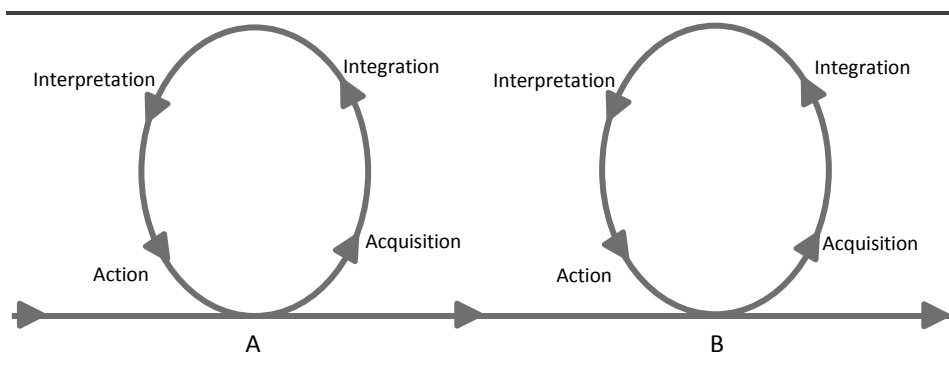


Figure 2-4 Organisational learning cycles, and principle of continuity (based on Dixon, 1999)

HEIs gather information from their surrounding environment and their acting experiences such as research. Organisations use the knowledge generated for ESD diffusion and ensure commitment at all levels to change towards a common goal. In the particular case, the common goal is full integration of ESD.

One of the challenges which organisations face as learners is to design suitable learning experiences capable to foster collective and transformative learning. Whole Systems Design (WSD) is a collaborative design-based approach which promotes organisational change in order to enhance a collective response to complex problems (Pittman, 2004).

WSD starts with members and stakeholders collaboratively identifying visions and ideologies for the organisation followed by cultivate strategies for designing structures and managerial patterns aligned with vision (Pittman, 2004). To some extent, the WSD is aligned with learning cycles represented in the above figure. At the practice level, WSD collaboratively grounds project-design among stakeholders and action research. HEIs stakeholders are composed by not only academic community (e.g. students, aca-

ademic staff and administrative staff), but also external partners (e.g. government, potential employees, other HEIs institutions, etc.).

The HEIs are complex organisations with capabilities to learn towards sustainability (Dixon, 1999; Pittman, 2004), with the following characteristics:

- Living identity and unity (HEIs have their own vision and mission developed and shared by all members);
- Dynamicity and adaptability (HEIs are open systems, capable of changing and adapting to the surrounding environment);
- Integration of ESD (HEIs integrate and interrelate with Earth systems, but also integrate in their learning processes at all levels and in all structures).

In this way, the integration of sustainable education in higher education involves all levels of the organisation, members and structures, but also underlies guiding principles for practice (see for example Huckle & Sterling, 1996; Sterling, 2001; Corcoran & Wals, 2004; Wals, 2007; Lozano, 2011a).

In the following, I present the strategies, levels and challenges of integration of sustainable development in HEIs.

2.4 Institutional strategies for sustainable development

This subchapter addresses the strategies developed by higher education institutions' (HEIs) to integrate sustainable development in their activities and structures. HEIs have different responses to integration of sustainable development which lead to different strategies and initiatives.

Higher Education Institutions' responses

HEIs responses towards sustainable development provide different strategies to integrate sustainable development in HEIs (Sterling, 2004; Holgaard, Graaff, & Kolmos, 2010). Sterling (2004: 58) refers four main types of responses, which are presented in table 2-2. The different responses can also be interpreted as successive stages for a full integration of ESD.

Table 2-2 Comparing different educational responses towards sustainability (adapted from Sterling, 2004)

	Type of response	Type of learning	Sustainability transition	State of sustainability	State of education
I	No response	Denial/ ignorance (no learning)	Very weak	No change	No change (or taken)
II	Accommodation “bold-on”	Adaptive	Weak	Cosmetic reform/ green gloss	Education about sustainability
III	Reformation “build-in”	Critically reflective adaptation	Strong	Serious greening	Education for sustainability
IV	Transformation “re-build or redesign”	Transformative	Very strong	Wholly integrative	Sustainable education, or education as sustainability

HEIs may have no response (type I response), or present weak and adaptive response towards ESD (type II response). Education about sustainable development (type II response) is characterised by “add-on” strategies to the already existent structures such as modules or course added to an already crowded curriculum (Sterling, 2001).

Table 2-2 presents two other responses which are a strong integration (type III response or education for sustainable development) and a very strong (type IV response or sustainable education).

In education for sustainable development (type III response), the use of the preposition *for* implies that the education must be in favour of a specific and indisputable product/goal (Wals & Jickling, 2002). In this level, institutions experience significant changes towards sustainable development by questioning exist paradigms; and increase level of awareness of ESD (Sterling, 2004). Examples of type III responses are the creation of educational programmes and courses for SD, greening campus operations, auditing and reporting on environment impacts of organisation. The fourth level of change (i.e. sustainable education) is characterised by a reordering of assumptions that lead to a paradigm shift. It is likely that HEIs changes towards sustainable development “become stuck” at third level, mainly due to the difficulties associated to a paradigm shift (Sterling, 2004). A paradigm shift implies a deep change of basic premises of thought, feelings and actions of organisation. Transformative education changes how education and its role are perceived, from a practice (education for change) and policy (education in change) point of view (table 2-3) (Sterling, 2004).

The transformative education, in opposition to transmissive, regards not only organisation as a whole, but is also extended to curricula, pedagogies used, students and

teacher role, etc. In this sense, design of learning experiences, enabling students to experiential a transformative learning process for ESD is needed (Ferrer-Balas, et al., 2008).

Table 2-3 Comparison between a transmissive and transformative education, both practice oriented and policy oriented (based on Sterling, 2004)

	Transmissive education	Transformative Education
	Instructive	Constructive
Education for change (practice)	Training (focus on skills for employment) & Teaching Communication (of 'message') Interested in behavioural change Information - 'one size fit all' Control kept at centre First order of change Product oriented 'Problem-solving' - time-bound Rigid Factual knowledge and skills	Education & Learning Construction of meaning Interested in mutual transformation Local and/ or appropriate knowledge important Local ownership First and second order of change Process oriented 'Problem-reframing' and iterative change over time Responsive and dynamic Conceptual understanding and capacity building
	Imposed	Participative
Education in change (policy)	Top-down Directed hierarchy Expert-led Pre-determined outcomes Externally inspected and evaluated Time-bound goals Language of deficit and managerialism	Bottom-up (often) Democratic networks Everyone may be an expert Open-ended enquiry Internally evaluated through iterative process, plus external support On-going process Language of appreciation and cooperation

ESD also encloses a constructivist perspective which advocates a joint construction of meaning (across disciplines, communities or organisations) regarding sustainable development crisis and how to address them. In this perspective, students are “constructors” of meaning, knowledge, skills and competencies for action and change. Furthermore, the constructivist view claims contextual and collaborative learning principles advocating the use of real world contexts as learning places (Steiner & Posch, 2006) (Segalàs, 2009; Mulder, Segalàs, & Ferrer-Balas, 2012).

An integration of ESD, and consequently a transformative education, encounters several drivers and barriers in HEIs. The barriers and drivers can be internal and external to the organisation, and emphasise different structures, actors and levels of the organisation (table 2-4).

Table 2-4 Examples of drivers and barriers to integrate ESD in HEIs, organised according to type as internal or external to the organisation (based on Moore, 2005; Lozano, 2006b; Ferrer-Balas, et al., 2008; Lozano-García, Huisigh, & Delgado-Fabián, 2009; Segalàs, 2009)

Type	Drivers	Barriers
Internal	<p>Visionary leadership;</p> <p>Sustainability champions (innovators as agents for change);</p> <p>Connectors for existing networks as promoters for interdisciplinary, and transdisciplinary research;</p> <p>Existence of coordination units, or projects, for the sustainable development transformation</p> <p>Increase of active learning pedagogies;</p>	<p>Culture and structure of organisation, such as: disciplinary boundaries and environment; academic staff individual power;</p> <p>Competition between and within students, departments, faculties, universities;</p> <p>Reward and promotion focus on publications, grants and research;</p> <p>Lack of desire to change</p>
External	<p>International frameworks (e.g. EHEA) and accreditation bodies (e.g. ABET);</p> <p>Existing of international networks and partnerships for ESD (e.g. AGS; ULSF);</p> <p>Increase of sources of funding and employability</p>	<p>Misdirected criteria for evaluation (e.g. lack of clear evaluative structures for university policy and plans);</p> <p>Pressure from society (focus on employable skills and knowledge)</p>

The above table presents examples of barriers for constructing a collaborative, participative and interdisciplinary environment for ESD within organisation. ESD is also contextual (Huckle & Sterling, 1996; Corcoran, Walker, & Wals, 2004), and therefore, strategies and approaches need to include knowledge about organisation visions and missions, culture, structures, etc., in order to identify potential barriers and drivers for ESD (see for example Lozano-García, Huisigh, & Delgado-Fabián, 2009; Cruickshank & Fenner, 2012; Svanström, Palme, Wedel, Carlson, Nyström, & Edén, 2012; Caeiro, Filho, Jabbour, & Azeiteiro, 2013). These allow for development of better strategies and approaches for organisations according to their culture and identity, and how to overcome barriers and integrate ESD. Nevertheless, comparative and screening studies point to overarching approaches to integrate ESD in HEIs (see for example Lozano, 2006b; Holmerg, Svanström, Peet, Mulder, Ferrer-Balas, & Segalàs, 2008; Segalàs, 2009).

Integration strategies for ESD

Integration of sustainable development involves top-down and bottom-up initiatives, all actors and structures. For example, leadership (top level) envisions sustainability as part of the university mission and vision, and the passage from vision to practice

should be extended to campus operations, educational programmes and involve students, academic staff, administration and management (Lozano-García, Huisingsh, & Delgado-Fabián, 2009). Furthermore, campus greening projects provide a learning place for students to act towards ESD allowing the integration of non-formal learning activities (Mulder, Segalàs, & Ferrer-Balas, 2012).

Several HEIs develop strategies to integrate sustainable development in their curricula (see for example Holmerg, Svanström, Peet, Mulder, Ferrer-Balas, & Segalàs, 2008; Lozano-García, Huisingsh, & Delgado-Fabián, 2009; Cruickshank & Fenner, 2012; Svanström, Palme, Wedel, Carlson, Nyström, & Edén, 2012). Main strategies for curricular integration of sustainable development are:

- Create new educational programmes, courses or modules on environmental issues, and/or sustainable development (i.e. standalone strategies)(type II responses);
- And weave sustainable development concepts throughout the already existent courses and curricula (i.e. integrated, or embedded, strategies) (type III response)

HEIs can adopt different strategies to integrate sustainable development. For example, strategies can be based on “light many fires” approach through creation of new standalone programmes and courses on SD, greening campus operations, integration of sustainable development in existent courses and programmes, provide staff development on sustainable development and reward or recognise (Lozano-García, Huisingsh, & Delgado-Fabián, 2009; Cruickshank & Fenner, 2012; Dresner, 2008; Mulder, Segalàs, & Ferrer-Balas, 2012). On the other hand, the HEIs may only manifest awareness and recognition of sustainable development by giving some coverage of environmental issues in relation to existent courses or programmes. Different strategies involve different degrees of participation and involvement of the different levels, structures and actors within the organisations leads to the different responses towards sustainability challenges as presented in table 2-2 (p. 36) (Sterling, 2004; Lozano, 2010).

Therefore, the curricular integration of sustainable development should take an integrative, systemic, holistic and interdisciplinarity principle as a core part (Sterling, 1996; Sterling, 2001).

In sum, HEIs main challenge to integrate ESD is initiating organisational learning capable of increasing the level of sustainable development transitions towards a paradigm shift for sustainable education. HEIs different types of responses and sustainable development transitions include changes at, for example, management, evaluation and assessment, curriculum design and development levels. It is important to assess and

report the level of sustainable development transitions in HEIs as a mean to develop strategies and initiatives to increase sustainable development responses.

Assessment and reporting of sustainable development

In the last decade, a considerable number of HEIs have been incorporating and institutionalising sustainable development in their activities, such as curricula, research, outreach, operations, assessment and reporting (Lozano, 2011b; Lozano, Llobet, & Tideswell, 2013).

Assessment and reporting sustainable development efforts are self-auditing and voluntarily activities that have been carried by industry and corporations through, for example, environmental management systems (EMS) and corporate social responsibility (CSR) (Kørnov, Thrane, Remmen, & Lund, 2007; Duckworth & Moore, 2010; Lozano, 2011b).

Through EMS, companies and public sectors take responsibility for their impacts (socio-cultural, political, economic and environmental) on the broad community. It demands tools and systems to support reliability and to facilitate the development of cleaner production processes and products (e.g. business models, product development, etc.) (Kørnov, Thrane, Remmen, & Lund, 2007). Social responsibility (SR) and corporate social responsibility (CSR) are process-based approaches, focusing on the interconnectedness of the organisation actors and decisions, and their impacts (social and ecological) on the community within which they operate (Duckworth & Moore, 2010).

EMS and CSR are examples of approaches through which higher education institutions (HEIs) assess and report their impacts on the surrounding community, but, furthermore, how to develop further strategies and initiatives (Kørnov, Thrane, Remmen, & Lund, 2007; Duckworth & Moore, 2010; Lozano, 2011b) in order to:

- Be accounted for;
- Be transparent and ethical;
- Take responsibility of their actions and impacts;
- Develop cleaner processes and products

Examples of tools and guidelines for assessment and reporting on environmental, socio-cultural and economic impacts are Global Reporting Initiatives (GRI) (GRI, 2011); International Organization for Standardization (ISO) series, such as ISO 14000; ISO 26000; ISO 9000 (ISO, 2013). These also help to reorient actions for more sustainable

practices (Kørnov, Thrane, Remmen, & Lund, 2007; Duckworth & Moore, 2010; Lozano, 2011b; Lozano, Llobet, & Tideswell, 2013).

HEIs commonly use GRI, ISO 14003, Eco-Management and Audit Scheme, and the Social Accountability 8000 Standard (Lozano, 2011b). GRI is considered the best option for assessing and reporting on sustainable development, however, this was not developed for universities missing the educational dimension in its criteria and indicators (Lozano, 2011b; Lozano, Llobet, & Tideswell, 2013).

There are several examples of tools and guidelines to assess and report the integration at education dimension of HEIs (table 2-5) (Shriberg, 2002; Lozano, 2006a; Lozano, 2011b; Lozano & Peattie, 2011; Caeiro, Filho, Jabbour, & Azeiteiro, 2013).

Table 2-5 Examples of tools for assessing and reporting sustainability in HEIs (based on Shriberg, 2002; Lozano, 2006a; Lozano, 2011b; Lozano & Peattie, 2011; Caeiro, Filho, Jabbour, & Azeiteiro, 2013)

Examples of tools for assessing and reporting sustainability in HEIs
<ul style="list-style-type: none"> ● National Wildlife Federation’s State of Campus Environment ● Higher Education 21’s Sustainability Indicators ● Environmental Workbook and Report ● Greening Campuses ● Campus Ecology ● Environmental Performance Survey ● EMS self-assessment ● Environment Sustainability Assessment Questionnaire (ESAQ) ● Auditing Instrument for Sustainability in Higher Education (AISHE) ● Graphical Assessment of Sustainability (GASU) ● Sustainability Tool for Assessing University’s Curricula Holistically (STAUNCH©)

Even though the above examples are a good point of departure for reporting, several of them (e.g. GRI, National Wildlife Federation’s State of Campus Environment; Higher Education 21’s Sustainability Indicators; Environmental Workbook and Report; Greening Campuses; EMS self-assessment) lack the educational dimension such as philosophy, ethics, long term vision, systems thinking, interdisciplinarity, etc. (Lozano, 2011b).

Education is one major activity of HEIs, from where the future professionals and citizens are educated. Therefore, HEIs have a responsibility to assess and integrate sustainable development and its principles in the educational programmes in order to promote a sustainable education.

Based on GRI guidelines, Graphical Assessment of Sustainability (GASU) is an example of a tool to assess and report sustainable development at an educational level. The education dimension encloses three categories: curriculum (e.g. incorporation in the

curricula, capacity building and administrative support), research (e.g. grants, publications and products, programmes and centres) and service (e.g. service and community learning) (Lozano, 2006a). Another example is Sustainability Tool for Assessing University's Curricula Holistically (STAUNCH©), which encloses two fundamental objectives:

1. *To systematically assess how and the extent to which a university's curricula contributed to education for sustainable development (ESD) by assessing its modules, degrees and schools;*
2. *To facilitate consistent and comparable assessment efforts capable of handling a large quantity of modules and of being applied across multiple institutions (Lozano & Peattie, 2011, p. 115-116)*

Similar to EMS and CSR tools, curricular assessment tools for ESD are self-audit and regulatory tools, and they help HEIs to take responsibility for their education towards sustainable development and to re-orient efforts to make it part of organisation culture and praxis. Some tools can be used to assess sustainable development in universities' curricula (such as GASU and STAUNCH©) through themes and concepts to be integrated, but also crosscutting themes as promoters for a systematic and interdisciplinary approach (Lozano, 2010; Lozano, 2006a). In the following, I address the education for sustainable development in terms of knowledge, competencies and skills aligned with suitable learning strategies for their development.

2.5 Learning and teaching for ESD

Sterling (1996: 22-24) points out twelve characteristics for education for sustainability. These, referred also as primary requirements, outline learning principles, learning environment characteristics and strategies to develop knowledge and competences for ESD (Lambrechts, Pons de Vall, & Van den Haute, 2010).

Table 2-6 Characteristic, and description, of Education for Sustainable Development (ESD)
(based on Sterling, 1996: 22-24)

Characteristics of ESD	Description
1. Contextual	ESD should be applied and grounded in the local economic, social and ecological context and community, followed by regional, national international and global contexts .
2. Innovative and construc-	Drawing inspiration from range of fields (including science, ethics, politics, economics, design and psychology) offering insights and ways forward that

Characteristics of ESD	Description
tive	promise a safe, humane and environmentally sustainable future.
3. Focused and infusive	Primarily grounded in, but not limited to, social development and human ecology, equity and future, at the centre of a holistic approach which touches all other areas
4. Holistic and human scale	Recognising that all educational dimensions, such as curriculum, pedagogy, structures, organisation and ethos are mutually affecting and need to be seen as a consistent whole; and that this works best at a scale that relates to the needs of learners and educators. It is also holistic in the sense of being both learner-centred and socially oriented (constructionist).
5. Integrative	Greater emphasis on interdisciplinary and transdisciplinary enquiry, reflecting that no subjects, factors or issues exist in isolation.
6. Process oriented and empowering	ESD is engaged and participative rather than passive; the emphasis is on learning rather than teaching. In particular, action research with its emphasis on critical reflection, experimental learning cycles and democratic ownership of change.
7. Critical	Recognising that no educational values are politically neutral, ESD should draw on the body of critical theory associated with deep green and red-green orientations as these constitute the prime challenge to the modernism hegemony.
8. Balancing	Balance between dual nature, which includes personal aspects such as knowledge and values, cognitive and affective learning , rationality and intuition, object and subject, material and spiritual; and collective aspects such as economy and ecology, present and future, local and global, individual and community.
9. Systemic and connective	Putting emphasis on relation and pattern (including dynamics and flows, distortions, feedbacks and causation); encouraging a participative systemic awareness and wisdom in relation to designing sustainable and multilevel physical, environmental, social and economic systems.
10. Ethical	Clarifying ethical issues, but also nurturing normative ethical sensibility that relates and renders seamless the deeply personal and collective, i.e. it extends the boundaries of care and concern beyond the immediate and personal to a participative sense of solidarity with others, distant people, environments, species and future generations.
11. Purposive	Exploring, testing, criticising and nurturing sustainability values and alternatives, with an explicit intention to assist change .
12. Inclusive and lifelong	Not selective, but all persons in all areas of life, and extending throughout their life time .

For example, learning characteristics can be related to learning principles such as contextual, experiential and collaborative learning. They also point to interdisciplinary, reflexive and transformative, creative and innovative, process-oriented learning environments.

The ESD characteristics listed in table 2-6 (p. 42) point at type of learning strategies needed to develop knowledge, skills and competencies for ESD. Examples of such strategies are Problem Based, Project Organised Learning, Case Based Learning, CDIO, Community Based Learning, Enquiry Based Learning, etc. Nevertheless, the learning strategies share common principles with ESD and active learning approaches, such as student-centred learning (see for; Lambrechts, Pons de Vall, & Van den Haute, 2010; Habron, Goralnik, & Thorp, 2012; Steiner & Posch, 2006; Wals, 2007; Sipos, Battisti, & Grimm, 2008; Brundiars, Wiek, & Redman, 2010; Mulder, Segalàs, & Ferrer-Balas, 2012; Svanström, Palme, Wedel, Carlson, Nyström, & Edén, 2012). Figure 2-5 illustrates examples of common learning principles, learning environment and learning strategies for ESD.

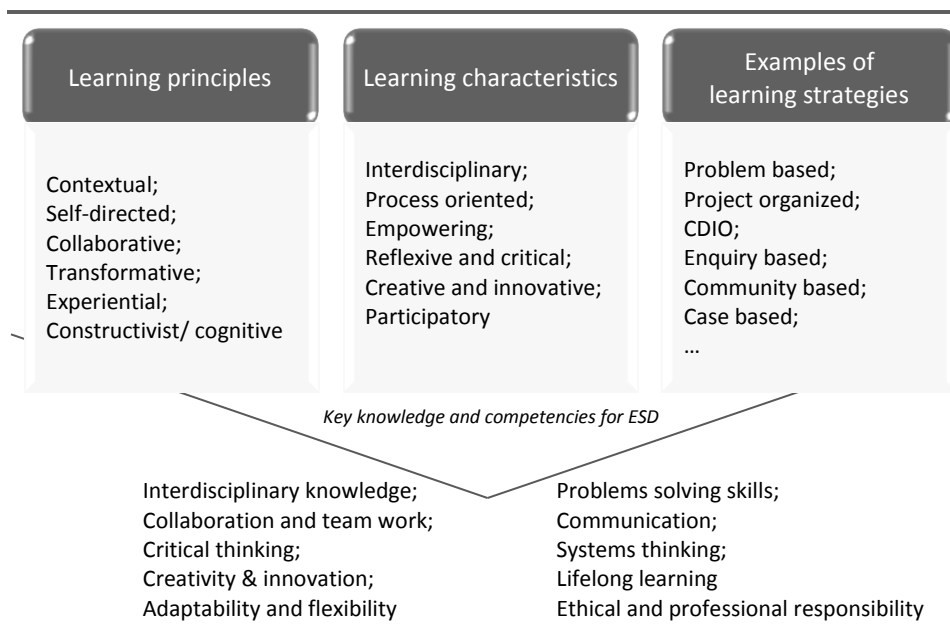


Figure 2-5 Main learning principles, characteristics, strategies and competencies for ESD (based on Sterling, 2001; UNESCO, 2005; Steiner & Posch, 2006; Sipos, Battisti, & Grimm, 2008; Lambrechts, Pons de Vall, & Van den Haute, 2010; Brundiars, Wiek, & Redman, 2010; Habron, Goralnik, & Thorp, 2012; Mulder, Segalàs, & Ferrer-Balas, 2012)

Examples of learning principles for ESD are contextual learning, collaborative learning, self-directed learning, etc. Furthermore, the ESD learning process is centred on the *whole person* concept (i.e. head, heart and hands) which encloses cognitive, social and affective dimensions (Sterling, 2001; Sipos, Battisti, & Grimm, 2008).

In sum, the above learning principles, strategies and competencies for ESD are interrelated and call for new views towards learning processes and the learners' role. Here, learners are not confined to students, but also to teachers, lecturers, managers, groups, organisations and communities (Sterling, 2001). ESD claims for learning strategies that secure its learning principles throughout the learning process, such a contextual, self-directed and transformative learning, rather than just focus on type of learning outcomes. Problem Based Learning (PBL) is an example of a learning strategy, which can be defined in terms of learning principles, such as the ones mentioned above. The following chapter presents a literature review of PBL organised around learning principles and how they support the development of learning outcomes.

3 Problem Based Learning

Problem Based Learning (PBL) is considered an innovative learning approach being used all over the world in different domains such as medical, engineering, nursery or science education (Savin-Baden & Howell, 2004; Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005).

This chapter presents a literature review of PBL theory, and its principles. The chapter is organised in the following subchapters: Role of the problem (3.1); Learning dimension (3.2); Content dimension (3.3); Social dimension (3.4); PBL models and curriculum organisation (3.5). The last subchapter presents the final remarks of literature for the overall study (3.6).

The first PBL experiences in higher education started in the late 1960's, at McMaster University (1969, Canada), Roskilde University (1972; Denmark), Aalborg University (1974, Denmark) and at Maastricht University (1974, Netherlands). These universities organised the learning process around problems differently. For example, at McMaster and Maastricht Universities, the problem solving process is organised around cases, while in Roskilde and Aalborg Universities, it is organised around projects. Nevertheless, all the different practices of PBL share the same fundamental learning principles and strive for a more student-centred and contextualised learning environment, based on the relation between theory and practice (Borrows & Tamblyn, 1980; Christensen, 2004; Kolmos, de Graaff, & Du, 2009).

In PBL, learning starts with a formulation of a problem, from real and ill-structured situations. The problem drives and contextualises learning process. Also, the learning process is based on students' experiences, increasing their motivation for and involvement in learning. Students are responsible for their knowledge construction and cognitive development. PBL is rooted on the most progressive theories of cognitive psychology and learning such as constructivist, contextual and experiential learning (Borrows & Tamblyn, 1980; Biggs, 2003; Savin-Baden & Howell, 2004; Kolmos, de Graaff, & Du, 2009).

Kolmos *et al.* (Kolmos, de Graaff, & Du, 2009) point out three main dimensions to organise the PBL learning principles. They concern the learning dimension (problem based, experienced and contextual); the content dimension (interdisciplinary, exemplary, relation between theory and practice); and the social dimension (team based

and participatory). These dimensions are parts of the PBL learning process. Likewise, the following literature review also takes its point of departure in the role of the problem, followed by the learning, content and social dimensions of PBL principles.

3.1 The role of the problem

In PBL, the learning process is driven by problems. Students engage in processes to identify, analyse and formulate a problem to be solved. Along these processes, including the solving process, students construct their knowledge, develop complex reasoning skills, critical thinking and self-directed learning (Barrows, 1986; Biggs, 2003; Mauffette, Kandlbinder, & Soucisse, 2004; Savin-Baden & Howell, 2004). In this sense, it is important to start by defining what a problem is and its role in the learning process.

The English Dictionary defines a **problem** as *“a situation, person, or thing that needs attention and needs to be dealt with or solved”* (Cambridge University Press, 2013). Throughout our lives, we find ourselves in situations identifying potential problems, which need our attention and aim to be solved. They can be simple problems or more complex problems, demanding more time, resources and engagement to be solved. For example, what is the fastest route to take to the work place when already being late? How do I fill out tax forms? Or how can I decrease my house energy consumption to save money and reduce my impact on the environment?

Also, a problem is a problem when someone perceives it as such, depending on the person's views and perspectives, and what constitutes a problem for one person may not constitute a problem for another. Therefore, problems are social constructions, and their identification is based in situations in which the people involved identify and define them as relevant to be solved (Olsen & Pedersen, 2008).

Problem identification

A problem can be defined as a wondering, often originated from an observed phenomenon (i.e. situation, event, person or thing), between how things are (present state of being) and ought to be (idealised or hypothetical way of being). A problematic situation causes contrasts, conflicts, contradictions, stress, frustration, sorrow and/or indignation, which impel people to act in order to change its current state. Problems can also be defined as un-exploring potentiality of a situation or object. For example, the primary function of a mobile phone is to make and receive calls, nowadays mobile

phones include photographic and video cameras, agendas, emails, GPS applications and so forth (Qvist, 2004; Jonassen, 2011).

The learning process starts with students being acknowledged and involved with situations possible to be problematized, analysed and understood, from which a problem is formulated. These processes are known as **problem analysis and formulation**. The analysis and understanding of what is observed (problematic situation or problem scenario) and what is aimed to be creating tension involves emotions and cognition. In order to change a situation defined as problematic, students need to understand what is observed, why it is, how, where and when it can be changed. These are examples of questions which help to deconstruct and identify elements of the problem scenario. The problem analysis encloses mobilisation of prior knowledge, understanding one's knowledge, analysis, culminating in a formulation of a problem normally in the form of a question to be solved (Qvist, 2004; Savin-Baden & Howell, 2004; Jonassen, 2011).

Types of problems

Karl Popper (referred by Christensen, 2004) distinguishes two types of problems: practical and theoretical problems. Practical problems are defined as situations which influence our living conditions and are perceived as wrong, bad or unsatisfying. The situation can be social, personal, and/or technical and prompt us to make changes to the real world. The theoretical problems exist when we wonder about the character or background of a situation. Examples of theoretical problems regard the reasons behind the problem, i.e. why it constitutes a problem.

Practical and theoretical problems are interconnected, and students need to know why a certain situation constitutes a problem (theoretical problem) as part of the problem analysis before they can look for solutions (practical problem) (Christensen, 2004). Problems vary; they can be solved through a simple mathematical equation, or be more complex like social problems such as how to eradicate poverty. Different types of problems also enclose different types of learning and cognitive tasks (Savin-Baden & Howell, 2004; Jonassen, 2011).

The above categorisation of problems stresses the importance of combining the abstract with real-life situations with impacts on people's lives. Complex real-life problems, e.g. facing the sustainability challenge, call for such a combination of theoretical and practical problems, and also, different problem characteristics come into play.

Problems characteristics

Jonassen (Jonassen, 2011) identifies five main characteristics of problematic situations. These characteristics and their descriptions are presented in table 3-1.

Table 3-1 Landscape of characteristics of problems (based on Jonassen, 2011)

Characteristic	Description
Structuredness	Variety between ill-structured and well-structured problems. In ill structured problems, the problem elements and information are unknown, leading to a multi solutions, solving path. It also implies multiple criteria for assessing the solutions, and uncertainties about what concepts, principles and knowledge required for problem solving. Frequently, it requires from learners to make judgments, express personal options and beliefs about the problem. Ill-structured and well-structured problems initiate different cognitive processes, including metacognition and argumentation
Context	The context of the problem represents the situation in which the problem is embedded. Or, context is the situation which is analysed and from which problems are formulated, defined. Context relates to the structuredness of problems. Well-structured problems are more abstract than ill-structured problems. In ill structured problems, the context constitutes an important part of the problem itself and in the solutions.
Complexity	Problem complexity is related with the number of issues, functions, or variables involved in the problem; the number of variables, interactions, predictability of these. Working with very complex problems implies a larger cognitive load for the student.
Dynamicity	The dynamicity is related to the way elements, factors and variables that compose the problem change over time.
Domain specificity	Domain specificity is related with problem solving strategies that become specific to certain domains. One example is the different forms of reasoning being dominant in some disciplines.

These characteristics are presented as continua, from ill-structured to well-structured problems; context to abstract problems; simple to complex; static to dynamic; domain specific to general. They are also interconnected, for example, an ill-structured problem is more complex, calls for more knowledge domains, initiates the contextual and leads to different cognitive tasks and strategies to be developed along the problem analysis, solving and assessment of solution (Jonassen, 2011).

The characteristics also relate to some of the PBL learning principles. For example, for ill-structured problems, the knowledge required to analyse and understand the situation moves beyond the discipline domain boundaries towards interdisciplinarity. Or, the context, real and situated, corresponds to the contextual learning principle. Fur-

thermore, the above descriptions also point to different types of knowledge and skills developed in the different poles of the characteristics (e.g. disciplinary and interdisciplinary knowledge; cognitive and metacognitive knowledge) (de Graaff & Kolmos, 2003; Savin-Baden & Howell, 2004).

The dominant characteristics of problems in an educational programme often mirror the discipline as well as societal development. For example, the rapid knowledge production and technological breakthroughs may shape engineering problems towards the professional practice. On the other hand, societal challenges call for contextual characteristics, which bring new dimensions to the learning objectives beyond the technological knowledge.

3.2 Learning dimension

According to Illeris (Illeris, 2004, 2007), learning implies a change of state (e.g. before and after a learning process takes place); it involves individual mental processes which lead to change; and interactions between the individual and social environment are preconditions for learning. In the premises mentioned, learning is defined as a change process resulting from individual and social interactions. Problem solving approaches are in somewhat in alignment with this learning definition, for example: problem solving aims at changing a given state; involves cognitive processes (e.g. identify knowledge, mobilise and learning new knowledge from which solutions can be built); and also, it involves interactions between students (through group work) and real-world environments (as problems are defined by real-world situations or phenomena) (Borrows & Tamblyn, 1980; de Graaff & Kolmos, 2003; Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005).

This study adopts the above learning definition proposed by Illeris (Illeris, 2004) to explain the PBL theory and its learning principles.

Figure 3-1 illustrates the different dimensions of learning, their interconnections and relations with student learning.

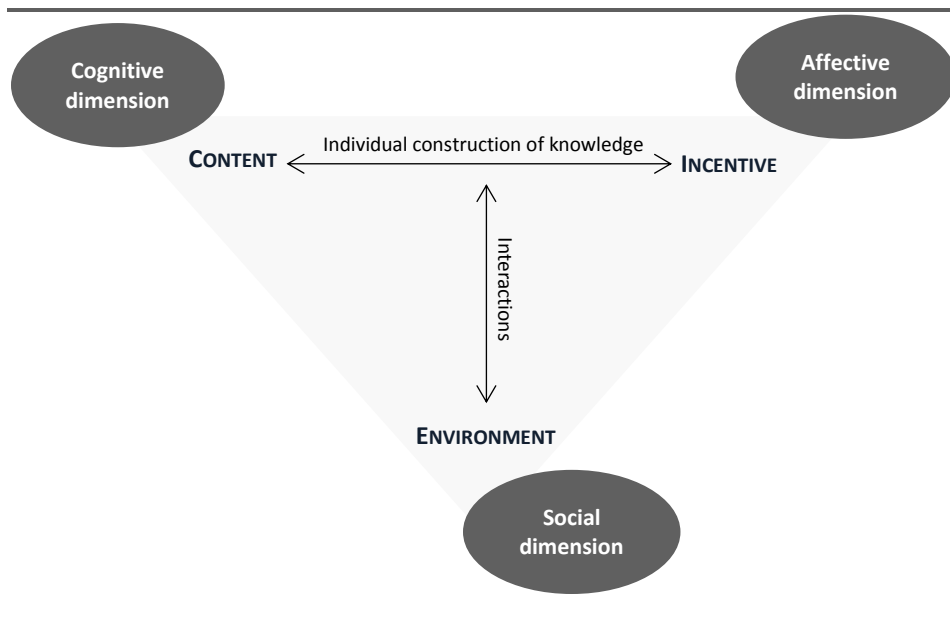


Figure 3-1 Learning dimensions based on Illeris (2004: 22-29)

The content and cognitive dimension refers to students' acquisition, assimilation, processing and accommodation of knowledge in their cognitive structures. This dimension is based on cognitivist and constructivist theories, as elaborated by Piaget and Kolb (Illeris, 2007). The incentive and affective dimension advocates that students' learning is not absent of feelings and emotions, and draw from individual experiences. Some of these assumptions are based in Dewey's experiential theories in which the environment and social dimension relates. The social dimension of learning occurs through social interactions between the individual and surrounding environment (Dewey, 1997).

In the PBL environment, all these dimensions of learning are represented. Even though the affective dimension plays a central role as incentive for learning, in the following, I focus on PBL learning principles which emphasise the interaction between the cognitive dimensions (content and construction of knowledge) and the social dimension (role of environment and social interactions in students' learning).

Cognitive and constructivist learning

The cognitive and constructivist approach to learning advocates that students should be actively responsible for their learning process. Commonly, such pedagogies fall under the umbrella of active learning approaches and are student-centred. In the tra-

ditional, teacher-centred approach, students are seen as passive agents in the learning process, and the assessment focus on the reproduction of knowledge. Students are perceived as knowledge “banks” where knowledge delivered by the teacher is absorbed. The main cognitive tasks are centred on the ability to memorise and reproduce knowledge. This approach to learning has met criticism in contemporary society which is focused on knowledge production rather than its simple reproduction. In a society characterised by fast knowledge production, focus is on processing, re-constructing meaning and use of knowledge for innovation rather than just replicating it (Weinbaum & Rogers, 1995; Illeris, 2004).

In the constructivist approach, students are actively engaged in the learning process, and thereby, they mobilise knowledge, integrate new knowledge and produce new meanings in their cognitive structures. These are examples of metacognitive tasks, and through them, students are actively engaged in their own learning process (Anderson, et al., 2001).

In this new approach to learning, value is also given to the role of the context in which students learn, the experiences and interactions of students within this context, leading to meaningful and deep learning (Mauffette, Kandlbinder, & Soucisse, 2004; Savin-Baden & Howell, 2004).

Contextual learning

PBL advocates for the use of real situations as point of departure for learning, in which students mobilise prior knowledge and construct new knowledge to solve problems (Kolmos, de Graaff, & Du, 2009). In traditional learning environments, attention to the context in which learning takes place as well as the interaction between students and the surrounding environment is neglected (Illeris, 2007).

In PBL, real contexts are brought into education, and the contexts are to be meaningful and concrete to the students. In these contexts, students develop a deeper and strategic approach to learning which is characterised by intentions to understand; interactions with content; relations between new ideas and prior knowledge; relations between concepts and everyday experiences; time management, etc. These are example of complex cognitive tasks that move beyond memorising and reproducing knowledge (Biggs, 2003; Savin-Baden & Howell, 2004).

Looking into education as a mean to prepare for life, professionally and socially, it is important that theoretical knowledge learned acquires meaning in and for different contexts (Weinbaum & Rogers, 1995).

According to Dolmans *et. al.* (Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005) the situation in which knowledge is constructed determines its use. Furthermore, it also enables students to transfer it and apply to new learning situations or contexts. Learning through problems potentiates this and educate better professionals (Litchfield, Frawley, & Nettleton, 2010).

Johnson (2002: viii) points to eight characteristics for contextual learning:

- Makes connections that have meaning;
- Self-regulated learning;
- Doing significant work;
- Collaboration;
- Critical and creative thinking;
- Nurturing the individual ;
- Reaching high standards;
- Using authentic assessment

The above characteristics link with several competences and skills pointed out in the literature as being developed when learning is initiated by problems. This is also supported by Biggs (2003); Savin-Baden & Howell (2004).

Experiential learning

Based on Dewey's works (Dewey, 1997, 1999) experiences play an important role in the learning process in order to create meaning for students. Here, emphasis is on experiences for education of quality in opposition to everyday experiences and their use in the current language (Dewey, 1997; Illeris, 2004).

Learning also encloses the creation of meanings and personal understanding of the world based on individual and interactions. Once more, the active role of the students and the role of the environment as the place to act are stressed by, for example, de Graaff & Kolmos (2003). PBL provides these conditions in the learning process as it is participant directed (de Graaff & Kolmos, 2003; Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005). Students are the ones leading the learning process and making the decisions along the process, appropriating elements from previous experiences, modifying and integrating them in the present ones. By their turn, experiences constitute the bases for future ones. This is the principle of continuity of experiential learning.

The concept of continuity implies the interconnection of different experiences through time, and criteria to distinguish educative experiences from mis-educative ones. As Dewey (1997: 36) formulates:

*[...] Every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after. [...] Every experience affects for better or worse the attitudes which help decide **the quality of further experiences**, by setting up certain preference and aversion, and making it easier or harder to act for this or that end.*

The continuity principle also works as quality criteria for experiences, which will have an impact on the learning quality as well. Every experience is a moving force; it drives students forward to navigate in “unknown waters”. It arouses curiosity, strengthens initiatives and purposes. Experiential learning points to empowerment of students and high levels of motivations into learning.

In 1984, David Kolb (Kolb, 1984), presented a cycle learning model, emphasising the role of continuity in the learning process. Kolb’s learning cycle includes four stages which enclose different cognitive tasks and levels of abstraction from the learners. These lead to the construction of four types of knowledge (divergent, assimilative, convergent, accommodative) resulting from interactions of four dimensions (concrete experience, reflective observation, abstract conceptualisation, and active experimentation). These dimensions and their interplay with different type of generated knowledge allow for design of different learning activities and environments in which students engage different types of reasoning (e.g. deductive and inductive) and therefore, different learning experiences and knowledge construction.

Illeris (2004) points out weaknesses in the Kolb’s model such as the absence of social interactions as part of the learning process; however, there is a great emphasis in learning as a continuing process based on students’ experiences and interaction with the environment. In her theory about organisational learning, Dixon (Dixon, 1999) integrates a social dimension to Kolb’s learning. Organisation learning cycles advocate that organisation members collectively engage in gathering information from the external environment and engage in work-related experiences to generate knowledge. In this sense, the organisational learning cycles take the Kolb’s learning model to the level of collaboratively learning. Also, organisational learning emphasises the ability of an organisation to intentionally and continuously transform itself through learning processes in order to increase the stakeholders’ satisfaction, underlying also continuity of learning process in commutation with the external environment.

Beside the principle of continuity, Dewey (Dewey, 1997) also points out the principle of interaction as interplay between students and the so-called situation in the surrounding environment. In the PBL approach, the problem scenario poses the possibility for students to problematize, identify and formulate problems.

Comparing this process, problem analysis and formulation, with Dewey's principle of interaction, calls for interaction between students (such as knowledge, perceptions of the world, beliefs, attitudes, etc.), and the problem scenario (i.e. environment). This question encloses students' views and perceptions towards the world based on their experiences, and constitute by itself a learning experience (Dewey, 1997) (de Graaff & Kolmos, 2003).

PBL draws learning environments, and contexts, in which students base the learning in their own experiences and interactions with their environment promoting a meaningful, deep learning, ownership, motivation and engagement in the learning process.

Exemplary learning and critical thinking

Exemplary learning appears in learning theories from German philosophers (see for example Kant, Negt, Klafki) and link them with project organised learning, (Christiansen, 1999; de Graaff & Kolmos, 2003; Holgaard, Bøgelund, Kolmos, & Dahms, 2006; Illeris, 2007).

The concept of exemplary learning is aligned with experiential learning principles (Illeris, 2007) and develops students' abilities to transfer skills and competencies from one problem solving process/area to another (de Graaff & Kolmos, 2003).

De Graaff and Kolmos (de Graaff & Kolmos, 2003) defined exemplary practice as follows:

This is a central principle, as the student must gain a deeper understanding of the selected complex problem. However, there is an inherent risk with PBL that a sufficiently broad overview of the subject area is not provided. The students must therefore acquire the ability to transfer knowledge, theory, and methods from previously learned areas to new ones.

Illeris (Illeris, 2004), based on Negt (1971) and Christiansen (1999), argues that the interaction between students and environment must reflect or exemplify relevant societal structures, materials and situations as part of the learning experience and ought to be transferred to other learning situations.

Related to the concept of exemplary learning is the concept of *Bildung*. This concept is grounded in Germany's philosophical and pedagogical traditions and relates to the process of individual formation through education. Immanuel Kant's (referred by (Holgaard, Bøgelund, Kolmos, & Dahms, 2006) defines practical *Bildung* as creation of personality, freedom to act and membership of a society in accordance with inner values. Classical *Bildung* encloses four dimensions:

- Scholastic mechanical - cognitive (e.g. qualifications);
- Pragmatic - practical (e.g. use of qualifications);
- Moral - ethical (e.g. principles used to assess the outcomes of the practical experiences)
- Aesthetics - (e.g. attention and creativity leading to variety)

However, these definitions do not seem to enclose change over time, as a person is not the same along his/her lifetime, and some of the changes result from personal experiences, social interactions and overall society development. The relation between the concept of exemplarity and *Bildung* results from Wolfgang Klafki works. Klafki distinguishes between two types of *Bildung*: *Formale* (analogous to scholastic mechanical) and *Materiale Bildung* (analogous to pragmatic). A third type, *Kategoriale Bildung* emerges as a result of individuals' situated experiences of the interaction of the content and methods (Holgaard, Bøgelund, Kolmos, & Dahms, 2006).

The principle of exemplarity is developed based on the *Kategoriale Bildung* and its relation with PBL principles. In the PBL principles presented above, the learning process involves students' experiences, prior knowledge, its use, and construction of new meanings towards the world. Also referred above is the creation of an identity and sense of belonging to a community as part of the learning process. This provides a complex and situated understandings of society and social relations in which students are immersed (Holgaard, Bøgelund, Kolmos, & Dahms, 2006).

The relevance of exemplary learning as a PBL learning principle is the possibility of students to make generalisations of how to transfer and generate new knowledge (e.g. self-directed learning) when confronted with new situations that require complex metacognitive skills for the problem analysis or solving process, and thereby, exemplary learning can be characterised as meaningful and deep learning. These can be within or out of disciplinary boundaries leading students to deal with complex and unpredictable situations, but also to make valued judgements based on context and social values (de Graaff & Kolmos, 2003; Holgaard, Bøgelund, Kolmos, & Dahms, 2006).

Critical thinking and reflection starts by questioning in order to examine and interpret how the world is and how our knowledge is shaped by what surrounds us (Tilbury, 2007). Critical thinking and reflection are cognitive acts carried out by students individually and collaboratively within domains of knowledge, and for action (Barnett, 1994). It is a continuous process of reviewing models, theories and ideas applied to a context and at different levels: personal level (individual); interpersonal, community and social levels (collaboratively). These require different levels of abstraction, including more factors and systems involved, increasing the complexity of reasoning (Schön, 1987).

Critical thinking is a step towards transformative learning, understood as a process of effective change of students' frames of reference (*i.e.* worldviews) (Moore, 2005). Through reflexivity and critique, students are involved in a learning process which revises theoretical, cultural, institutional and political contexts, leading to a reorganisation of the assumptions underlying students' worldviews (Schön, 1987; Cranton, 1996; Mezirow, 1997; Savin-Baden & Howell, 2004).

In PBL, problem analysis and identification take point of departure in questioning a given context, situation or case, as a means to understand and formulate a problem to be solved. Critical thinking and reflection is considered one of the process competencies developed by students in a PBL environment and throughout the entire problem solving process (Savin-Baden & Howell, 2004).

3.3 Curricula content dimension

In an educational system, content is organised through the curriculum learning objectives, also defined as intended learning outcomes (ILO) or learning objectives, to be learned by students when engaging in the teaching and learning activities. However, the concept of curriculum encloses more than just knowledge to be learned, it also encloses the role of the academic staff, infrastructures, assessment strategies and resources, etc. This section presents the content to which students are exposed in a PBL learning environment.

Knowledge and interdisciplinary

Students construct knowledge within one, or more, disciplinary domains through a learning process. The learning process involves different cognitive tasks necessary for acquire, understand, use and generate information. Different learning theories bring different explanations and views, about how students acquire and integrate the new

information in their existent cognitive structures (Illeris, 2007). Learning new knowledge requires reasoning and cognitive tasks; different cognitive tasks and reasoning lead to different types of knowledge such as factual and cognitive knowledge, procedural knowledge, metacognitive knowledge and world/evolutionary knowledge (OECD, 2000; Savin-Baden & Howell, 2004; Qvortrup, 2006).

Curriculum learning objectives or intended learning outcomes (ILO) are statements which describe the level of reasoning at which students should be operating and constitute the criteria for assessment. Normally, ILOs are expressed through **verbs** pointing at what students have to enact in order to achieve the desired learning objective. Learning outcomes define what a student learns after the learning process. While ILO set the criteria for assessment, learning outcomes characterise what students have actually achieved through the learning process. Ideally, and according with curriculum constructive alignment, learning outcomes should equal to ILO, meaning that what the curriculum intends for students to learn (ILO) is achieved by students through the learning activities and proved by the assessment (Biggs, 2003; Cowan, 2003).

Literature provides some examples of taxonomies (e.g. Blooms' revised taxonomy) (Anderson, et al., 2001) and frameworks (e.g. the SOLO taxonomy) (Biggs & Collis, 1982; Biggs, 2003) to formulate ILOs aligned with cognitive and constructivist perspectives.

In the Blooms' revised taxonomy, the learning outcomes are elaborated in a matrix relating four knowledge dimensions (factual, conceptual, procedural and metacognitive knowledge) with six cognitive dimensions. The cognitive dimensions are clustered around six **verbs**: remember, understand, apply, analyse, evaluate and create. The knowledge and cognitive dimensions are listed in crescent order of complexity (Anderson, et al., 2001).

The SOLO taxonomy presents a hierarchy of verbs used to formulate the learning outcomes and structured them in four level of complexity (uni-structural, multi-structural, relational and extended abstract). For example, a verb such as "identify" is commonly used to formulate uni-structural learning outcomes, while verbs such as "analyse", "relate" and "apply" are used for relational learning outcomes. The SOLO taxonomy goes further and attributes a quantitative and qualitative character to these different levels of learning and relate them with four knowledge types (declarative, procedural, functional and conditional) (Biggs, 2003).

In a PBL environment, students are engaged in different activities that enable them to develop competencies in the highest levels of complexity presented in the above taxonomies. For example, the McMaster Problem Solving (MPS) strategy includes the following stages: i) engage trough reading and listening; ii) state problem through analysis and identification; iii) explore through analysis, evaluation and application of

criteria; iv) plan a solution through analysis, manage resources and apply heuristics; v) carry out a plan by application, analysis and evaluation; iv) evaluate and look back through analysis, evaluation, communication and generalisation (Woods, 2000).

In sum, the different activities along the problem solving process provide a frame for students to analyse, understand, mobilise, evaluate, synthesise, apply, reflect, etc., and develop metacognitive knowledge (Woods, 2000; de Graaff & Kolmos, 2003). However, problems are formulated from real contexts and may include several knowledge domains or disciplines in simultaneously opening for interdisciplinarity learning (de Graaff & Kolmos, 2003; Savin-Baden & Howell, 2004; Kolmos, de Graaff, & Du, 2009).

Self-directed learning

Self-directed learning, also referred to as self-regulated learning, relies on students' competence to regulate and govern their own learning. Self-directed learning is by itself a complex learning outcome. It encloses several cognitive tasks operating simultaneously such as:

- Diagnose of learning needs, formulate learning goals and identify learning resources
- Create strategies to learn new knowledge;
- Develop knowledge about own learning preferences and styles.
- Reflect, and evaluate the appropriateness of new knowledge.

Self-directed learners also develop a high level of motivation to achieve higher standards, and challenge traditional boundaries and limits for learning, which relates with experiential and contextual learning principles of PBL discussed above. The PBL learning environment enables students to become independent learners, which is the basis for long life learning. Students acknowledge their own learning preferences and styles and they learn "how to learn" (Johnson, 2002; de Graaff & Kolmos, 2003; Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005).

Relation between theory and practice

One of the drivers for PBL practice in 1970's was to provide students the possibility to mirror the professional environment and simultaneously develop professional and academic skills in their education. However, to some extent, the call for young gradu-

ates with “ready to use” professional skills has to some degree influenced how PBL environments have been organised. This aligns with Barnett’s thesis (Barnett, 2000) regarding the “the end of knowledge” in which universities are becoming entrepreneurs in order to secure their future. According to his claims, universities secure their future:

“only by marketing its knowledge wares; in the process, its knowledge becomes performative in character and loses its power to enlighten”
(Barnett, 2000: 411)

For example, in medical education, the problem is presented to students through a case with e.g. a patient diagnosis description (Barrows, 1986; de Graaff & Kolmos, 2003; Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005).

Another example is engineering education with PBL working with ill-defined problems organised around projects. In project organised learning, students are presented with broader and open problem scenarios which call for analysis and understanding. A complex scenario provides the opportunity to break the problem into simpler and smaller problems that are more suitable to the given time and resources (Kolmos, de Graaff, & Du, 2009). Both approaches lead to different learning outcomes also because students engage in solving different problems with different cognitive tasks (Biggs, 2003).

In such a PBL environment, the professional practice is contextualised through the use of real problems and become part of students’ learning experiences. It also develops skills and competencies such as problem analysis and problem solving, communication, collaboration, etc. close to what is experienced in the working environment (Kolmos, de Graaff, & Du, 2009).

3.4 Social dimension

An ill-structured problem calls for dialogue, whereas PBL typically occurs in small groups of students, providing possibilities for consensus and close collaboration. In these groups, collaborative learning grounds on students experiences on, for example, assuming different roles within the group and develop competencies such as leadership, communication, team work, management and cope with diversity (Savin-Baden & Howell, 2004). It is part of PBL identity but also emphasises the social dimension of learning. Beside students’ collaboration in groups, they also collaborate with a member of the academic staff who acts as a facilitator, mediating and facilitating the group learning process.

Collaborative and peer learning

Collaborative learning is more than just coming together and work in order to achieve certain of goals or objectives established, it is also a mean for structuring interdependence (Topping, 2005). In PBL, learning occurs between peers and through collaboration promoting the development of competencies related with self-directed learning and lifelong learning. It also increases the quality of experience in learning leading to higher motivation and self-esteem (Savin-Baden & Howell, 2004).

Boud *et al.* (1999: 413) define peer learning as the:

“[...] use of teaching and learning strategies in which students learn with and from each other without the immediate intervention of a teacher [...]”

Here, the facilitator is put “in second place”, acting as an observer, resource and mediator of students’ learning process. Peer learning is considered by the same authors as *reciprocal peer learning* when students assume both roles of teachers and students, helping and supporting among equal status from similar social groups (Boud, Cohen, & Sampson, 1999; Topping, 2005; Papinczak, Young, & Groves, 2007).

Collaborative and peer learning are concepts aligned with constructivists and social constructivist theories of learning (Topping, 2005). Vygotsky elaborates it through his concepts of Zone of Proximal Development (ZPD) and Zone of Current Development (ZCD). ZCD represents the level a student can reach through an individual and independent problem solving process, while the ZPD is the potential of the student when learning through collaboration with competent peer (Harland, 2003). In this sense, peer learning allows students to reach ZPD in their learning process.

Students are to engage in activities supporting the learning process of others and promote reflection and self-assessment of their own knowledge (Topping, 2005; Papinczak, Young, & Groves, 2007). For example, in supporting each other’s learning, students develop cognitive tasks such as:

- Reflection on one’s own knowledge by monitoring, detecting, diagnosing and correcting misconceptions and needs for new knowledge;
- Knowledge of abilities, learning styles and preferences pointing to weaknesses and strengths;
- Develop communication skills by explaining each other’s concepts, principles and theories by transforming thoughts into language;

In sum, collaborative and peer learning develop critical thinking and self-directed learning, but also team work and communication skills.

Social and participatory-oriented

Students are active participants in the group decisions and learning processes, including building an identity and sense of belonging in a community of practice. In a collaborative learning environment, students shape their identities through creation and negotiation of meaning towards the world (Wenger, 1998; Illeris, 2004, 2007).

Etienne Wenger has developed a theory of learning as a process of social participation (Wenger, 1998). Wenger presents the concept of identity as being composed by processes of identification and negotiation through a process of social interactions, participatory or non-participatory. In a PBL environment, students learn from social interactions and construct identity through different modes of belonging. For example, students develop and adopt each other's ideas, carry out several activities jointly; share experiences and understandings of the problem solving process (including emotions). Students develop a sense of membership and ownership towards experiences and meaning, and by shared experiences and practises, they develop what Wenger calls a community of practice. The construction of such a community of practice and shared identity involves power issues and different levels of participation, leading participants to assume different roles in these social interactions (Wenger, 1998; Savin-Baden & Howell, 2004).

Through the learning process, students experience different roles within a group such as "teacher", "student", "leader", "manager", etc. They take out lessons from these experiences – they construct meaning. These skills and competencies are being more and more valued by employees and they push universities to bring them in as part of the curriculum objectives (Boud, Cohen, & Sampson, 1999; Savin-Baden & Howell, 2004).

3.5 PBL models and curriculum organisation

A PBL environment is a complex and dynamic learning environment with actors (e.g. academic staff, students), structures (e.g. curriculum, facilities) and frameworks (e.g. assessment). PBL practices are observed in different areas of education, but also in

different contexts, countries and cultures. Different PBL models have been emerging resulting from research and practices, sharing the same learning principles and a vision towards change, and the different models have different implications on the curriculum construction.

PBL models

PBL models can be distinguished as hybrid and pure models. In a pure model, as for example the McMaster PBL practice developed in late 1960's, groups of students were presented with problems they need to solve, one after the other. However, students did not have courses or lectures to provide the knowledge base for the problem solving process. While in a hybrid model, the curriculum encloses time allocated for problem solving process as well as courses (Savin-Baden & Howell, 2004).

According to Barrows (Barrows, 1986), the combination of design variables for PBL is endless. The author thereby argues for taxonomy to categorise PBL, and proposes the following, which mainly relates to medicine:

- Lecture-based cases,
- Case-based lectures,
- Case method,
- Modified case-based,
- Problem-based,
- Closed-loop problem-based

In a PBL curriculum, the problem solving process, and consequently learning process, can be organised in different ways. Inevitably, the type of problems, time allocated to solving process, resources provided, etc., affect how the curriculum is designed and organised around problems. For example, in a hybrid PBL model, courses are seen as resources for students for gathering and accessing relevant knowledge to mobilise and use in the problem solving process (Savin-Baden & Howell, 2004).

The most common examples of how PBL is organised are by cases or projects, whereas the first form of organisation is more common for medical education and the latter one in engineering education. Case and project organised learning also encloses different learning outcomes due to how the learning around problem is organised (Biggs, 2003). Biggs (Biggs, 2003) also claims that the learning quality (e.g. type of knowledge students develop) in project organised learning is higher when comparing with case studies. Typically, cases enclose more information that problem situations students are confronted with in the beginning of the learning process. For this reason, the project

organised learning pulls for more metacognitive tasks from students in order to navigate and solve the problem.

The above taxonomies have been criticised for addressing only course and unit level and not the institutional level. Kolmos *et al* (2009: 15) argues for a systematic and integrative approach regarding a curriculum change towards PBL environment, using the key elements that compose the curriculum practice such as:

- Objectives & knowledge;
- Type of problems, projects and lectures;
- Progression, size and duration;
- Students' learning;
- Academic staff and facilitation;
- Space and organisation;
- Assessment and evaluation;

The above elements of the curriculum can be aligned with the PBL principles presented in this chapter.

Curriculum change towards PBL pulls, for example, for students and staff to assume new roles, new responsibilities on the learning process; and new types of resources and ways of supporting the problem solving process (e.g. how lectures relate to the problem solving process), etc.

Attending to the PBL objectives, Kolmos *et. al.* (2009: 13) propose five PBL models based on Savin-Baden works (2000, 2007) where the perception of knowledge, learning, problems, students' roles, teachers' roles and assessment are aligned with learning goals (table 3-2).

Table 3-2 presents, and characterises the five PBL models in relation with type of knowledge, learning goals and problem scenario, students' and staff roles and assessment.

Table 3-2 PBL basic models (based on Savin-Baden 2000, 2007)

Model	Knowledge	Learning goals	Problem scenario	Students	Facilitator	Assessment
(I) PBL for epistemological competence	<i>knowing what</i>	Use and management of knowledge	Limited-solutions already known	Receivers and problem solvers	A guide to correct propositional knowledge	Test of epistemological competence

Model	Knowledge	Learning goals	Problem scenario	Students	Facilitator	Assessment
(II) PBL for professional action	<i>Know-how</i>	Outcome focused acquisition	Real life situations	Pragmatics induced by professional culture	Demonstrator of skills	Testing competencies for work place
(III) PBL for interdisciplinary understanding	<i>Know-what & know how</i>	Synthesis of knowledge across disciplines	Knowledge to act and interact	Integrator of boundaries	Coordinator of knowledge and skills	Skills and contextual knowledge
(IV) PBL for transdisciplinary learning	Reconstruction	Critical thought from subject positions	Resolving and managing dilemmas	Independent thinkers	Orchestrator of opportunities	Demonstrate an integrated understanding
(V) PBL for critical contestability	Contingent, contextual & constructed	A hybrid imagination	Multidimensional and open	Explorers' of underlying assumptions	Commentator, a challenger and decoder	Open-ended and flexible

The above models imply different learning environments, demanding, for example, different types of knowledge (from cognitive to metacognitive), more or less disciplines (from disciplinary to transdisciplinary) to address different learning goals, different roles for students and academic staff, as well as diverse approaches to assessment. These models are mainly prescribing and based on experiences with engineering education and its grand challenges. For example, in model V - PBL for critical contestability - learning goals aim for mixing scientific and technical knowledge with cultural awareness which pulls for more transdisciplinary knowledge production (i.e. hybrid imagination). This model of PBL would enclose a more holistic and systems-thinking approach to the problem solving process, moving beyond the discipline boundaries and constructing new ones (Jamison, Christensen, & Botin, 2011).

The PBL models presented above are not fixed and rigid models, but rather an area of possibilities one can navigate in when designing a PBL curriculum. The different types of knowledge and learning outcomes (ILOs) imply a look into the type of problem areas that students are presented with as a starting point. Therefore, different types of intended learning outcomes can lead to different curriculum models. I return to these models into more detailed in chapter 4 as ground for development of a theoretical and empirical framework for this study.

Final remarks

Problem Based Learning (PBL) literature review was organised and presented according with the learning principles that characterise this learning approach and make it innovative. PBL is far from a simple and reductionist approach to learning, as it brings a new view to learning processes and the quality of the outcomes. Learning processes are organised, and driven by, problems that involve cognitive, social and emotional dimensions. PBL is based on contextual and experiential learning, together with self-directed and collaborative learning principles. The mentioned principles foster development of higher order reasoning skills (e.g. metacognitive and interdisciplinary learning), critical thinking, long-life learning, problem analysis and solving skills, capable to be transferred and applied in new learning contexts. However, the learning outcomes depend upon the type of problem scenarios and their characteristics.

PBL is considered one of the most suitable learning methodologies for addressing the challenges pose to engineering education and education for sustainable development (ESD), due to its learning dimensions, complexity and outcomes.

Similarly to ESD, PBL is an integrative approach to learning. For example, designing PBL environments pulls for interconnection between several aspects of learning and institutions, e.g. curriculum organisation; students', academic staff role; assessment; learning outcomes; etc. These different elements should be aligned in order to promote learning and foster development of different types of knowledge, critical thinking, self-directed learning, problem solving skills (Savin-Baden & Howell, 2004, Kolmos, de Graaff, & Du, 2009). The following chapter examines in more detail the similarities between PBL and ESD, allowing the identification of variables used to investigate how PBL can support the integration of ESD in engineering education.

4 Similarities between PBL and ESD

Problem Based Learning (PBL) is used to address engineering education challenges, and also integration of sustainable development. The PBL environment supports a learning process involving not only cognitive dimensions, but also emotional and social dimensions. PBL can be defined in terms of learning theories and principles as was discussed in previous chapter (chapter 3, p. 47). It is considered one of the most innovative learning approaches which lead to development of knowledge, skills and competencies to address engineering education challenges. Furthermore, PBL also presents similarities with education for sustainable development (ESD) principles. Education towards sustainability literature has been presented in chapter 2 (p. 25), which closed with references of what kind of learning principles, environment and outcomes are needed for ESD. Some of the ESD characteristics, such as contextual and self-directed learning, participatory, problem based, critical, are similar to PBL philosophy. This chapter discusses the similarities between PBL and ESD learning principles and whether PBL can support the integration of ESD in engineering education from a theoretical perspective. Furthermore, such a perspective allows identifying common PBL and ESD analytical variables for further investigation.

This chapter is organised in three subchapters; the first subchapter discusses the similarities (4.1). The second subchapter presents the analytical variables identified based on PBL and ESD similarities (4.2). The last subchapter presents the data collection strategy regarding the variables identified (4.3).

4.1 Similarities between PBL and ESD

In her previous works, Savin-Baden (2000, 2007) elaborated five basic PBL models (table 4-1). These models provide a holistic view of the PBL environment and key dimensions to organise the learning process around problems. Examples of these dimensions are knowledge, learning goals, problem scenarios, role of students and facilitators, and assessment.

Table 4-1 PBL models based on work of Savin-Baden (2000; 2007)

Model	Knowledge	Learning goals	Problem scenario	Students	Facilitator	Assessment
(I) PBL for epistemological competence	<i>knowing what</i>	Use and management of knowledge	Limited-solutions already known	Receivers and problem solvers	A guide to correct propositional knowledge	Test of epistemological competence
(II) PBL for professional action	<i>Know-how</i>	Outcome focused acquisition	Real life situations	Pragmatics induced by professional culture	Demonstrator of skills	Testing competencies for work place
(III) PBL for interdisciplinary understanding	<i>Know-what & know how</i>	Synthesis of knowledge across disciplines	Knowledge to act and interact	Integrator of boundaries	Coordinator of knowledge and skills	Skills and contextual knowledge
(IV) PBL for trans-disciplinary learning	Reconstruction	Critical thought from subject positions	Resolving and managing dilemmas	Independent thinkers	Orchestrator of opportunities	Demonstrate an integrated understanding
(V) PBL for critical contestability	Contingent, contextual & constructed	A hybrid imagination	Multidimensional and open	Explorers' of underlying assumptions	Commentator, a challenger and decoder	Open-ended and flexible

The models move from a narrower, well-defined problems with focus on development disciplinary cognitive knowledge, to more ill-defined and complex problems with focus on metacognition and interdisciplinary knowledge. They also represent existent differences in the PBL landscape and provide possibilities for diverse practices by relating, for example, problem scenarios and learning goals (Savin-Baden, 2000; de Graaff & Kolmos, 2007; Savin-Baden, 2007).

For example model I, PBL for epistemological competence, emphasises construction of cognitive and factual knowledge and problems are characterised as narrow and defined focus on discipline knowledge, while model II, PBL for professional action, emphasises procedural knowledge, and is performance-oriented; problems are real situations. In model III, PBL for interdisciplinary understanding, aims for development of cognitive and procedural knowledge, it is performance-oriented, and the problem is centred in a situation calling for both theory and practice. Model IV, PBL for trans-

disciplinary learning, aims to test knowledge given and the problem is characterised as a dilemma. In model V, PBL for critical contestability, the knowledge is characterised as contingent (i.e. depends on or is conditioned by other factors), contextual and constructed by the learner for given situations. The problem scenario is open, complex and ill structured.

The PBL basic models provide key dimensions which can be related to key characteristics for education for sustainable development (ESD). This analyses, and relates the following dimensions with ESD:

- Knowledge (table 4-1, 2nd column);
- Learning goals (table 4-1, 3rd column);
- Problem scenarios (table 4-1, 4th column).

The knowledge dimension varies from factual and cognitive knowledge (i.e. know what) to procedural and metacognitive knowledge, implying different levels complexity in reasoning in the five PBL basic models. The different type of knowledge and learning goals are related with analysing and solving different problem scenarios. These dimensions are discussed in relation with research question next.

Metacognition

ESD advocates development of higher-order thinking skills, *i.e.* metacognitive knowledge and interdisciplinarity (UNESCO, 2005; Wals, 2007). Furthermore, sustainable development cannot be claimed as part of one discipline, but all disciplines and fields can contribute to it. It is by definition cross-disciplinary throughout its environmental, social and economic spheres (UNESCO, 2005; Roosa, 2010).

Metacognitive knowledge enables students to engage in higher order cognitive tasks such as understanding, analysing, synthesising and creating the factual knowledge (concepts, principles and theories) students are exposed to.

Interdisciplinarity involves construction of knowledge within different disciplines (i.e. knowledge domains), but also develop reasoning across different disciplines through collaboration. The complexity arises when students construct metacognitive knowledge within different disciplines and across different areas (e.g. science and technology, economics, policies, history, philosophy, etc.). Three principles are claimed to be needed in order to promote interdisciplinarity in education (Steiner & Posch, 2006).

They are:

- Development of disciplinary expertise (metacognition within disciplinary domain),
- Construct knowledge in different disciplines from different knowledge domains (factual and metacognitive knowledge across different disciplines and across areas),
- Develop cross disciplinary thinking through collaboration (peer learning).

These are considered important conditions for learning, and they address the complexity of sustainable problems. Furthermore, construction of metacognitive knowledge on different disciplines promotes systemic and holistic thinking which constitute one of the key learning principles for ESD. The above also stresses the importance of collaboration as a learning condition to develop such competencies for ESD (Stauffacher, Walter, Lang, Wiek, & Scholz, 2006; Steiner & Posch, 2006).

The above PBL models provide a frame of reference for which type of combinations (knowledge, learning goals and problems) may promote the development of key ESD competencies. For example, Model III, PBL for interdisciplinary understanding, enclose a combination of know-what (cognitive knowledge) and know-how (procedural knowledge), emphasising the relation between theory and practice. It is also claimed, as key competencies for ESD, strategic knowledge (which includes systemic, anticipatory, normative and action-oriented competencies in ESD) and practical knowledge (which regards the relation between theory and practice) (Brundiers, Wiek, & Redman, 2010). Furthermore, the models move from a learning within discipline-specific boundaries through narrower problems (model I) to multidimensional and open problem scenarios to foster metacognition and transdisciplinary (model V) (de Graaff & Kolmos, 2007; Savin-Baden, 2007).

The above indicates that PBL fosters metacognition and interdisciplinarity, and allows the creation of learning conditions for collaborative learning and systems thinking. However, these depend not only on the problem scenarios, learning goals, but also on the role that students, facilitators and assessment assume.

Learning goals and problem scenarios

ESD learning goals are related to its principles and characteristics such as contextual, critical, transformative, systemic and holistic, transformative, lifelong, purposive, ethical, etc., (chapter 2, p. 42) (Sterling, 1996; UNESCO, 2005; Steiner & Posch, 2006).

Problems are not only drivers for learning in a PBL environment, but also for creating conditions for meaningful and contextual learning. Problem scenarios ought to be real and characterised in terms of complexity, context, structuredness, dynamicity and domain specific (Jonassen, 2011). Different combinations of these foster different learning outcomes not only in terms of knowledge constructed and disciplinarity, but also critical thinking, self-directed learning, problem solving skills, collaborative and transformative learning (Savin-Baden & Howell, 2004; Jonassen, 2011).

ESD also advocates for lifelong learning and emphasises the local relevance and cultural appropriateness of sustainability (Sterling, 1996; UNESCO, 2005). Self-directed learning, which underlies the lifelong learning skills, and contextual learning are two principles of PBL theory explained in further detail in chapter 3 (p. 51).

Once more, the role of the problem is fundamental to lead the learning process and fulfil the learning goals established for ESD, such as system thinking and transformative learning, capacity building for community learning and decision making (Steiner & Posch, 2006; Sipos, Battisti, & Grimm, 2008).

Transformative learning advocates students' contestability, revision and transformation of frames of reference, views and perspectives toward the world. Transformative learning implies breaking through current paradigms, and practices, that do not align with social and sustainable development visions (Cranton, 1996) (Moore, 2005). In this sense, students revise the discipline, profession and culture role of current practices towards sustainability principles and visions, and construct new ones aligned with such principles. Furthermore, transformative learning as an intentional and continuous process allows students to change and address the social challenges in parallel (Dixon, 1999; Sterling, 2004).

Transformative learning can be promoted through collaborative learning (Cranton, 1996; Mezirow, 1997) in which students critically reflect on different aspects and issues along the problem solving process (Mogensen, 1997; Savin-Baden & Howell, 2004; Tilbury, 2007).

Critical thinking encloses different reasoning and understandings of reality which can be developed through a PBL process. It is argued that through collaboratively solving real, complex problems students are able to develop critical thinking skills and transform their perspectives towards learning, knowledge, attitudes and beliefs (Schön, 1987; Barnett, 1994; Mezirow, 1997; Mogensen, 1997; Savin-Baden & Howell, 2004; Tilbury, 2007). Mogensen (Mogensen, 1997) proposes four perspectives of critical thinking for environmental education and action competence. They are epistemological, transformative, dialectic and holistic perspectives. In the epistemological perspective, students identify factual and normative aspects of a problematic situation in their historical and cultural roots. In the transformative perspective, in which transfor-

mations take place at different levels: attitudes, values of the person, or broader views of political, economic structures. In a dialectical perspective, the sense of community and the contextualisation of information are developed. Students understand that different people or communities have different meanings and understandings towards the same knowledge, and that knowledge depends on latent values and beliefs. The dialectic concept refers to a dynamic view of progress and development which takes place by questioning and breaking into parts existent and dominant practice to reconstruct new ones. In the holistic perspective, students understand that thinking is not only cognitive and intellectual, but also emotional, involving feelings and emotions (Mogensen, 1997).

In sum, transformative learning is a core principle for ESD, and PBL creates conditions for promoting such learning by fostering critical thinking. Students get engaged in different types of critical thinking (Schön, 1987; Mogensen, 1997; Savin-Baden & Howell, 2004) and collaborative learning (Cranton, 1996) which supports transformative learning.

The above PBL models IV (PBL for transdisciplinary learning) and V (PBL for critical contestability) point to reflexivity and critical thinking as possibilities for, for example, re-construction of meanings. However, it is important to stress that PBL models for epistemological and professional competence are not absent of reflectivity and critical thinking; the objects of reflection and critical thinking do not necessarily lead to transformative learning (Savin-Baden & Howell, 2004; de Graaff & Kolmos, 2007).

In sum, transformative and contextual learning are two examples of learning goals for ESD. PBL is, by its turn, a learning approach which creates conditions for their development through analysing open problem scenarios and solving real complex, ill structured problems. Through this process, students are able to develop competencies such as critical thinking, self-directed learning and collaborative learning. It is important to stress that only by solving problems in teams; students collaboratively learn and critically reflect for transformative learning (Cranton, 1996; Mogensen, 1997). Once again, it is necessary to create conditions to foster transformative learning.

PBL as a support to integrate ESD

According to the above, PBL can support the integration of ESD by fostering:

- Metacognition;
- Interdisciplinary;
- Critical thinking;
- Collaborative learning;

- Self-directed learning;
- Contextual learning;
- Problem analysis, formulation and solving processes

By their turn, the mentioned points can be related with five PBL basic models and strategies for ESD. For example, metacognition relates with knowledge dimension, and interdisciplinarity with disciplinarity dimension. Critical thinking, collaborative, self-directed and contextual learning relate with learning dimension, and problem analysis, formulation and solving processes with problem scenario dimension (figure 4-1).

The different dimensions in which PBL supports the integration of ESD are illustrated in figure 4-1. The figure also illustrates the landscape of possibilities for ESD and PBL.

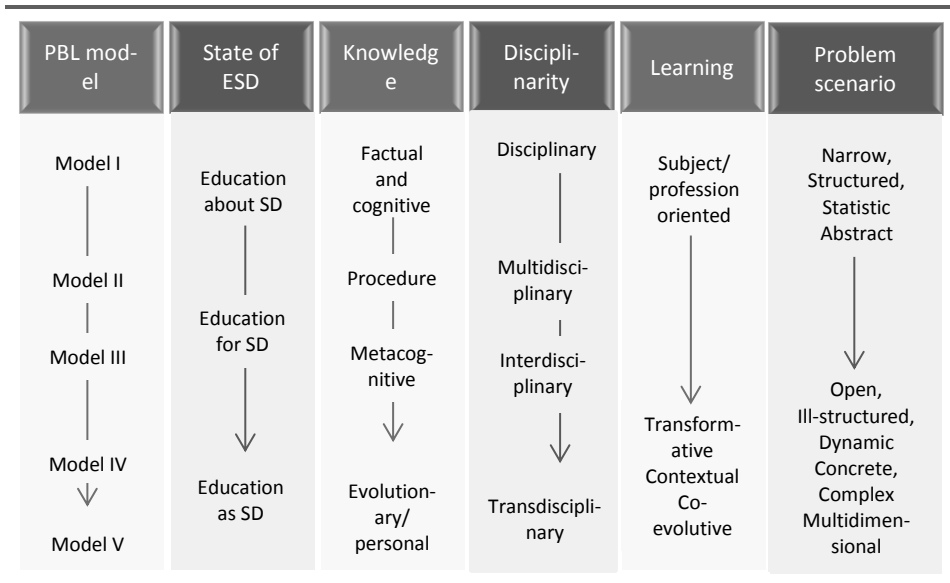


Figure 4-1 Comparison and conceptual understanding of PBL and ESD similarities

The dimensions represented in the figure allow for identification and definition of analytical variables to investigate PBL and ESD in engineering education. The learning dimension is elaborated through more literature review in the following subchapter.

4.2 Identifying analytical variables for research

Based on the similarities between PBL and ESD, it is possible now to identify analytical variables to investigate in which ways PBL supports the integration of ESD in engineering education (table 4-2). The analytical variables cover a range of aspects of the learning process. For example, problem scenarios, types of knowledge, disciplinarity and critical thinking. These are related with PBL and ESD similarities and dimensions discussed previously. However, other correlated variables emerge such as: process competencies, EESD principles, SD aspects and curriculum organisation. These are also related with the learning dimension (table 4-2).

Table 4-2 Variables and criteria for PBL and ESD which are based on their common learning principles (based on Guerra, 2012; 2013)

Variables	Criteria
<p>Problems (Savin-Baden & Howell, 2004; Jonassen, 2011)</p>	<p>Structured/ ill-structured; Concrete/ abstract; Practical / conceptual; Qualitative/ quantitative</p>
<p>Knowledge (McCormick, 1997; McCormick, 2004; OECD, 2000; Anderson, et al., 2001; Savin-Baden & Howell, 2004; Qvortrup, 2006; Kolmos, de Graaff, & Du, 2009)</p>	<p>Factual & Conceptual; Procedural; Metacognitive; Personal & evolutionary</p>
<p>Disciplinarity (Savin-Baden & Howell, 2004; Davies & Devlin, 2007; Bolitho & McDonnell, 2010; Borrego & Cutler, 2010)</p>	<p>Disciplinary; Cross/ multidisciplinary; Interdisciplinary; Transdisciplinary</p>
<p>Criticality (Mogensen, 1997; Savin-Baden & Howell, 2004)</p>	<p>Epistemological; Transformative; Dialectic; Holistic</p>
<p>Process competencies (Sterling, 1996; Sterling, 2001; Savin-Baden & Howell, 2004; Doods & Venables, 2005; Bourn & Neal, 2008; Kolmos, de Graaff, & Du, 2009)</p>	<p>Problem analysis & solving Communication Collaboration Creativity and innovation</p>
<p>Other EESD principles (Doods & Venables, 2005; Bourn & Neal, 2008; Engineering Education for Sustainable Development, 2004)</p>	<p>Systemic & holistic Flexibility & adaptability</p>

Variables	Criteria
<p>Sustainability aspects (Sterling 1994; GRI, 2011; Bourn & Neal, 2008)</p>	<p>Environment Society Labour practices and decent work Human Rights Product responsibility Economic Ethics and professional responsibility</p>
<p>Curriculum organisation (Savin-Baden & Howell 2004; Kolmos, de Graaff, & Du, 2009)</p>	<p>Lectures Cases Projects</p>

Process competencies are related with competencies developed in a PBL environment, such as problem solving skills, collaboration, creativity and innovation.

Also, societies of engineering education stress the importance of sustainable development, and what the desirable learning outcomes are. See for example Declaration of Barcelona (Engineering Education for Sustainable Development, 2004), The Royal Academy of Engineering (Doods & Venables, 2005), or The Global Engineer (Bourn & Neal, 2008) which emphasise principles, knowledge, skills and competencies to be develop in engineering education for sustainable development (EESD). Examples of such competencies are multidisciplinary team work, critical thinking and problem solving skills, lifelong learning, adaptability and flexibility. Systemic & holistic and adaptability & flexibility are two principles defined for EESD which are also identified as analytical variables (table 4-2).

However, ESD is not only based on learning principles, it also claims for content regarding sustainability and sustainable development (SD) therefore, two more variables are added to the ones based on PBL and ESD similarities. Presence of SD content in engineering education is supported by accreditations bodies and engineering education societies (Engineering Council, 2004; Engineering Education for Sustainable Development, 2004; Doods & Venables, 2005; Bourn & Neal, 2008; ENAEE, 2008; OECD, 2009; ABET, 2010).

For example, ABET (2010: 4) explicitly states sustainable development as part of engineering students' outcomes, exemplified as follows:

*“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**” (ABET, 2010, p, 4)*

Another example is the use of sustainable development reporting guidelines, such as Global Reporting Initiative (GRI) sustainability guidelines (GRI, 2011), to assess the sustainable development present in curricula programmes (Lozano, 2006a; Lozano, Llobet, & Tideswell, 2013). The GRI (GRI, 2011) is one of the tools for institutions and companies for auditing and reporting sustainable development. According Lozano *et. al.* (Lozano, Llobet, & Tideswell, 2013), among all the existent tools for assessing and reporting SD at the institutional level, GRI guidelines is one of the best options. Here, GRI is used to pinpoint relevant themes which can relate to both disciplinary subjects specifically and SD aspects (table 4-2). One of the criticisms to GRI was the lack of educational dimension, philosophy and principles for ESD (Lozano, 2006a), which are present by analytical variables identified such as knowledge, disciplinarity, critical thinking and process competencies.

PBL and ESD advocate a student-centred approach. In this sense, the students ought to be not only responsible for constructing their knowledge, but also to select problem scenarios which enable them to develop knowledge and competencies for EESD. However, formal education programmes are following a curriculum which encloses intended learning outcomes (ILOs), in this sense, curricula developers and school leaders become important actors to promote EESD by formulated ILOs adequate and aligned with principles for sustainable education. Furthermore, under an ESD perspective also the organisation and surrounding communities are learners.

In sum, the analytical variables can be divided in two groups: PBL variables (such as problem scenarios, knowledge, disciplinarity, criticality, process competencies and curriculum organisation) and ESD variables (EESD principles and SD aspects).

4.3 Strategy for data collection

The above discussion provides a theoretical understand of PBL and ESD similarities and what analytical variables to be researched through an experts' and practice perspective. Overall, the strategy for data collection makes a transition between the theoretical understanding of PBL and ESD principles and their investigation in engineering education practice. The following briefly presents the overall strategy for data collection to investigate in which ways PBL can support integration of ESD by consulting experts and a practice perspective.

Expert perspective

The expert perspective aims to investigate strategies, drivers and challenges in integrating ESD in engineering education. This perspective analyses broadly the role of institutions' different structures, frameworks and actors to integrate ESD, and in which way PBL supports them.

The strategy for data collection is divided in two parts, as it follows:

- I Selection of experts, mainly identified through authorship on research articles regarding integration of ESD in engineering education;
- II Interviews based on defined criteria to investigate integration of ESD.

A holistic and systemic approach, integration of ESD involves all levels of institutions, from vision and mission to teaching practices (chapter 2, p. 29). External or internal drivers raise the organisational awareness for ESD, leading to development of strategies and initiatives to promote a change towards ESD. These strategies involve different levels of organisation such as campus operations, curricula development, content, pedagogies, role of actors and relations with external communities. Furthermore, the different strategies should align with ESD learning principles, at different levels. Therefore, it becomes important to analyse and comprehend the strategies for ESD and in which ways PBL can support them.

The variables to be investigated in integration of ESD through experts' perspectives are: strategy and role of actors; triggers and drivers; pedagogical approaches; challenges and future needs. The interview guide questions are organised around these themes and analysed accordingly. The research methodology to investigate the experts' perspectives is presented in more detail in chapter 5 (p. 81).

Practice perspective

The practice perspective investigates in which ways PBL practice support the integration of ESD in engineering education. Based on the similarities between PBL and ESD, a strategy for data collection is developed. The data collection aims to analyse analytical variables defined previously through a case study research.

The strategy for data collection is divided in two parts, as follows:

- I Define specific research questions, methods and sources of evidence for data collection;
- II Construct instruments for data collection and analysis

The main variables defined to be investigated in the practice are:

- Problems;
- Knowledge;
- Disciplinarity;
- Critical thinking;
- Process competencies;
- ESD principles for engineering;
- Sustainability aspects;
- Curriculum organisation

For each of these variables, criteria such as type of different knowledge, discipline, critical thinking, process competencies and EESD principles are defined for data collection. These have been presented in table 4-2 (p. 76).

The different variables are investigated through different research methods and sources of evidence. Examples of research methods are documentary analysis, interviews and direct observations. The different methods are with different sources of evidence such as formal curricula, actors (e.g. students, lecturers, study board developers). Figure 4-1 presents the main research methods, and respective sources of evidence for data collection.

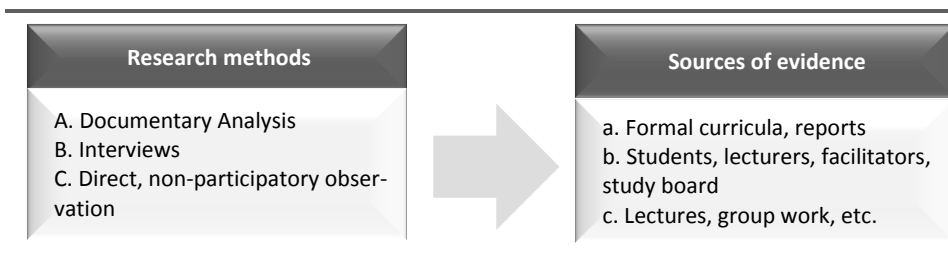


Figure 4-1 Research methods and respective sources of evidence

The choice of these qualitative methods is related to the overall goals of the study. The case study research methodology and data collection is explained in more detail in chapter 7 (p. 121).

5 Experts' perspectives on ESD

Research communities of practice regarding Engineering Education for Sustainable Development (EESD) are being established and increasingly institutionalised through conferences like for example the Biannual Conference of Engineering Education for Sustainable Development (University of Cambridge, 2013), the sustainability track in the SEFI annual conference, or working groups as the SEFI Task Force on Sustainability in Engineering Education (SEFI, 2014); and journals like the European Journal of Engineering Education (Taylor & Francis Group, 2014) or the International Journal of Sustainability in Higher Education (Emerald Group Publishing, 2014). These are “meeting places”, where strategies to integrate ESD in engineering education are reported, compared and discussed.

It is also becoming frequent to find cross-institutional and comparable studies regarding the integration of EESD. These studies provide possibilities to define common conceptual ground for ESD in engineering education, and identify shared experiences and recognise the institutional contextual factors to integrate EESD (see for example Lozano, 2006b; Lozano-García, Huisinigh, & Delgado-Fabián, 2009; Lozano, 2011b; Mulder, Ferrer, & van Lente, 2011; Cruickshank & Fenner, 2012).

This chapter presents the investigation of the research question from an experts' perspective. ESD and EESD experts from the described research communities of practice are consulted in order to seek insights to better understand in which ways PBL can support the integration of ESD in engineering, and have the following research aims:

- Select experts from around the world;
- Outline examples of strategies to integrate ESD in engineering education, including challenges and drivers, pedagogical approaches;
- Comprehend in which ways PBL can support the integration of EESD;

The following presents the design of this part of the study (5.1) the outcomes (5.2) and as a conclusion, the challenges and future perspectives highlighted by the experts will be synthesised and related with overall research question investigated.

5.1 Research methodology

The qualitative research design comprises two main methods: literature review and interview. Both methods address different goals: i) select EESD experts; and ii) collect the experts' perspectives regarding strategies to integrate ESD engineering at a global level. The strategy for data collection is illustrated in figure 5-1.



Figure 5-1 Strategy for data collection

Selection of ESD experts

The experts have been selected from literature review and readings carried out along the PhD study. The list of experts is presented in table 5-1. Nevertheless, when some of the experts were contacted, they suggested others to be taken into consideration to be interviewed given the scope and aim of study. It is the case of Mark Henderson from Arizona State University.

Table 5-1 Experts contacted and interviewed

Experts name	Source of selection			Interviewed on
	Journal paper	Conference/ network	Pointed at by other experts	
1 Karel Mulder, PhD (TU Delft, Netherlands)	✓	✓	--	10 July 2013
2 Richard Fenner, PhD (University of Cambridge, UK)	✓	--	--	30 August 2013
3 Rodrigo Lozano, PhD (Utrecht University, Netherlands)	✓	✓	--	12 July 2013
4 Mark Henderson, PhD (Arizona State University, US)	--	--	✓	6 August 2013
5 Yona Sipos (University of British Columbia, Canada)	✓	--	--	17 July 2013
6 Francisco Lozano, PhD (ITESM – Monterrey, Mexico)	✓	✓	--	1 August 2013
7 Roger Hadgraft, PhD (RMIT, Australia)	--	✓	--	2 September 2013

Experts from different contexts (meaning country and engineering institutions) are contacted for interview. The selection is random and representative of different contexts (European, North and central American and Australian context) (table 5-1). The different contexts are also under different qualification frameworks and cultures of practice.

For this study, 11 experts out of 27 are contacted and 7 interviews carried out (table 5-1). The experts are contacted by e-mail to participate in the study. The contact letter is in appendix 1 (p. 1). From the experts contacted, less than half did not reply or were not able to participate due to work and time related constraints.

Data collection: Interview process

The interviews, structured, took place between July and September 2013. An interview guide has been produced and can be seen in appendix 2 (p. 2). The interview guide is sent to the interviewees the day before the interview took place. Nevertheless, the core questions from the interview guide are integrated in the contacting letter, send by e-mail. Also in the contact e-mail, there is a request for further readings and references from the interviewees in order for me to be better prepared for the interviews.

The interviews were conducted through Skype, and had duration of approximately 60 minutes. During the interview, the interviewer took notes and recorded the interview. In every interview, it was requested permission to record the interview and use it later on for research purposes. All interviewees agreed to have the conversation recorded. After the interview, a summary was produced and sent to the experts, so they could approve the content, and give feedback for improvement or clarify one or more points.

Data analysis

The analysis process was carried out by i) preparing interviewed summary; and ii) coding interview audio.

The interview summary was done after the interview and based on interviewer notes and the audio file. Its content was approved by the interviewee to confirm the content and interpretation given to interviewees' replies, and to some extent seek for validation and meet ethical requirements. Approved summaries of the interviews can be found in appendix 3 (p. 3). The interview summary content is organised in four cluster themes: contact information, suggested literature, background information, and interview summary (figure 5-2).

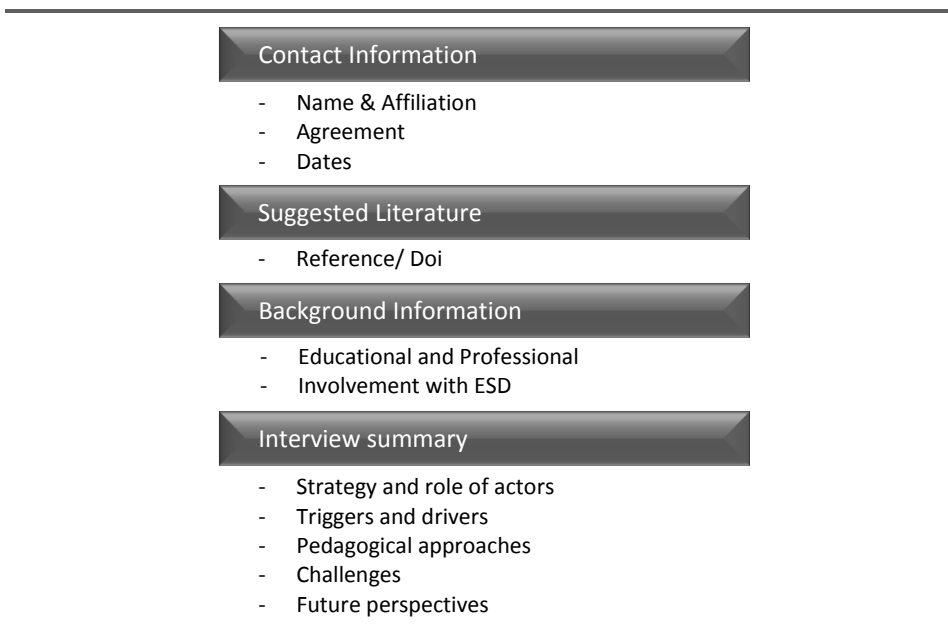


Figure 5-2 Organisation of interview summaries

After summarising the interviews, the second part of the data analysis was to code the audio files. The summaries substitute the full interview transcript to provide overview, whereas the coding process of the audio file was carried out to make sure that all relevant information was included.

For the content analysis, and coding, of the audio is used NVivo 10. The criteria for analysis are defined previously based on literature review from chapters 2 (p.25) and 4 (p. 69). The codes are based on the criteria defined. Table 5-2 presents the criteria defined and respective codes.

Table 5-2 Criteria of analysis used to code interviews audio files

Criteria of analysis	Code/ Colour	Examples of indicators
Background	Background (dark grey)	---
Overall strategy	Strategy (grey)	Top down, bottom up, initiatives, stand-alone course, elective course, programmes...
Role of Actors	Actors (red)	Students, academic staff, management...
Triggers and drivers	Drivers (light grey)	External drivers, internal drivers, accreditation...
Main pedagogical approaches	Pedagogical approaches (blue)	Lectures, field trips, project organised learning, PBL, community based learning...
Challenges	Challenges (orange)	Resistance, overcrowded curriculum, funding, support...
Overcome challenges	Overcome Challenges (yellow)	Persistence, seek alternatives...
Future perspectives for ESD	Future perspectives (green)	---

The software NVivo allows coding the full audio file and clustering timespans by theme and codes. This process enables the researcher to transcribe the time spans and use selected material to support the main findings presented in the following subchapters.

From the analysis of the interviews, three clustering groups emerged which allowed to organise the main results. They are:

- 1 **Elements for integration** (related with strategies to integrate EESD, and elements to take into consideration when elaborating them);
- 2 **Challenges** (related with different barriers and challenges each element of ESD integration meet);

- 3 Future needs and perspectives** (related with, for example, actions and initiatives carried out to integrate EESD needed for future)

5.2 Elements for integration

One of the research goals is to outline strategies to integrate education for sustainable development (ESD) in engineering education. After analysing the interview audio files and interview summaries, the strategies enclosed mainly five elements to be taken into consideration: structure, EESD content, learning, actors and resources/facilities (figure 5-3). These elements for integration are highlighted by almost all interviewees.

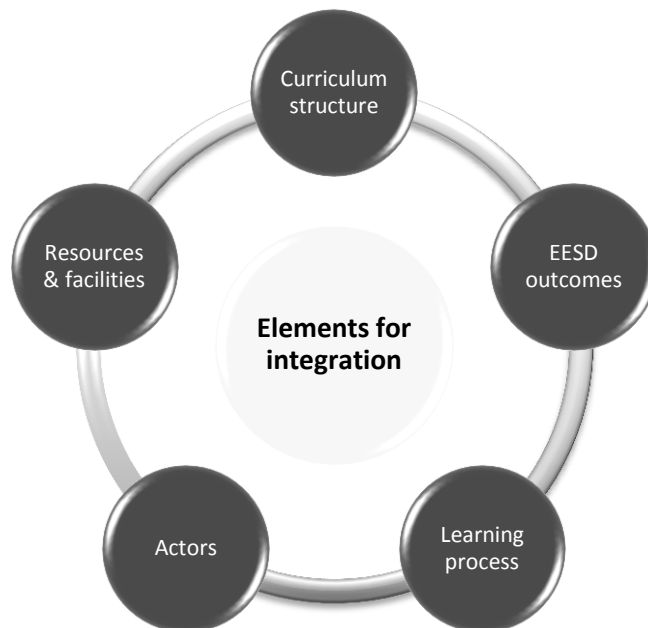


Figure 5-3 Elements for integration of ESD as emphasised by experts

The elements for integration are elements part of the structure of educational systems and are elements to take into consideration when designing and implementing strategies for EESD.

I. Curriculum structure

At a curricular level, EESD can be integrated through courses and programmes. However, there are some nuances in how these courses and programmes are developed and presented to students.

The existence of stand-alone courses in sustainability for engineering programmes is a frequent strategy for integrating sustainability in engineering education. In all the experts' contexts, establishment of a course in sustainability for engineering students has been a part of the ESD strategy. These can be mandatory courses as, for example, Dr Francisco Lozano mentioned, in ITEMS, Monterrey, México, three mandatory courses were designed for the whole university and *campi*.

Another possibility is elective courses in sustainability (i.e. students may, or may not choose these courses as part of their educational profile). These elective courses constitute some of the examples and are delivered mainly at an undergraduate level (see for example Dr Roger Hadgraft, RMIT - Australia, and Dr Richard Fenner, University of Cambridge - UK).

Elective and mandatory courses tend to be stand-alone courses leaving to students the relation between sustainable development and engineering field. These examples frequently constitute the "add-on" strategies of ESD in the curriculum.

According to Dr Rodrigo Lozano, adding on courses in sustainability to the curriculum is not enough to educate engineers for sustainable development. It is also needed to be related and integrated with discipline content of other courses, and with the overall programme. This position is shared with other experts claiming the need to pin point sustainability themes in different disciplines allowing a more systematic integration through the entire curriculum. Also these SD themes should reflect a balance between the three pillars of sustainability and not disrupt, or substitute the core content of engineering fundamentals, but rather contextualise them. This refers to an integrated strategy of sustainable development in the curriculum, in which sustainability principles and content are contextualised through the engineering specific education. This is shared by the other experts.

Regarding educational programmes, engineering education institutions offer full programmes in engineering with sustainability in their core (University of Cambridge, master programme in engineering for sustainable development; RMIT, bachelor programme in Sustainable Engineering Systems). However, there are other possibilities posed by interviewees Dr Mark Henderson, from Arizona State University, and Dr Karel Mulder, TU Delft.

According to Dr Mark Henderson, Arizona State University is frequent to have elective programmes where students can earn credits beside their formal education pro-

gramme. Examples of these programmes are GlobalResolve™ and EPICS, which have in their vision sustainable development principles and humanitarian engineering.

“GlobalResolve™ works together with a range of partners to develop sustainable technologies and programmes in the areas of energy, clean water and local economic development for rural communities in the developing world” (Arizona State University, 2009)

Several strategies can be designed to integrate ESD in the programmes. It can be done through stand-alone courses, but content related with overall programme and/ or specific engineering field. However, Dr Karel Mulder presents an alternative, which is through the master specialisation like it is presented in TU Delft, Netherlands (see for example (TU Delft, 2014).

According to Dr Karel Mulder, in TU Delft, Netherlands, the master programmes provide students with the possibility to take a specialisation in sustainable development along with their graduation projects. This is carried out in partnership with the different departments and courses. For this elective specialisation, students are faced with three main demands: the graduation project to be focused on a SD (related problem), colloquium (workboat with 5 ECTS) and 10 ECTS of SD elective courses (being at least 3 ECTS technical and 3 ECTS non-technical). This presents another possibility to integrate sustainable development in engineering master programmes beside the existence of stand-alone courses.

As pointed out above, the integration of sustainability in engineering education at a curricular level can be done through different ways and with different levels of commitment, and the chosen path also depends on what curriculum organisations, models and regulations allow. In all cases, courses seem to play a role, but at the same time the alignment and the interrelation with core subjects of the discipline has to be in place – a course in itself is important in an EESD strategy, but it is not sufficient.

II. EESD outcomes

As some prejudices pointed out, integration of education for sustainable development (ESD) in engineering does not imply the removal of engineering fundamentals and core disciplines. Rather the disciplinary domain is seen as a platform for integration of sustainable development aspects whenever it is relevant in the curriculum. As pointed at by among others, Dr Karel Mulder, Dr Francisco Lozano, Dr Rodrigo Lozano, Dr Roger Hadgraft, and Dr Richard Fenner it is necessary that the students develop a deep technical knowledge that is integrated within the sustainable development education.

Beside the EESD content and its relation with specific engineering fields, different kinds of skills are also highlighted by the experts. One skill is related with traditional, reductionist and a Newtonian approach to solve problems as part of engineering tradition. In broad terms, these approaches imply the ability to break complex problems into parts and solve them. It is stressed that students should develop system thinking and a holistic approach to solve problems.

Dr Richard Fenner points at the need to think about problems differently and by that essentially try to add to the traditional approach a more holistic and broader view. Dr Roger Hadgraft corroborates this view as he argues:

“We can’t just design a device. Instead we need to meet a need, and to meet a need you probably need to design a system, and a system needs to be used by humans. So you need to understand the human interface as well”.

Dr Roger Hadgraft

Integrating ESD in engineering education does not only bring new themes and content to be aligned with technological knowledge like for example system thinking and contextual learning.

III. Learning process

The learning process is regarding the more suitable pedagogies to integrate EESD. Interviewees pointed out innovative and active learning strategies but also characteristics for the learning environment (figure 5-4).

The figure 5-4 compiles the interviewees’ responses to learning environment and strategies mainly used to educate sustainable development in their institutions.

The learning environment characteristics like contextual, participatory, and transformative for example, are not only related with ESD principles, but also aligned with the learning strategies pointed out.

Taking for example the relation between contextual and transformative learning aligned with solving real world problems brings not only the real context for learning of engineering fundamentals, but also the ESD principles and content through active and student centred approach.

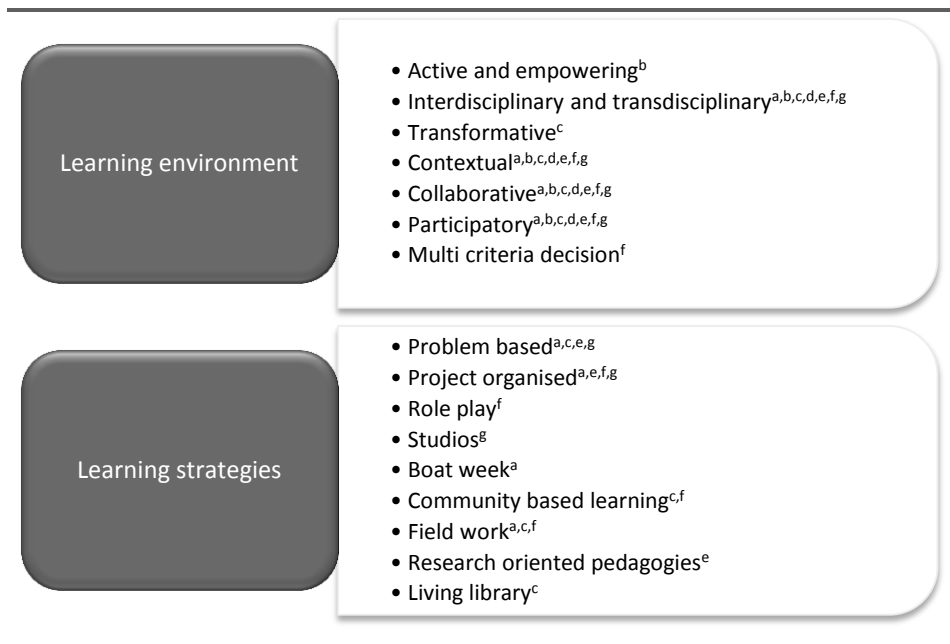


Figure 5-4 Learning environment and learning strategies pointed at by all experts
 (Legend: mentioned by a - Dr Karel Mulder; b - Dr Rodrigo Lozano, c - Dr Yona Sipos, d - Dr Francisco Lozano, e - Dr Mark Henderson, f - Dr Richard Fenner, g - Dr Roger Hadgraft)

Also another point stated by the interviewees is the importance of students' involvement in real and meaningful learning situations, pushing for decision making, embrace change, etc., within campus and/ or outside campus.

The experts' responses points to innovative and creative learning. Dr Yona Sipos from the University of British Columbia, Canada, gives the concepts of living libraries as a learning strategy in an academic staff development programme for participants to acquire skills and knowledge about pedagogies to teach ESD in their courses, or programmes. The main goal of this strategy is to enable participants to make use of the already existent resources regarding ESD at the University.

We use what we call living libraries. Actually we got experts in the university who had expertise in different pedagogical strategies, and it's not like the participants could "take them out of the library", but actually have a conversation with them about something.

Dr Yona Sipos

The most interesting is this living library when it comes to using a part of the learning approach to integrate ESD in engineering. This approach makes the bridge between generations of academics and learners, practitioners to address society needs.

Notice also that learning strategies, like community based learning, claim for a more open, and “out of the university walls” education. The education process and institution acquire more system thinking as well as in its actions by allowing students using community and social problems as scenarios for learning.

IV. Actors

Frequently, the strategies developed to foster any kind of change in an organisation, are classified as top down and bottom up strategies. In these strategies, the central point is from whom, and where, the initiatives to foster change have their point of departure. In top down strategies, the point of departure is to integrate ESD by management incentives. Bottom up strategies are instead driven by academic staff (as lecturers) or students. Nevertheless, there is need of a kind of alignment between both for change to take place (Sterling, 2004).

In some of the educational contexts presented here, the point of departure to integrate ESD in engineering education is from the top management - the dean or president from the institution (e.g. TU Delft, ITEMS, ASU), while others are more driven by external founding opportunities (e.g. University of Cambridge through the Royal Academy of Engineering and Cambridge MIT institute), or by involving the middle management in the initiatives (e.g. University of British Columbia through the head of departments). For others, it started by bottom up initiatives like at Arizona State University (ASU), where it was established an elective project, named Global Resolve, based on a vision of three people from the academic staff, being later on supported by the president. These initiatives implied finding financial support and funds to start up the project.

Nevertheless, in the mentioned examples the support from the bottom is strong, including involvement from lecturers and student bodies supporting the integration. For example, in TU Delft the committee established to develop a strategy to integrate ESD in engineering education included student representatives and lecturers from different areas.

According to Dr Rodrigo Lozano, the actors should assume their roles in education for sustainable development. The actors are: students, lecturers, management, alumni, and other external partners.

Figure 5-5 illustrates the main roles pointed at by interviewees that can be assumed by different actors to foster the integration of EESD.

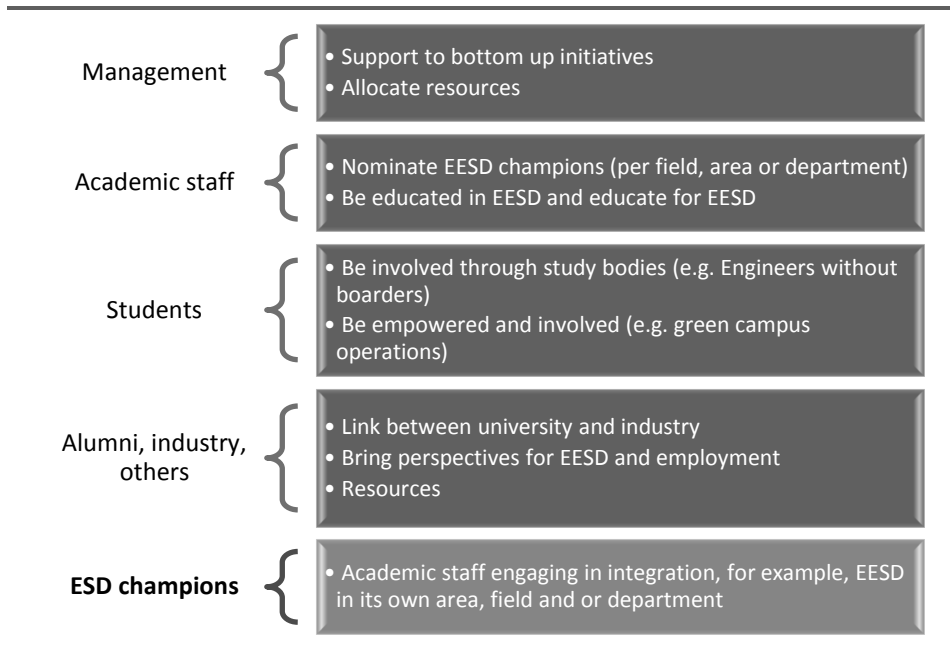


Figure 5-5 Examples of activities and initiatives different actors can be involved in

One of the strategies developed to integrate EESD is to reach as many as possible like all engineering departments and fields, but normally the point of departure is centralised and confined to a number of people.

Further attention is called for a “special” role, the nomination of ESD champions. Normally, EESD champions are representatives from academic staff who have interest in sustainable development in engineering education context. They are mediators to integrate ESD in specific fields of engineering education. The ESD champions are also bridges between different communities – to build more multidisciplinary collaborations.

At University of British Columbia, Canada, one of the strategies used is to ask the head of different departments to nominate lecturers to be involved in a staff development programme on ESD. Also in TU Delft, University of Cambridge and in RMIT, in the different engineering departments and schools, the elective courses in sustainable development are taught by academic staff from the department who are involved in research both sustainable development and discipline field. These academicians are

someone students and remaining academic staff recognise as a peer and member of the academic team.

V. Resources and facilities

The integration of ESD in engineering education also involved allocation of resources to different initiatives. To most of the experts interviewed, the first and most needed resource to start up the process of integration is the financial resource. Other resources also come into play, depending on the financial resources such as studies and tools for curriculum analysis, greening campus operations, rewarding systems for those who integrate ESD, staff development and teaching resources for ESD (figure 5-6).

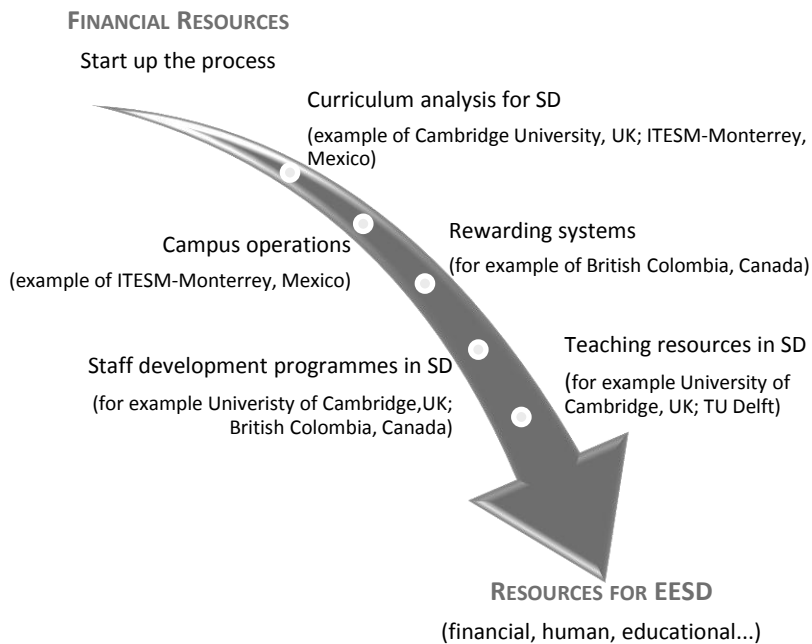


Figure 5-6 Examples of different resources for integration of EESD

The resources can be grouped in financial resources, human resources, and educational resources. However, different scenarios and levels within education systems make different use of these resources.

For example, University of Cambridge receive financial resources from external funding such as Royal Institute of Engineering and MIT Cambridge Institute to allocate in different levels and initiatives. Examples of these initiatives are the study and analysis of the curriculum and the opportunities to integrate ESD in the different engineering programmes; develop teaching materials to support lecturers in their teaching towards ESD; set up an elective course for bachelor levels of engineering education, and set up full M.Phil. in engineering for sustainable development.

Another example is brought by Dr Francisco Lozano with resources allocated to develop initiatives targeting greening campus operations. While at University of British Columbia, Canada, some resources are allocated to establish staff development programmes as a mean to potentiate the already existent human capital for ESD.

The different resources support different initiatives at different levels (e.g. teaching, management) within educational organisations with different needs and potentialities to integrate systematically ESD in engineering education.

5.3 Challenges and future perspectives

Attached to any change, there are challenges and barriers posed. Here is presented the challenges and suggestions to overcome the challenges and barriers to integrate sustainable development in engineering education. But there are also future perspectives for improving EESD.

5.3.1 Challenges

The challenges pointed at by the interviewees to integrate ESD in engineering education is mainly related with culture and context, resistance to change, sustainable development conceptualisation, and lack of collaboration among academic staff (figure 5-7).



Figure 5-7 Main challenges emphasise by the experts

I. Culture and context

Having this in mind, strategies to integrate sustainability in engineering education need to enclose knowledge and understanding of the culture of the institution, and the specific field of engineering, and from there you can tailor ESD initiatives and actions capable to start up the process and make it produce roots and fruits. In general, universities are very reluctant to change.

Different types of universities posed different challenges to changes starting bottom up, or top-down. According to Dr Rodrigo Lozano, private universities work very much like a corporation, being top down initiative much more easily to foster change in the institution that bottom up. Also, newer and smaller universities seem to be able to accommodate and change faster than old and established universities. In this sense, different contextual factors, including the culture of the organisation, posed different barriers to foster change and the possibilities to overcome these depend on the type of barrier as well:

Ideally I want everybody involved [ref. to change and integrate ESD]. Of course, that doesn't happen and we go back to the context. In some countries, and in some particular universities, like for example private universities, top level can decide what to do because that's the way it is. It works more and less like a company. In other universities, a public or

state university, the study body has a lot of power. So if the students start to ask for that, then the university is going to change. Universities tend to be very reluctant to change in many ways, specially old and established universities. Newer ones, smaller ones tend to change quicker. So what is... top-down, bottom-up, once more it depends on the context. If you start bottom-up, the incorporation can be slower and be blocked by the top management, but the institutionalisation would be easier [ref. integration of ESD] because many people are involved and empower.

Dr Rodrigo Lozano

The following types of challenges, and suggestions to overcome them, emerge from interview analysis and are, more or less, common to all experts' contexts. However, each context has its own specific challenges towards change because each context also has its own culture, therefore it is needed to be aware of these in order to foster the integration of ESD.

Another type of culture which, according to Dr Rodrigo Lozano, constitutes one major challenge to integration of ESD is the culture and teaching paradigm. This opinion is also shared by Dr Richard Fenner, Dr Karel Mulder, and Dr Roger Hadgraft.

This major challenge is related with the dominant teaching paradigm in higher education. Called the Newtonian-Cartesian approach, it is related with the reductionist view of knowledge domains and its compartmentalisation from each other. This is the opposite of a more holistic and transdisciplinary view towards knowledge and teaching.

I would say there is a major challenge and then a bunch of other ones. One is what you call Newtonian-Cartesian approaches, which is the way we have been teaching for the last 150 years of absolute reductionism... I am a chemical engineer, have a master in chemical engineering, have a PhD in chemical engineering, and the only thing I know is chemical engineering, I don't know anything else about life, for example. And that's the major challenge, break that old teaching paradigm and move to a more holistic and transdisciplinary one, where, yes you will have engineers but they will understand the interconnections of different issues of sustainability of engineering, and the disciplines. [...] Some people say it is difficult to change individuals, sometimes it is about the culture of organisation, culture of a particular group.

Dr Rodrigo Lozano

This approach also extended itself to the way engineers are being educated and their perception towards solving problems for example. In this approach, complex problems are broken into simple, and small, problems to be solved. In this process, contextual variables and needs are removed from the “equation” leading to simplistic solution, which not always may meet the need and integrate the big picture.

Dr Richard Fenner points at the need for a transformation of discipline culture in relation to solving the problem, a kind of paradigm shift in more focus would be given to context in which the problem is embedded, formulate a problem which meets a need, what kind of need and its implications, as it is supported by the above quote.

This paradigm shift in the discipline, and how it drives engineering education, implies a reflection from engineering education institutions, and educators, in which type of engineers they aim, and should, educate in order to meet the grand challenges of the future such as sustainable development.

II. Resistance to change

Most of the experts interviewed for this study furthermore argued that one of the challenges is the academic staff resistance to change, especially when integrating more social oriented subjects in engineering programmes.

Resistance to change is related, partly, with sustainability perceptions and prejudices brought by students and educators.

According to Dr Karel Mulder, both students and academic staff have shown resistance to change towards EESD. Some students show resistance and criticism to such approaches because they perceive it as “not being real engineering” and “lack link with real life engineering profession”.

Another example of prejudice towards ESD is given by Dr Richard Fenner, in which sustainability is defined “as being trendy”, which will fade away with time. However Dr Richard Fenner argues that it is needed time to the initiatives settle and produce fruits. Dr Richard Fenner and his collaborators started the master programme 11 years ago and continue to recruit around 35 to 50 students per year. Also the number of research projects increased.

Prejudices towards sustainability from engineering educators are related with tension between the concepts of engineering (e.g. objective, quantitative, rooted in mathematics and physics) and their perceptions of what sustainability is (e.g. social science and fluffy).

Another factor of resistance to the integration of ESD is the overcrowded curriculum, where there is a lack of space and time to add or integrate something more to what already exists.

Also Dr Richard Fenner points in fact to the challenge of lack of time and space for more sustainability at the undergraduate level, where the fundamentals are a priority, but at the same time, he stresses that it is important that students should develop awareness and knowledge about engineering for sustainability.

On the other hand, Dr Roger Hadgraft points out that he is “not a believer in the overcrowded curriculum anymore”. He also stresses the importance of fundamentals of engineering in the first years on the undergraduate level, but there are also other topics and options that can be explored, with aim to develop other fundamental skills for future practice such as lifelong learning and system thinking. These examples of skills would enable young engineers to continue acquiring knowledge throughout their lives as valuable in a society of information.

According to, for example, Dr Francisco Lozano, Dr Yona Sipos, and Dr Karel Mulder, top management support, and/ or rewarding, is fundamental for support bottom up initiatives and reduces others’ resistance to change by enrolling and acknowledging those involved in EESD initiatives. Dr Karel Mulder also stresses the importance to give ownership to staff and never substitute or give away the core discipline for sustainability.

III. Sustainability concepts

One of the challenges proposed by Dr Mark Henderson is related with engineering educators’ lack of practical knowledge of how to integrate, what to integrate and when. Almost all experts pointed to the need of providing educational resources for teaching sustainability in their own discipline, and the relevance to educate the educators and nominate EESD champions in their own department and area (pointed at by Dr Francisco Lozano, Dr Rodrigo Lozano, Dr Richard Fenner, Dr Karel Mulder, and Dr Yona Sipos).

Another one pointed at by Dr Karel Mulder is due to misunderstanding from both worlds (for example, engineers and social scientists). This is related with different communities of practice, their worldview and concepts regarding sustainability, therefore, it poses some challenges to engineers’ educators to develop a sustainability framework as part of their field of expertise and research, and which they have to teach. Dr Mark Henderson emphasise that the absence of a common understanding and concepts concerning an object (in this case sustainability) in students from differ-

ent areas of study (e.g. engineering and sociology) constitute a barrier for, for example, group work.

According to Dr Rodrigo Lozano, environmental sustainability and technocratic view are main definition of sustainability when it comes to engineering education, neglecting other contexts such as economic and social.

V. Collaboration

Collaboration is a challenge for both engineering education and students. Dr Mark Henderson gives the example of Arizona State University (ASU) where multidisciplinary groups of students work together in master programmes and/ or elective programmes. Students come from different departments and areas of study, and for example, they work with concept building in order to develop a common understanding of sustainability concepts. Regarding academic staff, Dr Mark Henderson argues that conditions for collaboration among academic staff have to be created. He brings the example of the nomination, in each department, of a senior sustainability scientist who can make the link between the different departments and the school of sustainability (where he has an office). This kind of collaboration is also inspiring for students in his perspective.

Academic staff collaboration is also a challenge at other levels, like for example, in the type of pedagogies and strategies developed which may bring different experts from different fields to work in close collaboration with students. According to Dr Roger Hadgraft, it is a challenge to bring together different experts from different areas and communities of practice (even within inside engineering).

Indirectly, the lack of collaboration and communication of academic staff from different schools and departments can lead to sustainability courses delivered at faculty level taking different approaches at each school, department, and/ or programme. Looking into the integration of ESD at institutional level, this promotes fragmentation of practices, definitions and frames, going also against principles such as interdisciplinary and collaborative learning. These are examples given by Dr Karel Mulder, and Dr Roger Hadgraft in relation to TU Delft and RMIT.

5.3.2 Future perspectives

In the interviews, it was asked the experts to give their opinion on what is needed to be done to integrate ESD in engineering education in the future?

Experts point at needs and future perspectives related with learning models, allocation of more resources, foster change, fight for sustainability literacy in low levels of educa-

tion, and reflect towards EESD meaning in practice (focus on word sustainability or practice its principles for example) (figure 5-8).

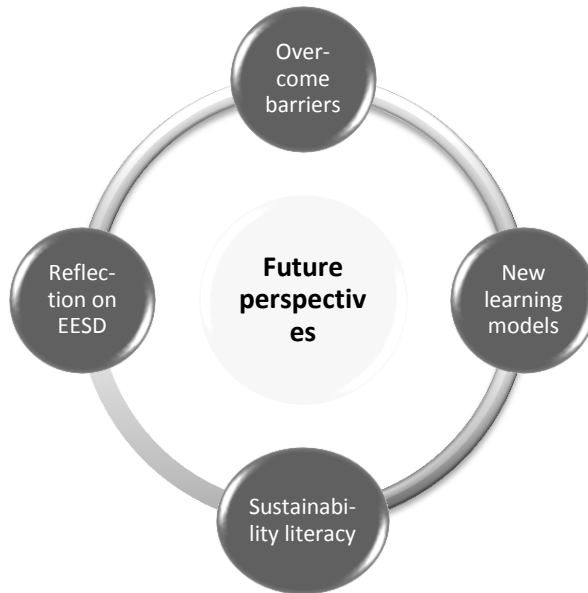


Figure 5-8 Main aspects emphasised as future perspectives and needs for EESD

I. Overcome barriers

The allocation of resources is a need for the future of EESD, but it is not only in respect of financial resources, but also educational and human resources. Also encourage change is sometimes linked with top management support like for example development of rewarding systems for integration of EESD in programmes and campus operations. Such encouragement should not only target staff, but also students.

Allocation of resources and support change are means to overcome some of the barriers and challenges posed above like for example, resistance to change, lack of sustainability concepts and empower employees and educators carrying out bottom up initiatives to integrate ESD.

The following suggestions are also linked with ways to overcome barriers, but highlight new ideas to innovative teaching and learning for EESD.

II. New learning models

New learning models to educate both educators and students for EESD are needed. Dr Yona Sipos, from University of British Columbia, Canada, argues for a combination of new and old learning approaches to create innovative environments for ESD.

For staff development, for example, there is a need of more academic staff courses and resources for teaching EESD. Also the academic staff development courses should be based on participatory, experiential and active learning principles, in which lecturers experience a learning process that they can reproduce with their students in their lectures.

Dr Mark Henderson and Dr Yona Sipos propose more PBL in ESD, but also point to the need of developing and improving PBL models for EESD.

On the other hand, Dr Roger Hadgraft brings forward the idea of creating studios as an innovative learning strategy, as an alternative to an overcrowded curriculum. The idea of the creation of studios relies on how the curriculum is organised. In each studio would have an overall theme, and students would come together with different experts to explore other possibilities. For example, one studio in which a group of students are able to work on something that is totally technical and along with a top class expert, while in another studio, there is a possibility to broaden up and study the impact of a certain technology in society. For example, in the first two years a lot of attention and time is put to develop engineering fundamentals skills and knowledge, and the following years, through these studios, students are able to develop other kinds of skills and competencies. Underlying these studios are real world life situations, and students can stretch their minds in several directions: more technical and/ or more social. In this way, the university can educate students with a starting point to shape their world view and build their profile. And after, wherever they go, they can develop themselves further. Aligned with these is also the need of more interdisciplinarity and transdisciplinary skills pointed at by Dr Karel Mulder.

III. Sustainability literacy

This theme relates to the presence and education for sustainable development at all levels of education - from elementary education to higher education levels. Dr Francisco Lozano points out that students arrive to university with different levels of sustainability literacy, and some people don't even reach higher education:

Further education... much more! We are finishing the United Nations Decade of Education for Sustainable Development and we need to go further, not just higher education. Because we are just a tiny crust in this

planet, we are not a plague, we are very few. So we need to go to primary and secondary education, because not all people reach higher education. [...] That's where we need to go, further down in education. And then higher education institutions will receive persons literate in sustainability and you don't have to waste time in that, you just start with that raw material and that you can go at higher level, or wider level.

Dr Francisco Lozano

There is no link, or continuous progression between ESD from low levels of education and higher education. Dr Francisco Lozano refers also as we are arriving at the end of the United Nation Decade of Education Sustainable Development (DESD), and it is important to reflect on what is the scope of sustainability literacy in all levels of education.

IV. Reflection on EESD

According to Dr Richard Fenner, some reflection is needed regarding the antagonism towards sustainable development from the engineering education communities. This is related with prejudices towards sustainability and ESD as being “trendy” and “fluffy” which constitutes a barrier to a transformation and integration of ESD in engineering education.

The question raised by Dr Richard Fenner is if the learning vision should be the use of word and fix definitions of sustainability to integrate ESD, or rather base the change towards ESD in the practice in its principles. It is something that is worth reflecting upon when it comes to strategies to foster change in higher education, because the focus would not be the name, but the principles, and its appropriation according with context, field and possibilities for ESD. One example given is a civil engineering programme from an UK University, which the change of programmes name for Earth Systems Engineering emphasise earth systems thinking in relation with civil and structural engineering practice.

When it comes to future perspectives, there is a unanimous need for continuing work to integrate education for sustainable development. According to Dr Francisco Lozano and Dr Rodrigo Lozano, the integration of sustainability in engineering education should be easy and quick due to what engineers are: pragmatic and problem solvers. However, there are several challenges and future work to be carried out.

Final remarks

The experts' perspectives provide an overview of elements, challenges and future needs to integrate ESD in engineering education.

The strategies for integration of ESD in engineering education are built at different levels, involving different actors, structures and frameworks, but they also face different challenges and barriers. Taken from experts' experiences and examples, integration of sustainable development in engineering education is not a simple and straight forward approach; it needs resources, academic staff commitment and creativity.

The strategies seem to work better with top management support, through allocation of resources and recognition systems, but also by engaging key and commitment people from bottom (e.g. student bodies, students' involvement in greening campus operations, and lecturers and nomination of EESD champions).

It seems that the ESD principles claimed to be present in learning environments also should be part of community of educators such as for example collaboration across departments, schools and programmes, interdisciplinarity, system thinking and holistic view towards a discipline and education programme. Otherwise, if these principles are not practice and driven factors of engineering educators they seem to be linked with several challenges and barriers such as collaboration, and resistance to change.

Another relevant point that is raised is the culture of the discipline, like for example the approach to solve problems. Problem solvers are also a corner stone of engineers' identity. In this sense, there may be needed a paradigm shift for engineering education and its view of the profession towards a more system thinking approach. This connects also with the example provided by Dr Roger Hadgraft and the creation of the bachelor programme of Sustainable Engineering Systems at RMIT, Australia, and the future perspective purpose by Dr Richard Fenner whether should we think in EESD in terms of concepts or practice principles?

Change in engineering education systems towards EESD presents itself as a multi-element system, with interconnection, where the success draws upon the synergies between the different actors (e.g. students, academic staff, management); frameworks (e.g. curriculum development and construction); structures (e.g. facilities and other resources). Educational institutions should start to see themselves, and behave, as open and complex systems, integrated in larger open systems (e.g. local community, state, and country, world), to serve, but also with reflections on its responsibility, place and impacts in its inclusive systems.

To finalise this chapter, the seven experts interviewed brought perspectives towards a better world by putting engineer students in the centre, and as future agents, breaking with traditions and close boundaries of the university.

According to some of the experts interviewed, Problem Based Learning (PBL) can support the integration of ESD in engineering education. For example, PBL can be used as pedagogical strategy, providing support to develop the learning outcomes for EESD. Furthermore, the use of real problems, solved through projects, contextualise both engineering subject and sustainable development content. Similarly with integration of ESD, also change towards PBL includes elements beyond the curricula structure and content. Examples of elements are allocation of resources and programmes for staff development (Kolmos, de Graaff, & Du, 2009).

The following chapters address the investigation in which ways PBL can support the integration of ESD in engineering education from the practice perspective.

6 Introduction to the Aalborg Case

In this study, the purpose is to understand the implications of integrating ESD in a PBL curriculum and, from there, conceptualise the synergies and tensions between EE, PBL and ESD. For this purpose, the case-study methodology is suitable to carry out the study. Corcoran *et. al.* (Corcoran, Walker, & Wals, 2004) argues that a case study is a suitable research tool to investigate integration of sustainability in higher education because it allows not only for description and explanation of the synergies of a certain context, but also problematizes the practice and points out potential towards changes.

According to several authors (Ragin & Becker, 1992; Bassey, 1999; Flyvbjerg, 2001; Scholz & Tietje, 2002; Cohen, Manion, & Morrison, 2007; Creswell 2009, Yin 2009), a case study is considered to:

- Have a unique character
- Result from a multiplicity of interactive factors
- Have empirical value
- Involve real life phenomena
- Study of practice
- Be a method of learning through description and contextual analysis

Through a case study, the investigator develops a deep understanding of what works and what does not work in a certain context, situation or activity, grounded in proper research (Flyvbjerg, 2001; Merriam, 2001; Corcoran, Walker, & Wals, 2004).

This chapter presents the case selection and introduces the case with emphasises on the aspects which make this a unique context to study, i.e. the presence of the PBL learning approach, presence of sustainability in different levels of institution, and in teaching practices.

6.1 Case selection

In this study, the case selection has been supported by both literature and empirical work. The case selection aims to identify potential engineering education institutions which combine PBL and ESD.

The strategy used to identify engineering education institutions includes three phases: institutional screening, institution analysis and outcome, as it is illustrated in figure 6-1. The strategy is based on content analysis of institutions' visions and missions, engineering programmes and courses.

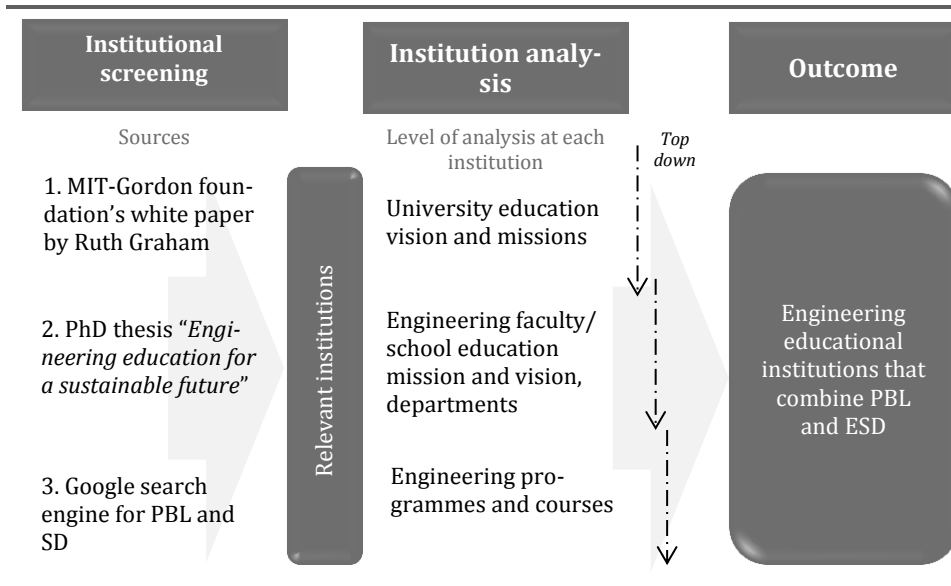


Figure 6-1 Strategy for case selection

Strategy developed for case selection resulted in a conference paper, which extended abstract is in appendix 4 (p. 25).

The institutional screening

The institutional screening started with listing relevant institutions using three sources: white paper, PhD thesis and Google search engine.

The criteria used for content analysis were: Engineering Education (EE), Problem Based Learning (PBL), and Education for Sustainable Development (ESD). For each of these criteria, a set of possible related key words were pointed out as sub criteria. Examples of sub criteria are problem solving, sustainable development, etc. (table 6-1).

Table 6-1 Criteria and sub criteria used for documentary analysis process for case selection

Criteria	Sub criteria
Engineering education (EE)	Technical programmes Technical universities
Problem Based Learning (PBL)	Project based learning Problem solving Problem oriented
Education for sustainable development (ESD)	Sustainable development Sustainability Environmental

It is relevant to explain the use of sustainable development (SD) aspects along this subchapter instead of ESD. As explained in chapter 4 (p. 69), more so than content, ESD is also learning principles. Therefore, content analysis gives an indication of some forms of education towards sustainable development in the engineering programmes, but it does not provide a full understand of principles that also make part of education. This constitutes one of the biggest limitations of this approach, but the aim is to select a case, or cases, for deep study in an informed way of the possible practices and practitioners within PBL and ESD exist in institutions. It also gives insights into trends and main strategies regarding ESD and PBL in engineering education institutions and programmes.

Two literature references are used as point of departure to pinpoint technical institutions practicing within both areas. The literature selected is a white paper focusing on engineering education and problem based learning (Graham, 2010) and a PhD thesis in engineering education for sustainable development (Segalàs, 2009). I acknowledge that other sources could be used with the same potential, and might point out other institutions. To cope with this uncertainty, the Google search engine is used to add additional references.

Table 6-2 shows the references together with a short description of the references and the number of engineering education institutions noted as potential cases. In total, 65 engineering education institutions are highlighted.

Table 6-2 First moment of methodology for selection of cases and number of potential cases per source

Reference	Description	Number institutions as potential cases
MIT-Gordon Foundation white paper, by Ruth Graham (Graham, 2010)	The white paper from MIT-Gordon Foundation, written by Ruth Graham, aimed to “provide insight into the context for Problem Based, Project organised Learning (PjBL) in UK engineering education as well as to identify a number of highly-regarded best practice approaches” (p.1). All the institutions referred in the paper were listed for further analysis.	29
PhD thesis “Engineering education for a sustainable future”, by Jordi Segalàs (Segalàs, 2009)	In the research carried out, “the experts opinion on the most suitable learning approach and pedagogical methodologies to teach/learn SD in engineering universities” (Segalàs, 2009, p. 247) was accessed. A total of 45 experts in sustainable development, from 17 European institutions were interviewed, and 34 pointed PBL as a suitable methodology to teach/learn Sustainable Development in engineering. All the 17 institutions were listed and analysed.	17
Google search for PBL and ESD	Search carried out on 10th to 15th of June, 2011, with a number of hints between 69.800.000 and 83.800.000. The key words for search were: problem based learning, project based learning, sustainable development and sustainability. The number of hints is not the total number of pages selected; only the first 200 pages referring to higher education systems were considered. Even though they all claimed to have PBL in their curriculum, most of them were in medical, nurse or psychology education. Regarding engineering education, only 19 were selected for a deeper content analysis of their homepages.	19

Institutions’ analysis

For each of the institutions pointed out in the screening, a content analysis of their homepage is carried out, using the same criteria as for the institutional screening. For each institution, the analysis starts with the institution’s vision and mission statements of university, faculty, schools and departments, followed by the analysis of the technical programmes and courses. The aim is to find quotes that support the presence of PBL and SD in engineering education. The relevant quotations regarding PBL and SD in engineering education are registered. Table 6-3 presents a summary of the institutions with visible reference to PBL and SD on the webpages analysed.

Table 6-3 Institutions that combine explicit PBL and ESD, per reference used in the study

Reference	MIT-Gordon Foundation white paper	PhD thesis "Engineering education for a Sustainable future"	Google search for PBL and SD
Institutions	<ul style="list-style-type: none"> • Queen Mary, University of London, UK • <u>University of Bristol, UK</u> • Loughborough University, UK • Nottingham Trent University • <u>Aalborg University, Denmark</u> 	<ul style="list-style-type: none"> • <u>TU Delft, Netherlands</u> • Herriot-Watt University, Scotland • Technical University of Catalonia, Spain • <u>University of Bristol, UK</u> 	<ul style="list-style-type: none"> • McMaster University, Canada • Maastricht University, Netherlands • Virginia Tech, US • Stanford University, US • Victoria University, Australia • Republic Polytechnic, Singapore • <u>TU Delft, Netherlands</u> • Brown Universities, US • Tamasek Polytechnic, Singapore • <u>Aalborg University, Denmark</u>

From all the institutions listed above, three appear in at least two of the references, and for this reason, they are considered relevant for further research. The three institutions are Bristol University, UK; Aalborg University, Denmark and TU Delft, Netherlands (Box 6-1), which each stand out concerning the combination of PBL and SD aspects in engineering education.

Box 6-1 Three institutions that stand out concerning the combination PBL and SD aspects in engineering education in comparison with others

1. Bristol University, UK

The Faculty of engineering stated that: "Our students are encouraged to be innovative and entrepreneurial in their learning and professional development." This institution also has three interdisciplinary programmes. At a programme level, engineering mathematics has "Drop-in problem classes start in week 2 and run until week 24", where students learn how to solve real problems. Project work is common in engineering programmes, but there is no clear and "formal problem based learning at Bristol University". However, at the course level in electrical and electronic engineering PBL was stated as being explicitly used. Regarding sustainability/sustainable development, it is part of the university's educational vision, offering opportunities to "all students to learn about and acquire skills for enterprise as well as to study issues of global importance such as environmental awareness and sustainability." A course called "Sustainability, Technology and Business" is offered and a description can be found online.

2. Aalborg University, Denmark

Aalborg University has a curriculum organised around problems. The PBL approach has been used at Aalborg University since its foundation in 1974, and is central in their education vision and strategy. The Aalborg University PBL approach is known as AAU PBL model. Sustainable Development is central at several programmes at master and bachelor level at the university. For example, the bachelor's programme in Sustainability and Biotechnology; bachelor's and master's programme in Urban, Energy and Environmental Planning, within specialisation in Environmental Management and Sustainability Sciences, Sustainable Energy Planning and Management. Furthermore, a centre for PBL and sustainability has been established as part of the UNESCO chair in PBL in engineering education.

3. TU Delft, Netherlands

At Delft University, master's programmes are "Problem-oriented, creative, innovative, learning by doing. Our objective is to produce graduates who are critical independent thinkers so they later become engineers capable of independently solving problems." Regarding staff development "Project oriented learning is the teaching method of the future: It stimulates students to use important knowledge from their classes and apply it in real life cases. Within a few months your students will change from consumers into self-directing professionals. No more free riders but motivated team workers. After finishing the master, students not only have the proper knowledge and skills, but they are ready to use them as well." Delft University included education for sustainable development as part of their strategy. In this university, several engineering departments have programmes and courses related to sustainable development.

Outcome

It is also important to stress that the institutions in question: (i) have PBL and SD in engineering programmes, or educational vision and mission; (ii) represent different contexts; (iii) and all have the potential to constitute a multiple case design approach or do comparative studies.

The case selected for this study is Aalborg University (AAU). AAU practices PBL at the institutional level which makes part of the institution's educational mission and identity. From an empirical point of view, the investigation of integration of ESD in a PBL environment does not enclose itself in a school or department, but as part of a wider structure of the faculty, e.g. problem oriented and project organised curricula. Most of other institutions have PBL as an approach used at a restricted level, e.g. programme or course.

6.2 Introduction to the Aalborg case

The organisation selected for case study is Aalborg University, Denmark. Aalborg University (AAU) presents the use of PBL at the institutional level, but also encloses initiatives for integration of sustainable development in its activities (learning, teaching, research and campus operation as it is presented in the following).

6.2.1 Organisation

I start by presenting Aalborg University's organisation, focusing mainly on the Faculty of Engineering and Science due to study goals.

Aalborg University is organised in four faculties. Each of the faculties are organised in schools, departments and research units (figure 6-2). The Faculty of Engineering and Science have their schools and study boards managing the different educational programmes (bachelor's, diploma and master's degrees).

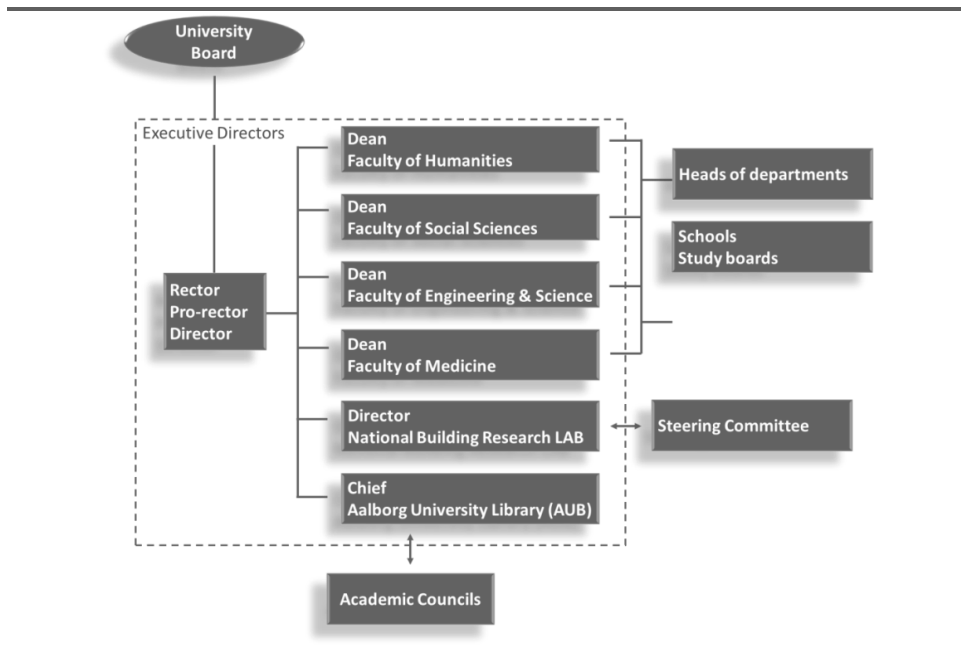


Figure 6-2 Organisational chart of Aalborg University (retrieved from Aalborg University, 2012)

Faculty of Engineering & Science: Organisation

The Faculty of Engineering and Science includes three schools: School of Architecture, Design and Planning (SADP), School of Engineering and Science (SES), School of Information and Communication Technology (SICT). Each school is organised in study boards responsible for creating and managing educational programmes (figure 6-3).

The School of Architecture, Design and Planning (SADP) and the School of Information and Communication Technology (SICT) enclose three study boards while School of Engineering and Science (SES) encloses six study boards and offers approximately of 63 programmes for bachelor's, diploma and master's degrees (Faculty of Engineering and Science, 2012).

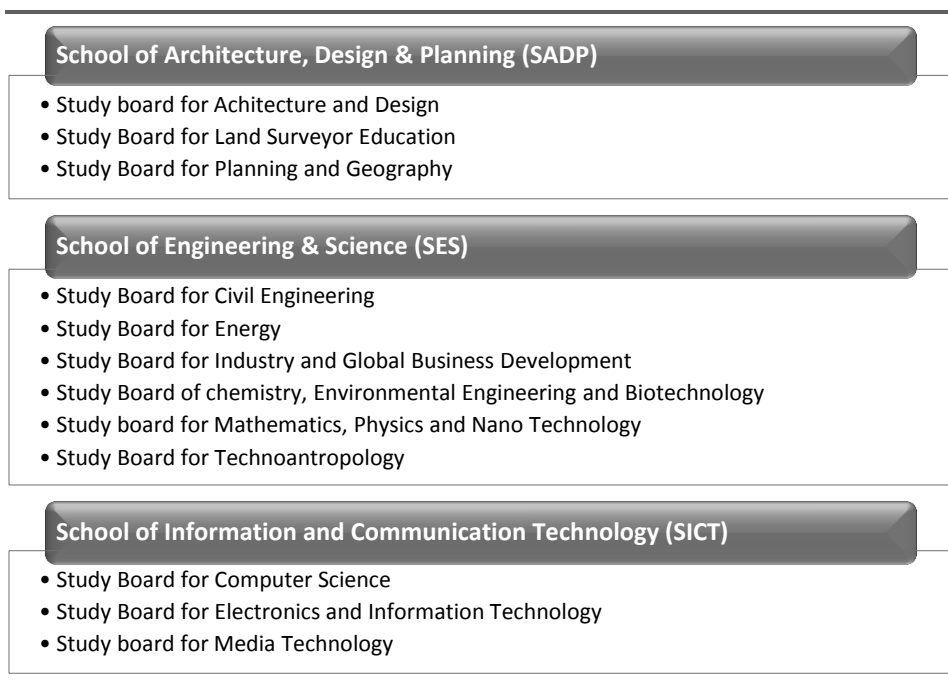


Figure 6-3 Faculty of Engineering & Science, schools and study boards
(Based on Faculty of Engineering and Science, Aalborg University, 2012)

Beside the study boards mentioned in figure 6-3, the faculty also encloses four independent study boards: study board for the admission course (only in Danish), study board for the first year (only in Danish), study board for technology management (only in Danish), study board for education, learning and philosophy (cross-faculty study board)

6.2.2 Aalborg PBL model

In the 1960's and 1970's, a hand full of higher education institutions were implementing a new form of education being student-centred, active and participatory as well as rooted in some democratic and socialist values. AAU is one of these institutions in which the PBL approach remains a core part of education and of its vision, as it is stated in the following quote:

*"[...] is **problem based project work** – also known as the **Aalborg model** and by extensive collaboration with the surrounding society"* (Aalborg University, 2012)

The Aalborg PBL model lies in three corner stones: problem, project and group. These corners stones reflect what drives and contextualises the learning process (real problems), and how the solving process is carried out through projects and in groups (peer learning). At Aalborg University (AAU), all education and programmes have been problem based, and project organised since its foundation in 1974. The Aalborg PBL model not only regards learning and teaching, but also research. This sets the ground for a shared culture in turn of PBL principles that encloses all levels, structures, frames, actors and activities of the organisation (Barge, 2010).

Problem based and project organised curriculum

At Aalborg University, all the educations are problem based and project organised since each programme's day one. Each semester is composed by courses and project modules. Normally, courses deliver the disciplinary knowledge (e.g. theories, principles, models, methods and tools) while the project module encloses the problem solving process. For each semester, a theme or problem field is given, broad within the problems that are contextualised (Barge, 2010; Kolmos, Holgaard, & Dahl, 2013).

The project work is carried out by a group composed by two to seven students, with one or two facilitators assigned (depending on the semester and level of the programme). Normally, the groups are formed by students. The problem solving process is documented in a project report and submitted by the end of the semester for assessment (Kolmos, Holgaard, & Dahl, 2013).

The Aalborg PBL model grounds its practices in principles of constructivism (participatory, self-directed learning and collaborative learning), exemplary and contextual

learning (relation between theory and practice). Nevertheless, the model is challenged by external identities such as ministerial policies, the European qualification framework of the Bologna Process, which led to changes in the curriculum organisation in 2010 (Kolmos, Holgaard, & Dahl, 2013).

Since 2010, each semester encloses 30 ECTS (European Credits Transfer System), 15 ECTS being allocated to project work and 15 ECTS to courses. These 15 ECTS are divided in three courses of 5 ECTS. The courses' contents do not necessarily have to be related to the project module. Figure 6-4 illustrates the curriculum organisation for the Faculty of Engineering and Science since 2010, known as the Aalborg "new" PBL model (Kolmos, Holgaard, & Dahl, 2013).

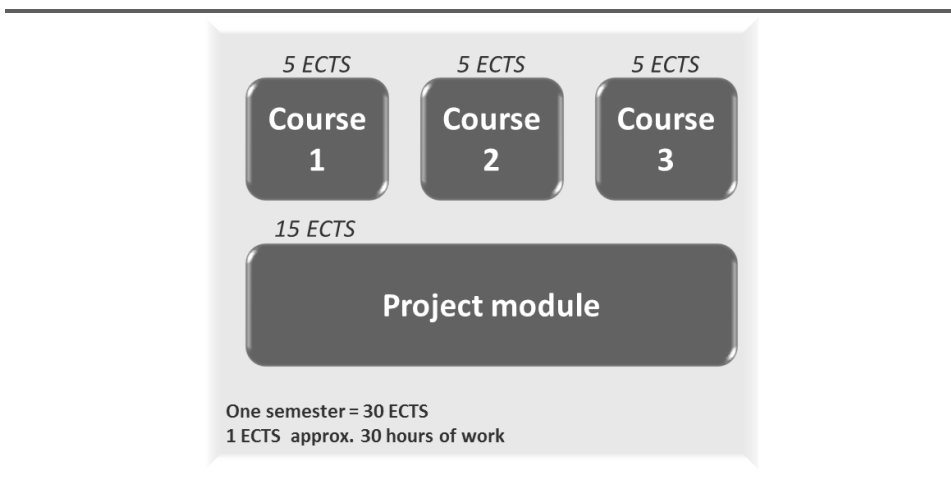


Figure 6-4 Aalborg "new" PBL model
(Adapted from Kolmos, Holgaard, & Dahl, 2013)

The learning outcomes stated in the written curriculum are categorised as knowledge, skills and competencies. This classification is given by the Danish Agency for Science, Technology and Innovation (Ministry of Higher Education and Science, 2013) based in the European qualification framework. The Faculty of Engineering and Science draws a template for written curriculum that is in accordance with the qualification frameworks mentioned and sets a common base for all written curriculum for all programmes (Faculty of Engineering and Science, 2012).

The Aalborg PBL model previous to 2010 and in practice for 20 years had a curriculum organised also in courses and projects units. However, the courses were classified in two types: general courses and project unit courses. The project unit courses were

courses which content delivered with the aim of supporting the project work (and therefore the problem solving process) and their content was assessed via the project. The general courses had content with no direct relation to the project, and their assessment was carried out independently from the project through oral or written examinations. Examples of general courses were physics, mathematics and other engineering science fundamentals. The semester coverage was 75% for project and related courses (distributed as 50% for project work and 25% for project unit courses) and 25% for general courses.

Studies carried out internally at the Faculty of Engineering and Science (Myrdal, Kolmos, & Holgaard, 2011; Kolmos, Holgaard, & Dahl, 2013) point to existent diversities within the university in relation to the PBL model. The focus of this study is in the Faculty of Engineering and Science, and here, some discussions are initiated towards the interpretation of the PBL learning principles and practice within the different schools and study boards. One of the most interesting aspects of this curriculum change and its efforts to continuously address the key learning principles of PBL is how external factors for change lead to internal questions regarding the practice and interpretations of PBL. It also supports that no educational system is a closed system, but rather open and interconnected with a broad society at local and global level.

The selection of the Aalborg PBL model as the case to study the integration of Education for Sustainable Development (ESD) in engineering education also draws attention to how a model may change through time, how it is practiced, and how it can accommodate other elements for change, like integration of EESD.

Notice that the Aalborg PBL model involves the different elements of the organisation structure such as different levels of management, structures (faculty, resources, programme administration, research, etc.), frames (assessment, European and Danish qualification framework, etc.); actors (heads of schools, department, study boards, students, academic staff, etc.) (Barge, 2010; Kolmos, Holgaard, & Dahl, 2013) and which, looking into how PBL can support the integration of ESD in engineering education, may highlight aspects that were not seen before in this field of research.

6.3 Aalborg University's mission for Sustainability

Education for sustainable development (ESD) is part of the strategy, visions and missions of AAU (Aalborg University, 2012). The university aims to develop a more explicit

profile in which world sustainable demands are addressed through a high qualified education

*“AAU wishes to profile itself more explicitly as an institution with a strong portfolio of further and continuing education programmes for highly educated staff and managers in the **business world and in the public sector** in areas with a **sustainable demand.**” (Aalborg University, 2012)*

The above statement does not only involve academic staff, but also the qualification profile of the students being educated at Aalborg University.

One of the strategy goals of Aalborg University for campus development is in relation with environmental management by reducing CO₂ emissions and other improvements, as it is shown in the following statement:

*“Prepare a complete sustainability strategy and a complete sustainable plan for the physical extension of the university in Aalborg, Ballerup and Esbjerg in cooperation with the Danish University Property Agency and the local authorities in Aalborg, Ballerup and Esbjerg, **and take concrete initiatives to implement environmental improvements and CO₂ reductions at the university**” (Aalborg University, 2012)*

The University also has a committee working with initiatives for greening campus operations designated “Green AAU” (Aalborg University, 2013), enclosing three main streams: green knowledge, green mind, green campus, in which is stated the Aalborg University commitment to address the sustainability challenges proactively through greening minds, greening knowledge, greening campus (figure 6-5).

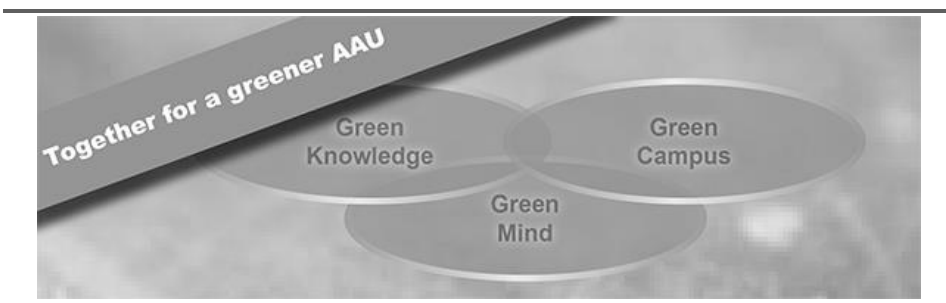


Figure 6-5 Frame for greening Aalborg University
(Retrieved from Aalborg University, 2013)

In the case selected, the existence of the PBL learning approach and integration of sustainability is observed, and it is in all its core activities (education, research and community service) at a University level.

Also, at faculty level, sustainability is part of its mission statements and strategy.

Faculty of Engineering and Science mission

In their education and strategy for 2015, the Faculty of Engineering and Science put strong emphasis on integration of sustainability regarding the grand challenges of society, including technology development as a means to provide welfare as it is stated in the following:

*“Our mission is to develop knowledge and create practical solutions in engineering and science for the **benefit of society.**”*

*“We are a progressive and internationally recognised faculty that produces knowledge and original technical solutions targeted toward **society’s “Grand Challenges”** [...] in close interaction with the surrounding society that sets new standards for basic research and applied **research in global sustainable welfare and technological development**”* (Faculty of Engineering and Science, Aalborg University, 2012, p. 5)

The interface between the technological development and society, including its impacts and improvements for a better world based on research is explicitly stated.

The faculty encloses different programmes within different fields of engineering, and they should to some extent, facilitate this interface between society, technology and sustainable welfare.

In 2012, the Faculty of Engineering and Science started an internal project with the aim of mapping the presence of sustainability in the existent curricula and highlight good practices related to PBL and Sustainability (called PBL-SUS project) (Hansen, Otrrel-Cass, & Dahms, 2013). The study was carried out in two phases:

- Phase 1: aim to map sustainability presence at programme and management level;
- Phase 2: aim to map and report sustainability at course and academic staff level.

The findings from phase 1 show that more than half of the programmes in the faculty do not have sustainability aspects integrated in the written curricula. In the second phase, the project's researchers asked the academic staff to provide examples of integration of sustainability aspects in their courses and programmes. One of the outcomes is a catalogue with 12 good examples of integration of sustainability at programme, course and project level. The catalogue's good examples include drivers, challenges, relation to sustainability, teaching activities and future perspectives pointed out by the participants. The working paper gives an overview of education for the sustainable development status of the Faculty of Engineering and Science and makes recommendations for a better and systematic integration across all schools and programmes (Hansen, Otrell-Cass, & Dahms, 2013).

6.4 Programmes for collection of data

To select programmes for further study, some of the formal curricula were read and some were selected as potential to constitute units of analysis. Here, the selection is not focussed on the presence of PBL, but rather on the presence of SD aspects.

All programmes from the Faculty of Engineering and Science have provided online access to the written curricula. Normally, all bachelors' programmes are written in Danish, with the exception of a few international programmes (written in English). On the contrary, most of the master's programmes are written in English.

The faculty has more than 100 programmes, and as the case study methodology argues for in-depth investigation, two programmes were selected based on the following criteria:

- 1 The programme has to have an explicit focus on SD aspects;
- 2 The program should not have SD as the core competence as the focus is on integration of ESD in engineering educational programmes at large;
- 3 The programme has to be international as the author cannot be fluent in Danish

To select a programme, some curricula written in English, were randomly selected and read through. For the curricula pre-analysis, the SD indicators pointed by Global Reporting Initiatives (GRI, 2011) as criteria were used.

A total of seven curricula representative of the different schools (School of Architecture Design and Planning; School of Engineering and Science; School of Information and Communication Technology) are represented in figure 6-6.

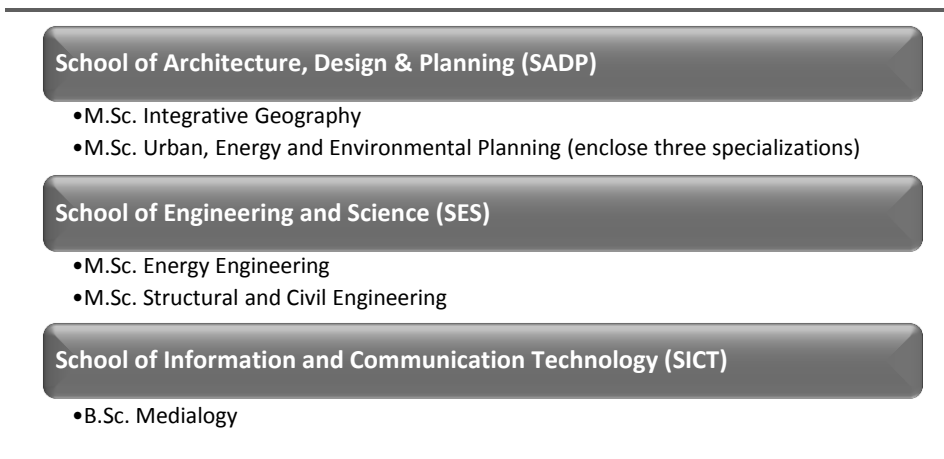


Figure 6-6 Curricula pre-analysed for programme selection for study and respective schools.

The programmes selected are M.Sc. in Urban, Energy and Environmental Planning with specialisation in Urban Planning and Management (referred to also as UPM specialisation) and M.Sc. in Structural and Civil Engineering (referred to also as SCE), both from different schools and study boards (figure 6-7). These two programmes enclose the sources of evidence from which data are collected.

The curricula from these programmes present aspects that can be linked with sustainability, but also represent opposite perspectives towards engineering practice. For example, M.Sc. in Urban, Energy and Environmental Planning with specialisation in Urban Planning and Management encloses a planning and socially oriented perspective towards engineering, while M.Sc. in Structural and Civil Engineering has a more technical perspective. Another example is M.Sc. in Energy Engineering (School of Engineering and Science) and M.Sc. in Urban, Energy and Environmental Planning with specialisation in Sustainable Energy Planning and Sustainable Sciences (School of Architecture, Design and Planning), however; the M.Sc. in Energy Engineering curriculum has no visible indicators than can be used to integrate sustainability in the education.

Aalborg University

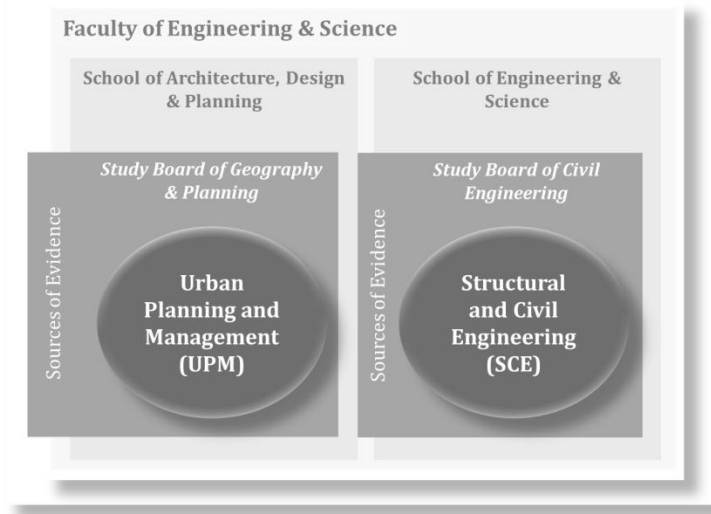


Figure 6-7 Contextualisation of the two cases studies (programmes) and sources of evidence

The following chapter presents the case study research methodology to investigate the selected programmes. Case study methodology includes strategy for data collection and analysis in detailed, and the pilot test.

7 Case Study: Research methodology

Chapter 4 (p. 69) presented the theoretical similarities between PBL and ESD, and a strategy to investigate in which ways PBL can support the integration ESD in engineering education from a practice perspective. The strategy presented in the referred chapter is part of a case study design and suggest methods and sources of evidence. However it does not include detailed procedures for data collection and analysis as well as the schedule of the case study research. A case study research methodology, or case protocol, aims to guide the researcher in the data collection and analysis process in the most transparent and systematic way possible. It provides methodological procedures and guidelines for collecting and handling data, but also to argue for the research quality in terms of validity, generalizability and reliability (Ragin & Becker, 1992; Creswell, 2009; Yin, 2009). This chapter describes the preparation for data collection and analysis as well as the respective instruments and procedures to carry them out.

7.1 Preparing for collection and handling of data

Design and construction instruments for data collection and analysis are part of the preparation for a case study. This chapter starts by presenting the methods, sources of evidence and respective instruments for data collection, moving on to defining the overall criteria of the study (e.g. criteria for data collection and analysis), and testing the instruments constructed through pilot tests.

7.1.1 Instruments for data collection and sources of evidence

The instruments are designed for specific sources of evidence following the rational of case study strategy for data collection. Figure 7-1 presents the methods for data collection and the respective instruments for sources of evidence.

Methods	Instruments	Sources of evidence
<input type="checkbox"/> - Documentary analysis	<input type="checkbox"/> - Content analysis grids	<input type="checkbox"/> - Formal curricula <input type="checkbox"/> - Projects' reports <input type="checkbox"/> - Semester coordination
<input type="checkbox"/> - Interviews	<input type="checkbox"/> - Interview guides <input type="checkbox"/> - Checklists	<input type="checkbox"/> - Study board members <input type="checkbox"/> - Lecturers <input type="checkbox"/> - Facilitators <input type="checkbox"/> - Students
<input type="checkbox"/> - Observations	<input type="checkbox"/> - Observations schedules	<input type="checkbox"/> - Lectures <input type="checkbox"/> - Group work <input type="checkbox"/> - Students' presentations

Figure 7-1 Data collection methods, instruments and sources of evidence

The different sources are interconnected and aim to: (i) reflect the dynamics and complexity of the learning process taking place; (ii) pointing to the challenges and potentialities between the two, but also within the engineering field of each programme (figure 7-2).

The detailed case study strategy for data collection and instruments used are in appendices 5 and 6, respectively.

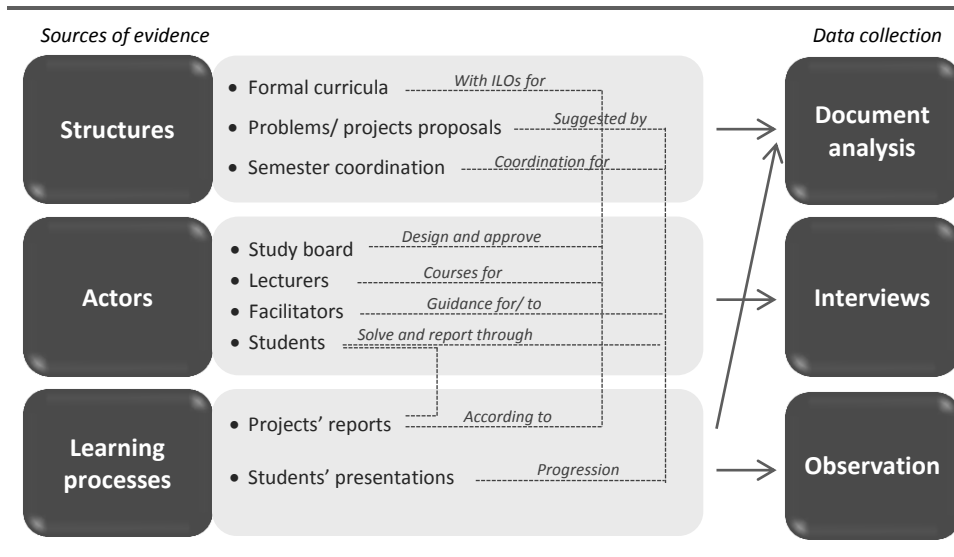


Figure 7-2 Sources of evidence from where data was collected and respective methods and analysis

The different sources of evidence are clustered according to the role they have within the educational system. For example, formal curricula, projects proposals and semester coordination are documents within teaching and learning organised within a given programme. The actors refer to people involved such as students, facilitators, lecturers and study board members. The learning outputs are related to situations and documents in which students express their learning. The interconnection between the different clustering groups is expressed in terms of how one influences and is influenced by others. Figure 7-2 aims to illustrate such interconnections of the different structures, actors and learning outputs in the programmes.

7.1.2 Defining criteria for analysis

The instruments for content analysis aim to collect data regarding PBL variables, ESD principles and SD aspects. These also set the ground for the data analysis procedures. The criteria are generated from comprehensive literature review previously explained in chapter 4 (p. 76).

The criteria are divided in PBL variables, ESD principles and SD aspects. The criteria used for the different PBL variables are presented in table 7-1. For each criteria, indicators are defined which enable identification of PBL variables as they are investigated

through curricula and projects analysis, observations, interviews and checklists. The indicators are in appendix 7 (p. 57).

Table 7-1 PBL variables, criteria and examples of indicators

PBL variables	Criteria	
Knowledge	Factual & conceptual (<i>know what</i>) Procedural (<i>know how</i>)	Metacognitive Personal, evolutionary (<i>know-why</i>)
Disciplinarity	Disciplinary Cross-disciplinary Multidisciplinary	Interdisciplinary Transdisciplinary
Learning	Lifelong learning	Contextual Learning
Process competencies	Problem analysis and formulation Problem solving Critical thinking	Creativity and innovation Communication Collaboration

For ESD, two types of criteria are developed aiming at two types of analysis. One is concerning ESD principles, and the other SD aspects. These two are used in different sources of evidence for data collection and analysis. I explain both separately in the following.

ESD principles resulted from a literature review towards engineering education principles for sustainable development as it is explained in chapter 3. There are six ESD principles and for each were generated indicators to use in the face to face interview (table 7-2).

Table 7-2 ESD principles and examples of indicators used in the face to face interview

ESD principles	Examples of indicators
Systemic and holistic	Capable of placing engineering field in perspective with others areas of knowledge; Develop knowledge beyond core STEM disciplines like sociology, ethics, business, etc.
Flexibility and adaptability	Handle uncertainty by keeping open as many future options possible; Reflect on how alternative solutions that fit with the sustainable development approach can be identified.
Contextual	Develop alternative solutions that are locally relevant and culturally appropriate;

ESD principles	Examples of indicators
	Develop alternative solutions that are culturally appropriate.
Problem solvers	Use technical engineering knowledge to solve real problems; Involve others' perspectives and knowledge (e.g. local representatives, politicians, stakeholders, etc.) in defining and solving complex problems.
Participatory and decision making	Bring social, economic and environmental experts and implications to seek a balanced decision; Professional engineers participate in the decision making as well as in their professional roles.
Creativity and innovation	Thinking "out-of-the box"; Combining old ideas with new ideas.

Overall, the principles and indicators ESD presented in the literature are formulated as statements which makes it difficult to make a more objective and systematic analysis of their presence in written documents, presentations, etc. For this reason, a framework capable of pointing out the presence of SD aspects through the use of indicators as keywords is used.

Therefore, the SD aspects, criteria and sub-criteria are defined based on the Global Reporting Initiatives indicators (GRI, 2011) (table 7-3).

Table 7-3 Sustainable Development (SD) aspects for content analysis

Criteria	Environmental	Human Rights	Labour practices and decent work
Examples of indicators	Environment Materials Energy Water Biodiversity Emissions, effluents, and waste Products and services Compliance Transport Others	Human rights Investment and procurement practices Non-discrimination Freedom of association and collective bargaining Child labour Forced and compulsory work Security practices Indigenous Others	Employment Labour/ management relations Occupational health and safety Training and Education Diversity and equal opportunity Equal remuneration for men and women Others

Criteria	Society	Product responsibility	Economic
Example of indicators	Society Local community Corruption Public policy Compliance Others	Product responsibility Customer health and safety Product and service labeling Marketing and communication Customer privacy Compliance Others	Economic performance Market presence Indirect economics impacts Others

Indicators of SD aspects are composed mainly by keywords and aim mainly analysis of curricula, projects' reports, and observations.

7.1.3 Pilot test

The pilot test precedes the data collection. The pilot test aims to adjust and improve instruments for data collection and acknowledge the researcher how to handle the instruments and collect data (e.g. conducting interview).

For the pilot test, a programme was selected and its curriculum analysed followed by a face to face interview with an academic staff member. The curriculum analysed was from the M.Sc. Energy Engineering and the interviewee an academic staff from the same programme, whose role encloses supervise groups and deliver courses.

The curriculum analysis preceded the interview and provided an overview of the PBL variables and SD aspects present in stated intended learning outcomes (ILO).

For the pilot test interview was characterised as structured. The interview guide was composed by questions and five checklists for interviewee to fill in. The checklists enclosed indicators regarding PBL variables (e.g. type of knowledge, disciplinarity and critical thinking), ESD principles and SD aspects. The interview was recorded and lasted approximately 40 minutes. The interviewee also filled in the checklists during the interview.

At the end of the interview, it was asked the interviewee for feedback regarding how the interview was conducted and how it could be improved. He suggested for example:

- Order of some questions could be change in order to have a better relation between them instead of abrupt change of topics asked about;
- Avoid being more than two or three seconds of silence, checking what to ask next.

Afterwards, some reflection was given about the implications of having a very structured interview guide. A very structured interview guide would not allow following up in relevant experiences, perspectives and suggestions the interviewees may have to share. Even though the interview guide included the main questions and themes, it also opened up for following up on questions that may rise along the interview process. Furthermore, the PBL variables and SD aspects resulted from formal curriculum analysis are similar to the interviewees responses, increasing the quality, and validity of the data collection instruments.

7.2 Data collection and analysis procedures

The following presents the data collection and analysis procedures. These are common to the study programmes at the Faculty of Engineering and Science, Aalborg University.

The data collection encloses three main methods: documentary analysis (curricula and projects' reports); face to face interviews (study board members, lecturers, facilitators and students); observation (lectures, student's group work and presentations).

Content analysis constitutes the main method of data analysis. Along with the strategy for data collection, the main criteria for data analysis were also defined. These criteria constitute the ground for coding and analysis of all data collected.

The procedures of data collection and analysis are organised by methods of data collection and presented in the following.

7.2.1 Documentary analysis: Formal curricula & Project reports

The documentary analysis is used to analyse formal curricula and students' project reports. The formal curricula are important as they prescribe the PBL approach and the integration of SD in the programme, whereas the students' reports represent the written outcome of this integration.

Formal curricula

The data collection starts with curriculum analysis of the programmes M.Sc. in Urban Planning and Management (UPM) specialisation and M.Sc. in Structural and Civil Engineering (SCE).

The formal curriculum analysis aims to:

- Understand the curriculum structure;
- Point to PBL variables in the formal curriculum;
- Pinpoint themes that can be, or are, related to sustainable development.
- Investigate how PBL variables and ESD are stated in ILOs

The formal curriculum includes intended learning outcomes (ILOs) for the overall programme, which reflects the accumulated knowledge, skills and competences expected after two years progression in the specific education. This calls for an analysis of ILOs the overall programme and the course and project modules. In the curriculum, the programme structure and presence of PBL variables and SD aspects in the learning outcomes are analysed.

For the curriculum analysis, a content analysis grid is developed which is composed by the three parts represented in figure 7-3. The curriculum analysis grid used is in appendix 6 (p. 37).

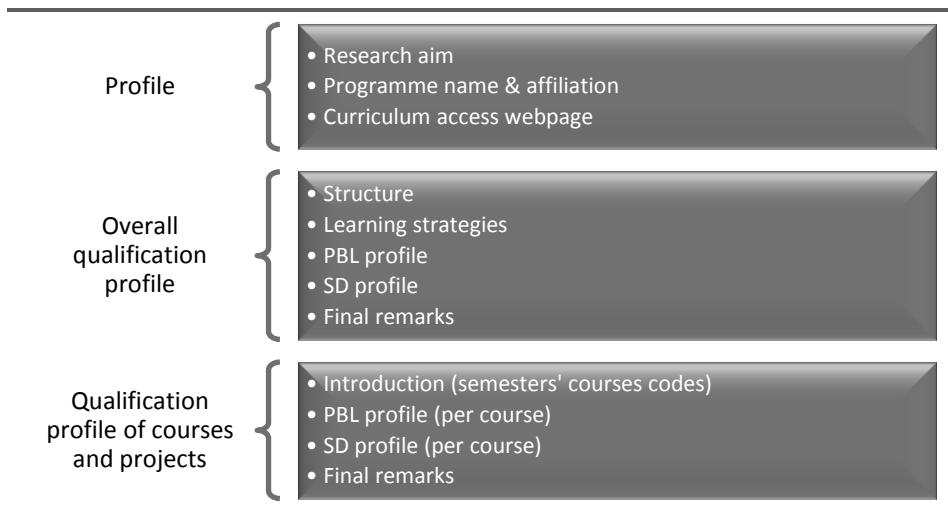


Figure 7-3 Curriculum content analysis grid elements

The first part of the content analysis grids encloses the general and identification information of the programme, followed by two levels of analysis of the intended learning outcomes formulated. The overall profile refers to curriculum objectives which the ILO aims for students to have when they graduate, while the courses and projects qualification profile regards the ILO formulated for each of these modules. The bottom line is the courses and project modules progression should reflect the overall qualification profile. This means that ILO formulated for the overall qualification profile should be developed by the learning taking place in the courses and modules along the four semesters of the programme.

The curriculum analysis grid is filled with quotes from the formal curriculum that are similar to indicators generated for criteria and sub-criteria PBL variables and SD aspects. Based on a process of analysis, a data analysis report for each programme is written, where:

- A content analysis grid filled for each programme is presented
- The emergent PBL-SD profile is presented
- Emergent issues may be follow up through other sources of evidence (for example, interview question “how a specific ILO are achieve”)
- The questions and goals stated for the curriculum as source of evidence are addressed

These reports also allow revising interview guides and formulating more specific questions for specific actors, in particularly study board members considering “why”-

questions. The curricula from AAU can be easily accessed through the university and faculty official homepages. Also, names such as study board members' name and contact can be obtained from the official homepages of the faculty schools. All this information is added to the curriculum analysis and report.

After the curriculum analysis, the main actors of a semester of the programme were contacted for follow-up interviews. One of the contacts is the semester's coordinator who provides documents concerning the semester coordination.

The semester coordination documents are elaborated for each semester by a coordinator (an academic staff member who also has the role, for example, of facilitator, lecturer) and delivered to students. The document encloses a description of semester's courses and project modules as well as some project proposals. These documents complement the formal curricula analysis, and were sent by the semester's coordinators of each programme.

Projects' reports

According to the semester timetables, students start to work in groups in their projects at the beginning of the semester. They have an entire semester to identify, analyse, specify and solve a problem in a project setting and produce a final report. The project reports are the base for the assessment and are submitted as a base for oral examination by the end of the semester. Therefore project reports can be considered a representation of what students learned collectively.

The reports analysis aim is:

- Pointing out themes and aspects which students learn and which can be related to sustainable development themes
- Understanding the structure of a project and how it reflects the PBL process
- Triangulate data with the other sources of evidence

Unfortunately, in this study, the only project reports collected are from the students from the Urban Planning and Management (UPM) specialisation. Regarding the Structural and Civil engineering (SCE) master programme, it was very difficult to obtain access and receive responses both from students and facilitators for interviews. However, the university has a database for projects where all projects from bachelor to master and from all semesters and all programmes should be submitted. Until September 2013, there were several attempts to search and to access projects from the 3rd semester of SCE master programme, but without success.

The content analysis grid is composed by three parts: project information; PBL profile; SD aspects (figure 7-4). The project reports' content analysis grid is in appendix 6 (p. 40).

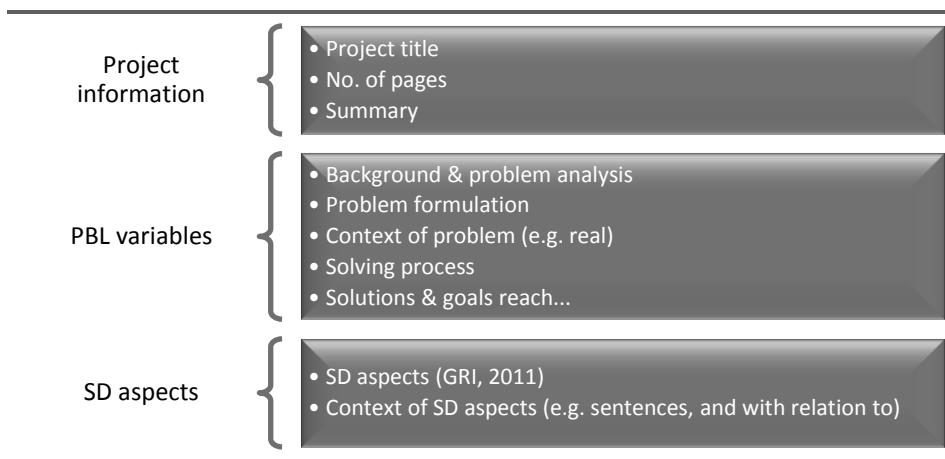


Figure 7-4 Projects' content analysis grids parts and elements

The projects constitute the documentation of the problem solving process, and therefore, the main criteria for its analysis concern PBL indicators for problem analysis formulation, solving process and analysis of solutions. The curriculum has an ILO regarding the development of problem formulation and solving skills, but does not move further on how it is achieved. The projects' analyses provide input regarding these processes and complement the curriculum analysis.

Therefore, criteria are developed for analysis of PBL variables regarding problem analysis and formulation, solving process and reflection of solutions presented (table 7-4).

The analysis starts with corresponding criteria in the table below to the different headings of the projects' table of content. These provide a range of pages in which the examples of indicators are verified to exist or not. The information (range of pages for each criterion and verification of existent indicators of analysis) is registered in the projects' content analysis grids.

Table 7-4 PBL criteria for problem formulation and solving skills achieve through project documentation and examples of indicators for projects' analysis.

Criteria	Examples of indicators
Background information & problem analysis	Presence of a state of the art leading to formulation of questions
Real and open situation	Presence of real cases, situations, etc., from where students formulate problems.
Problem formulation	Presence of research questions, and or statements that suggest something problematic aimed to be study
Solving process	Presence of, for example, plan, methodology, tools or methods to provide a possible answer (s) to questions formulated in the above
Possible solutions	Presence of results, hypothesis and assumptions which may be the answer to the problem.
Problem answered	Presence of answers to questions, discussion of results and conclusions.
Goals reached	Presence of methodological goals, expected outcomes, linked with plan, or methodology, of solving the problem.
Reflexive in process	Presence of several rival theories, methods and solutions, and point arguments why to support the different choices

The projects' content analysis grid has a third part, regarding the presence of SD aspects in the projects. Projects' analysis towards SD aspects is carried out by automatic searching of key words present in table 7-3.

The projects' reports are converted in PDF files, after it is used to make an automatic search of SD aspects using the search tools as illustrated in figure 7-5. All the SD aspects criteria and indicators are for the projects' content analysis.

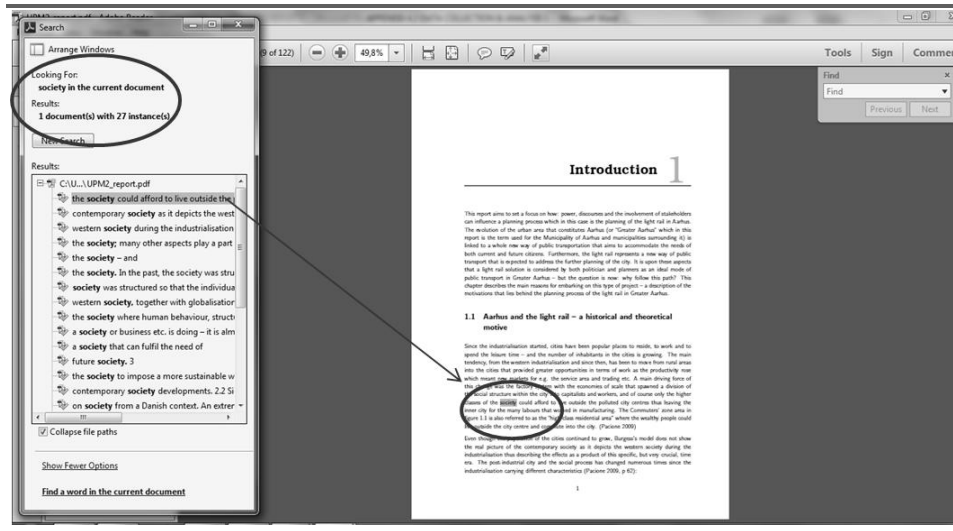


Figure 7-5 Illustration of automatic search in the projects' PDF files

The number of instances (*i.e.* number of times the word is found in the text) is registered in the grid as well as quotes of the paragraphs and pages where they are found. Along with the number of instances, it is also registered to which keyword they are associated. Where the key words are verified in order to certify that they are used in an SD context, the quotes has been noted.

Data handling/analysis

The data collection through curriculum and projects analysis resulted in content analysis grid filling inclosing examples of indicators found in the mentioned documents. The information contained in the two content analysis grids filled is handling through addressing the specific research question and aims formulated in the strategy for data collection (appendix 5, p. 31). They result reported in similarly way as the results of curricula analysis, *i.e.* describing which PBL variables and SD aspects are present.

7.2.2 Face to face interviews: Study board, lecturers, facilitators and students

Along with curriculum analysis, semi-structured interviews are considered a main method for data collection in this case study. The interview instrument consists in interview guide and checklists. It targets the main actors of programmes under study - study board members, lecturers, facilitators and students. The interviews aim to:

- Understand the PBL curriculum organisation
- Validate curriculum and project’s content analysis
- Compare formal and practiced curricula
- Investigate the PBL variables and in ways they support integration of ESD

The interview guide is composed by questions, five checklists and an auxiliary scheme of the problem solving process (i.e. problem analysis and formulation, problem solving, creating solution) (figure 7-6). The interview guide, checklist and scheme are in appendix 6, in page 42 and page 47 respectively.

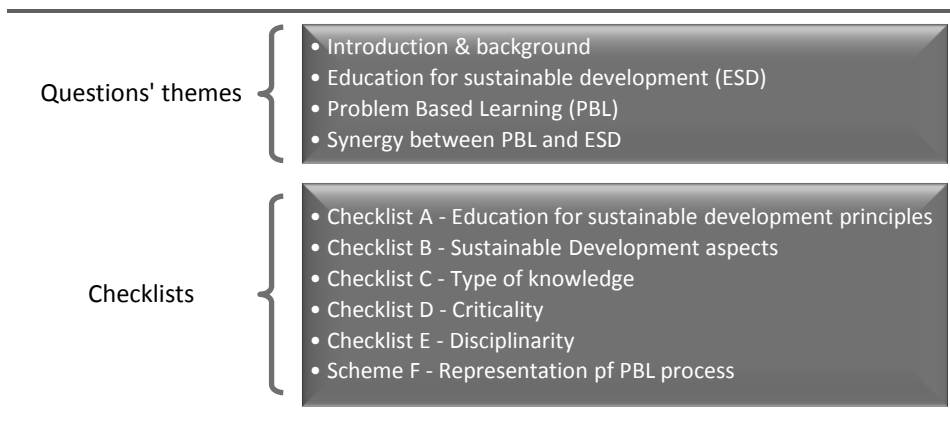


Figure 7-6 Organisation of interview instrument

The questions are divided in four clusters themes as it is presented in figure 7-6 followed by probing questions. The checklists are filled along the face to face interview and related to a suitable cluster theme. Like for example, the cluster themes “education for sustainable development” encloses direct questions and checklists A and B.

The interviewee is asked, face to face, to fill in the five most important indicators they consider to be developed in the learning process. The checklists are filled in by the interviewees during the interview and followed up by “why”-questions. They are composed by the main indicators presented in the theoretical framework concerning: ESD principles (**checklist A**); SD aspects (**checklist B**); type of knowledge (**checklist C**); criticality (**checklist D**); disciplinarity (**checklist E**); and a scheme representing PBL process (**scheme F**).

According to the strategy for data collection, specific questions are addressed only to students and facilitators as part of the learning process, while others are specifically

for study board members and lecturers due to the formal curriculum. For example, scheme F is only use as an auxiliary picture when interviewing students and facilitators in relation to different moments and tasks carried out along the project work and their relation with the overall PBL process. Therefore, the different groups of interviewees have different interviews guides, due to small differences in the questions asked.

The interviewees are organised in groups according to their roles in the programme as member of study board, lecturers, facilitators or students. Some of the actors may have more than one role, like for example facilitator and lecturer in one or more semesters of the programme, providing other examples of their experiences from other roles.

The interviews were carried out between May of 2012 and January of 2013, corresponding to two semesters (table 7-5).

Table 7-5 Time frame when interview took place

Programme	Spring 2012 (2nd semester)	Autumn 2012 (3rd semester)
M.Sc. UPM specialisation	Facilitators Students	Study board Lecturers
M.Sc. SCE	Study Board	Lecturers Facilitators Students

The number of interviews varied per group of participants (number of members interviewed), and consequently per programme and semester. The students interviewed in the spring semester were students from the UPM programme and they were in their second semester, while the students interviewed from civil engineering would be in their third semester (autumn semester).

Table 7-6 Number of interviews aimed, and number of interviews achieved

Group	M.Sc. UPM		M.Sc. SCE	
	Aimed	Achieved	Aimed	Achieved
Study board	12 (6 staff members; 5 students, 1 secretary)	1	14 (6 staff members, 7 students, 1 secretary)	3 (includes responsi- ble for the pro- gramme)
Lecturers	3	2	7	4
Facilitators	4	4	6	2

Group	M.Sc. UPM		M.Sc. SCE	
	Aimed	Achieved	Aimed	Achieved
Students	5 groups (18 students)	4 groups (6 students)	4 groups (13 students)	0
Total of inter-views	24	11	31	9

The interviewees were contacted via e-mail where a contact letter and a project summary were attached. The contact letter includes the aims of the study, purpose of the interview and time expected for the interview. The contact letter and project summary are in appendix 7 (p. 57).

Study board members and semester coordinators were the first group contacted for interview, in May of 2012, as they can work as channels to identify and contact the remaining interviewees of the programmes.

The interviewees were contacted and reminded within two to three weeks apart for three times. The interviews were scheduled according with the interviewees' availability. The interviews were recorded with consent of interviewees and assure anonymity.

Data handling/ analysis

The interview analysis is divided into phases: one the coding and transcription of respondents' answers to questions, and the checklists' content and relevant comments made by the respondents.

From this point on, when I refer to "interviews' analysis" I am referring specifically to the answers from the interviewees to the direct questions from the interview guide and checklists analysis or the comments made by interviewees.

The interview analysis encloses procedures as such listening and coding the audio file, transcribing and summarising. To carry out these tasks the N-Vivo 10 software tool was used. The audio files are analysed by using N-Vivo 10 software tool. The N-vivo is a tool used for content analysis of different sources of evidence, like for example Word and PDF files, pictures, videos, audio files, webpages, etc.

The functionalities of N-vivo 10 for analysis of qualitative data are several, leading to several strategies, approaches and forms to analyse data. Nevertheless, here, I focus only on functionalities which allow listening, coding, and simultaneously transcribing an audio file.

One of the advantages of using the N-vivo is the possibility to listen, define codes (in N-vivo tool they are named nodes), code audio files and transcribe relevant frames of the interview by timeslots.

The analysis' process started with creating an N-Vivo 10 project file and uploading the audio files. Each audio file uploaded corresponds to a source of evidence, i.e. to an interviewee. After that, the codes and sub-codes presented in table 7-7 are introduced in file. There is also the possibility to give a colour to the different codes created. These are used to code the audio files.

Table 7-7 Interview guide main themes, codes, sub-codes and colours used in N-vivo 10

Interview guide theme	Code/ colour	Sub-codes (e.g.)	
Education for Sustainable Development	ESD (yellow)	<ul style="list-style-type: none"> – Drivers for ESD integration – Who integrate – Main challenges – Challenges address 	<ul style="list-style-type: none"> – Strategies to integrate – SD learning outcomes – Assessment – Pedagogy – Who teach
Problem Based Learning	Curriculum (orange)	<ul style="list-style-type: none"> – Educational intention – Phases (<u>scheme F</u>) – Programme structure – Problem presentation 	<ul style="list-style-type: none"> – Problem formulation – Knowledge (<u>checklist C</u>) – Disciplinarity (<u>checklist D</u>) – LO assessment
	Processes Competencies (light grey)	<ul style="list-style-type: none"> – Criticality (<u>checklist E</u>) – Creativity 	<ul style="list-style-type: none"> – Group formation – Collaboration
PBL and ESD	Synergies (dark grey)	<ul style="list-style-type: none"> – PBL phases & SD (scheme F) – SD content (<u>checklist A & B</u>) – Challenges – Students' motivation – Support to students 	<ul style="list-style-type: none"> – Reflect on learning process – Reflection on SD – Importance of SD – Other knowledge, skills & competencies – PBL and SD perspectives
Other	Background (red)	<ul style="list-style-type: none"> – Projects' presentation 	<ul style="list-style-type: none"> – Interviewees
	Other experiences (pink)	<ul style="list-style-type: none"> – Professional 	<ul style="list-style-type: none"> – Personal histories

All the audio files were listened through more than once and coded. The codes are used directly in the audio file, and it "breaks" the audio file in small segments. These segments are summarised in a table, and some are fully transcribed. The sub-codes are

used to code specific portions of the transcriptions. After these stages of analysis, the interviews are summarised.

The interview analysis encloses the following tasks listening; transcribing; coding and summarising (figure 7-7).

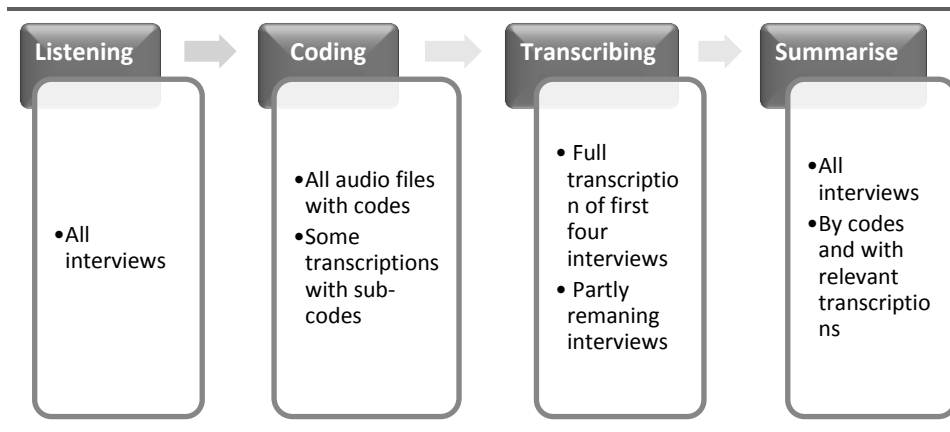


Figure 7-7 Interview analysis mainly phases and tasks carried out

A full transcription was made of the four first interviews carried out, allowing specific coding of transcriptions by using the sub-codes defined. For the remaining interviews, only the most relevant timespans are transcribed

Based on N-vivo transcription and coding, all interviews are summarised. The summaries are structured by themes and with relevant quotes transcribed.

The checklists are composed by the indicators of criteria defined in table 7-1 (p. 124), table 7-2 (p. 124) and table 7-3 (p. 125). The results are organised in excel sheets, one per checklist. Also relevant transcriptions of interviewees' comments towards checklists made during the interview were coded and included in interviews' summaries. The excel sheets enclose the respective criteria and indicators of checklists, interviewees identification code, programme, and it is filled in with interviewees responds.

7.2.3 Direct observations: Students' status seminar

The case study research methodology plans to collect data from observations of lectures, facilitation processes and group work.

The observations aimed to:

- Point out which PBL variables, and SD aspects are present in actions taken during learning processes such as group work, lectures or other forms of presentations and/or communications;
- Investigate the dynamics of the learning process taking place;
- Complement other sources of evidence.

However, direct observations only enclosed the semester **status seminar** of the M.Sc. UPM specialisation. According to the semester coordinator for 3rd semester of M.Sc. SCE, the status seminar event is optional, and depends on whether students want or do not want to have it. A status seminar is a meeting place where students present and get feedback to their project progression from others groups and facilitators.

The observation schedule for status seminars is composed by three grids: (i) identification; (ii) SD aspects; (iii) PBL variables (figure 7-8). The grids include the timespan given during the observation: for example, in the grid marked with 5 min., it means that in these first five minutes, SD aspects have been observed. The time division and what aspects to note is the researcher's decision. The observation schedules are available in appendix 6 (p. 53).

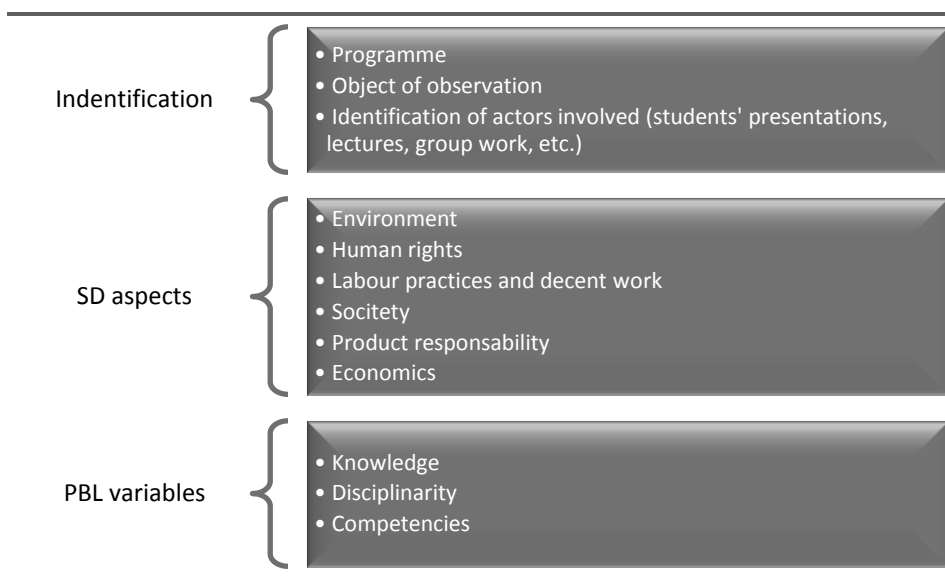


Figure 7-8 Components of three grids from observation schedules

The identification grid aims to collect information regarding: i) name of the programme (M.Sc. UPM or M.Sc. SCE); ii) date of observation; iii) object of observation (e.g. lecture, project work, status seminar, etc.); iii) and actors being observed (e.g. students, lecturers, etc.).

The SD aspects considered for observation are the same for the other sources of evidence, and are presented in the above table 7-3.

The PBL variables are regarding type of knowledge, disciplinary and process competencies. Not all the PBL variables' criteria are considered due to the complexity of the concept (e.g. disciplinary, critical thinking, self-directed learning...), also, the researcher must keep in mind the clear definitions of such concepts so indicators can be observed and registered.

For observational purposes, the indicators associated with observation of PBL variables are simplified, and reduce some key number of words as it is presented in appendix 5 (p. 55). The observation outcomes aim to complement the other sources of evidence outcomes.

The status seminar observed was concerning the 2nd semester of UPM specialisation. The status seminar had a duration of two hours approximately, with a total of five groups presenting their projects through case (normally a real situation) and problems (normally formulated as research questions), problem solving strategy (normally as research methodology) and status of progression. Each group had ten minutes presentation followed by five minutes of discussion, where colleagues and facilitators posed questions and provided feedback to the group. Each group was composed by three to four members.

Data handling/ analysis

The observation schedules are analysed using criteria defined in the above tables (table 7-1, p. 124, and table 7-3, p. 125) and organised in grids as illustrated in the following figure.

Group No.		1		2		3		4		5	
PBL principles		Presentation	Discussion	Presentation	Discussion	Presentation	Discussion	Presentation	Discussion	Presentation	Discussion
Knowledge	Factual & Conceptual										
	Procedural										
	Metacognitive										
	Personal, evolutionary (know-why)										
Disciplinary	Disciplinary										
	Cross-disciplinary										
	Interdisciplinary										
Competencies	Lifelong learning										
	Contextual learning										
	Problem analysis & formulation										
	Problem solving										
	Creativity & innovation										
	Communication										
	Collaboration										
Comments											

Figure 7-9 Example of grid to organised that analysed from observations. The example concerns the PBL variables, however, the SD aspects grid as the same structure.

7.3 Critical aspects of case study: criteria for research quality

Like any other research activity, it is needed to clarify criteria and procedures that assure the quality of the research activity. These are validity, reliability and generalizability. One of the largest weaknesses of the case study as research approach is its low constructions towards these criteria. For example, how a case is selected; what phenomena are being studied and why? However, researchers have been put effort into defining and elaborating strategies so such criteria is met along the research process (Bassegy, 1999; Flyvbjerg, 2001; Merriam, 2001; Yin, 2009). Furthermore, these concepts are also rooted in the quantitative approaches to education (Golafshani, 2003). However, how can the criteria of research quality be defined and constructed in a qualitative study? This study aims to investigate in which ways PBL supports the integration of ESD in engineering education. And, as it is described in the introduction chapter, it encloses a qualitative approach under the constructivist worldview, recognising that the educational concepts (e.g. PBL principles and ESD principles), practices and perspectives of the participants in the study are socially constructed as part of the social interactions and joint constructions of meaning which may change over time.

Therefore, the construction of validity, generalizability constructions in this study take into consideration its nature (qualitative) and its paradigm (constructivism) (Golafshani, 2003).

The following explains how the research quality is constructed by pointing out the procedures and outputs of the tasks carried out along the study. Concepts of validity, reliability and generalizability are used as criteria of research quality.

The construction of a case study research methodology increases the study's reliability, or the collection of data from different sources of evidence increases the validity of the study (Yin, 2009). The most difficult criteria to argue for is the generalisation, at least in the terms that is more common defined in research - its findings and in relation with quantitative research designs (Creswell, 2009). On the other hand, authors (Bassey, 1999; Flyvbjerg, 2001; Yin, 2009) argue for different types of generalisation within case study research, depending on what can be generalised in the study and to which extent. Research activity is complex and encloses several constructions and phases, involving theory and practice. Some of types of generalisation pointed out by the different authors depend on, for example, the type of case study (see, for example, Flyvbjerg, 2001; Yin, 2009); and analytical procedure (see for example, Bassey, 1999; Yin, 2009).

7.3.1 Validity versus “*Validities*”

Validity refers to accuracy of the findings of the study in relation with procedures carried out for data collection and analysis (Creswell, 2009). The construction of validity takes its point of departure in, for example, identifying the adequate measuring tools and operations towards the concepts being studied (Yin, 2009).

For this study, the constructions of validity starts with comprehensive literature review regarding PBL, ESD and Engineering Education to support the assumptions that PBL is a suitable learning approach to integrate ESD in engineering education. The comprehensive literature review lead to analytical variables (presented in chapter 4, p. 76) which outlines the learning principles common to PBL and ESD for engineering education. In sum, the theoretical framework provides the concepts to be studied; however, it is through the empirical framework that the research strategy starts to form.

In the strategy for data collection (appendix 5, p. 27), specific research questions to be answered through the collection and analysis of data are identified. To each questions is associated a method for data collection, and to each method corresponds the sources of evidence. The strategy follows the construction of instruments for data

collection, and definition of criteria and indicators of analysis. Notice also that several sources of evidence with specific data collection instruments are used, but rather focusing on collecting the same type of data. For example, the same SD aspects are used as indicators in the analysis of formal curriculum, in the interview checklists, project reports analysis, etc. This means that the concepts being studied are “measured” by different instruments of data collection, using different sources of evidence.

The definition of analytical variables and strategy for data collection set the ground for constructions validity and trustworthiness of the study regarding the concepts and procedures which preceded the data collection and analysis.

Validity encloses two types: internal and external validity (Yin, 2009). The internal validity was explained in the above. The external validity concerns the generalizability of the study, what can be generalised and how, which will be explained in the following section.

7.3.2 Generalizability & type of case: a matter of external validity

Literature suggests systematic phases for conducting a case, different types of generalisations. Yin’s name it external validity and define it in terms of analytical generalisation in comparison with statistical generalisations, common in quantitative research designs (Yin, 2009, p. 43). The analytical generalisation regards the procedures carried out to collect and analyse data, forming a kind of skeleton which is suitable to be used and applied in other contexts. The examples are the theoretical and empirical framework, but also the design of the case study, selection of case study procedures and development of case research methodology.

Flyvbjerg (2001) points to the myth of results of the case studies not being fit to be generalised. Notice that the goal of qualitative research and case study is to seek knowledge and understanding a phenomenon rather than quantify and extrapolate it. The author mentioned argues that the generalizability in case studies is related to the phenomenon being studied which determines the type of case.

Type of case

This case study started with conceptual and theoretical constructions for verification through the theoretical framework which determines the type of case to be carried

out. Flyvbjerg (2001, p. 77) and Yin (2009, p. 47) presents the concept of the *critical case*. In a critical case, if a set of assumptions are not observed as likely to happen, then it is more likely not to happen in similar contexts (and vice versa).

The first moment resulted in the conceptual alignment between PBL and ESD, where some synergies are conceptualised. This points to the main theoretical prepositions of the study, however, the tensions seem to have less visibility on this conceptual framework, which from a real-life context investigation will not only confirm the synergies, but point out the tensions between the both. The case study as research strategy is chosen due to the problem under study. The theoretical prepositions call for cases with PBL, ESD and Engineering Education as part of the practice context of the educational system (Ragin & Becker, 1992; Flyvbjerg, 2001; Yin, 2009). The single case selected is Aalborg University (AAU).

AAU has PBL as part of its educational identity being practiced for more than 40 years. In here, the challenge is not to change the engineering curricula to more active, problem solving and student-centred learning, but to integrate ESD in all engineering education programmes. The institution presents a unique context for investigating the PBL practices and how they support the integration of ESD in engineering education.

7.3.3 Reliability

Reliability concerns the replication of the results of the study when the study is under a quantitative and positivist paradigm. In qualitative research, a constructivist paradigm reliability is interlinked with validity of the study and vice versa. In this sense, reliability concerns how far the results obtained represent the reality of the phenomena being studied; how far they are trustworthy (Golafshani, 2003).

One of the strategies used is organisation of the case study in phases (e.g. design, case selection and protocol, collect and analysis, reporting), which one encloses clear and systematic activities to reach the purpose of the case study. Another one is the triangulation of data, and several sources of evidence (Cohen, Manion, & Morrison, 2007; Creswell, 2009).

However, it is always challenging to address reliability in case studies, once by definition, they are studies carried out within defined time and space, collecting data from different sources of evidence. These sources may change over time; therefore, the replication of the results is hard to replicate. For the reasons stated above, it is important to define parameters for replication of the results in terms of: time, space and context.

To increase the reliability of the case study, a study is carried out with the aim to collect experts' perspectives on synergies and tensions to integrate ESD in engineering education. This is presented in chapter 9 of this report.

Final remarks

In this study, the case study constitutes a major part of the empirical work carried out, from its preparation to data collection, analysis and result reporting.

The case study research design and process encloses several decisions along the way which have an impact on the research quality and outcomes. There is a great concern in the research quality aspects, and strategies are developed to address them as much as possible. For example, the approach for selection of case, the instruments and what data is aimed to be collected from each source of evidence.

The study is qualitative, encloses definitions and constructions of complex terms (e.g. different types of disciplinarity, types of knowledge, definition of problem, etc.) from different actors from different fields and expertise (researcher and interviewees). These may enclose a certain bias in the way that human knowledge and perceptions are not fixed and unchanged, meaning that the same question asked tomorrow could have a different answer. Therefore, ideally this study could close a longitudinal component, like for example, after a year, collect the same data from the same interviewees and participants.

This single case comprises two units of analysis, the UPM specialisation and the SCE master's programme, from which data was collected. Both programmes seem to be in opposite poles to engineering education – UPM is more socially oriented while SCE encloses traditional core of STEM disciplines in its curriculum. It is expected that both programmes highlight different synergies and tensions between ESD and PBL, taking into consideration the different curriculum constructions and practice (e.g. type of problem, disciplinary and knowledge, problem solving process, etc.). In the following chapters, the main findings from both programmes are presented.

8 Sustainable education for Urban Planners

This chapter presents the main results from a study of M.Sc. Urban Planning and Management (UPM) specialisation. The chapter is organised in four subchapters to report the results on the data collected from the formal curriculum (8.1.), practiced curriculum (8.2) and practice perspectives for PBL and ESD (8.3). The chapter ends with a summary of conclusions of the possibilities and challenges of UPM to combine PBL and ESD. The data collected and analysed are in appendix 9 (p. 67).

8.1 The formal curriculum

The formal curriculum is analysed through content analysis. The main focuses of analysis are the intended learning outcomes (ILOs), and aim to investigate how these align with PBL principles and which SD aspects enclose. The curriculum is analysed at two levels: the programme overall qualification profile reflecting the programme progression, and qualification profile of the different courses and projects modules that compose the programme.

8.1.1 Programme overall qualification profile

UPM is one of the three specialisations that compose the M.Sc. Urban, Energy and Environment Planning programme. The three specialisations share the same overall qualification profile (figure 8-1).

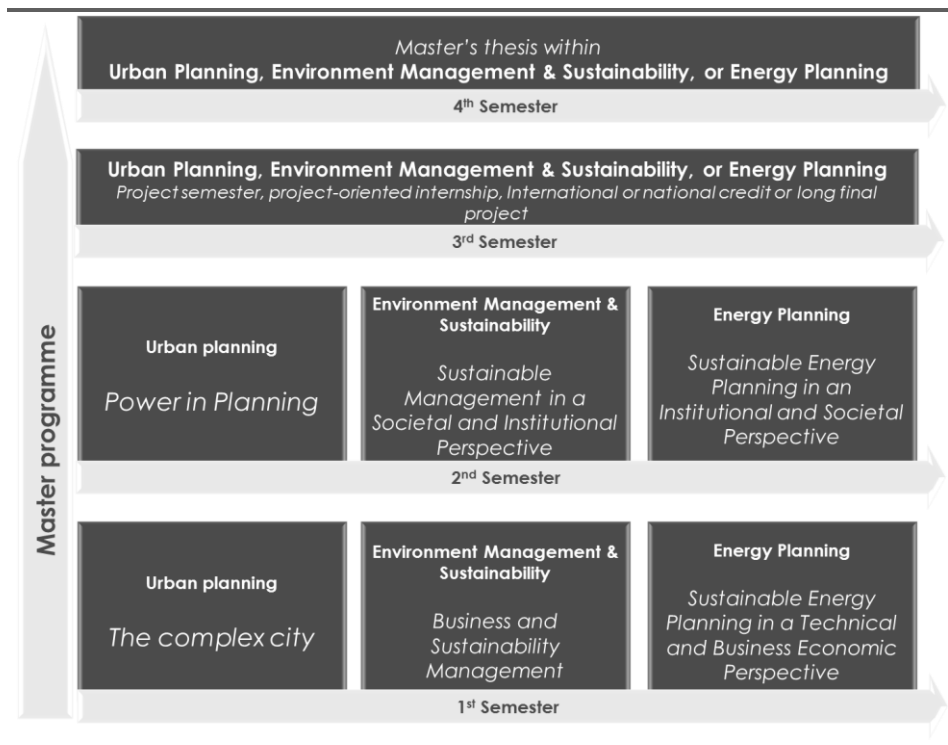


Figure 8-1 Organisation of the master programme in three specialisations (Adapted from SADP, 2010, p.6)

In practice, the specialisations are carried out as independent programmes, sharing only one course in the first two semesters. In the two last semesters, students have the possibility to: i) carry out long master thesis (in two semesters, 3rd and 4th), ii) do an internship (3rd semester), and master thesis (4th semester) within their own specialisation streams (figure 8-1).

The key principles of PBL are present in the learning outcomes of overall programme, as following table shows (table 8-1).

Table 8-1 PBL principles analysed in programme overall qualification profile

PBL principles	Criteria	Indicators retrieved from curriculum (SADP, 2010)
Knowledge	<ul style="list-style-type: none"> • Cognitive • Procedural • Metacognitive 	<ul style="list-style-type: none"> – Has knowledge about... – Handle the methods and tools... – Assess and choose among theories, methods, tools and...

PBL principles	Criteria	Indicators retrieved from curriculum (SADP, 2010)
Disciplinary	<ul style="list-style-type: none"> • Interdisciplinarity 	<ul style="list-style-type: none"> – ...theories and methods in planning, administration and/ or management [...]; analyse technical and social context [...] be part of interdisciplinary teams
Learning	<ul style="list-style-type: none"> • Self-directed learning • Contextual Learning 	<ul style="list-style-type: none"> – Independently develop own competencies and specialisation – Implementation of plans and strategies in Danish or international context
Process competencies	<ul style="list-style-type: none"> • Problem analysis & formulation • Problem solving • Critical thinking • Creativity & innovation • Communication • Collaboration 	<ul style="list-style-type: none"> – Can formulate and analyse essential problems [...]; discuss professional and scientific problems [...] – ...on a scientific basis draw up new models of analysis and solution... – ...reflect on the knowledge [...]; can formulate [...] problems [...] and critically by using relevant scientific methods. – Be part of interdisciplinary teams...

The learning outcome statements enclose indicators that correspond to the different PBL criteria. For example, cognitive knowledge is considered present in an intended learning outcome if when the presence of the verb “has” is verified. In this example the verb “has” works as indicator for criteria cognitive knowledge.

There are not explicit statements in the learning outcomes regarding problem solving skills. However, there are references to the ability to draw up new models of analysis and solutions.

Some of the learning outcomes combine more than one of the PBL criteria considered, as the following example shows:

*Can **assess** and **choose** among the theories, methods, tools and general skills on **urban, energy and environmental** planning and on a scientific basis draw up new **models of analysis and solution** (SADP, 2010, p. 4)*

The above example includes indicators regarding metacognitive knowledge (e.g. assess, and choose), interdisciplinarity (e.g. urban, energy and environmental content), creativity (e.g. new) and problem analysis and solving (e.g. models of analysis and solution). The learning outcomes formulated combine different types of knowledge, interdisciplinarity, problem analysis, solving, and creativity.

Not surprisingly, the overall profile involves simultaneously cognitive and procedural knowledge related to theories, methods and tools, and furthermore, there is an explic-

it emphasis on metacognitive knowledge based on indicators such as the ones mentioned in the above example.

In regard to SD aspects, the overall qualification profile of programme shows aspects related to environment, society and economic pillars of sustainability. This is no surprise due to the scope of the programme, involving education in urban, energy and environment planning. In the learning outcomes, there is reference to aspects concerning the specificities of the three specialisations, like it is shown in the following statement:

*Can assess if strategies, plans, projects or **infrastructure** systems are expedient and feasible in **technical**, town planning, area planning, **economic**, **environmental**, **business** and **social** respects (SADP, 2010, p. 4)*

Education for sustainable development (ESD) argues for systems thinking and holistic view, critical thinking, interdisciplinarity, among others. Some of these principles are considered competencies, and for students to develop these competencies, they have to engage complex cognitive task in their learning activities. For example, systems thinking and holistic view calls for complex reasoning and cognitive tasks, such as metacognition within different knowledge domains (e.g. interdisciplinary). In the above learning outcome, the verb phrases “can assess” point for construction of metacognitive knowledge, while the nouns like “technical, town planning, area planning, economic, environmental, business and social respects” point to knowledge in different domains. Notice the presence of environmental, economic and social respects which are the three pillars of sustainability.

Furthermore, the overall profile also includes an intended learning outcome addressing ethics and professional responsibility. According to Sterling (Sterling, 1996), ESD is also ethical, therefore ethics and professional responsibility is also used as an indicator for ESD.

8.1.2 Modules qualification profile

I recall the semester structure in three courses modules of 5 ECTS each, and one project module of 15 ECTS (chapter 6, p. 113). The three specialisations only share one common course in the first two semesters. The courses are “*Theory of Science*”, in the 1st semester, and “*Policy, Planning and Governance*”, in the 2nd semester. The two remaining courses are delivered only for UPM students.

The focus of analysis of the qualification profile of courses and projects is also the intended learning outcome statements, and which PBL principles and SD aspects are present.

Problem Based Learning variables

The PBL variables identified and defined in chapter 4 (p. 76) are present in the intended learning outcomes of the courses and projects modules. Figure 8-2 points out in detail which variables are identified in the learning outcomes. The curriculum analysis grids enclosing the detailed analysis of learning outcomes of all courses and projects' modules are in appendix 9 (p. 67).

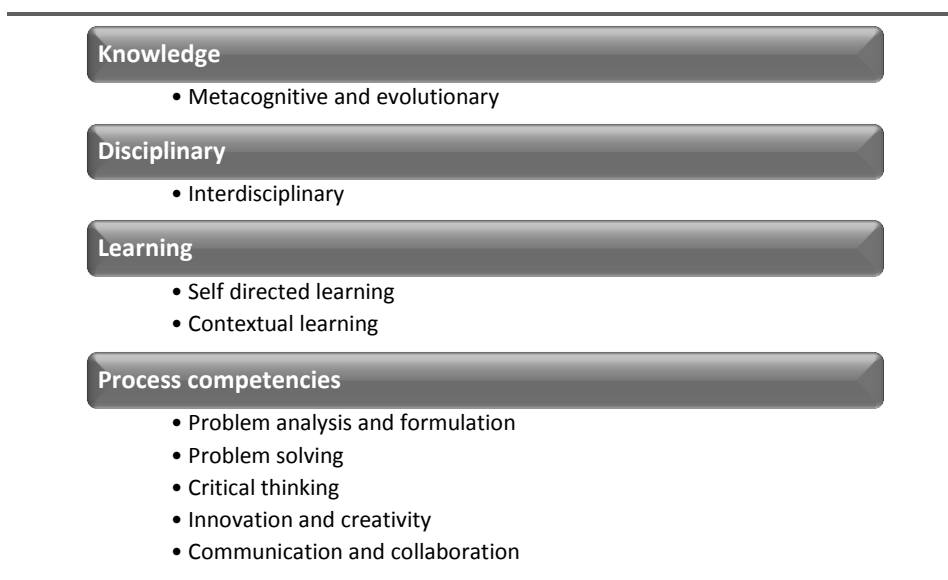


Figure 8-2 PBL variables and criteria present in learning outcomes of UPM courses and projects' modules

Similar to overall qualification profile, the learning outcomes have indicators regarding metacognitive knowledge, involving several disciplines from different knowledge domains (e.g. social sciences, technical, and humanities). In simple terms, the combination of metacognitive tasks within simultaneous disciplines within multi-knowledge domains promotes the development of system thinking.

One of the examples is the following learning outcome, classified as knowledge, stated in the first semester project module "*The Complex City*":

*Have thorough knowledge of the complexity of connections and effects between different changes in the **land use** and **transport infrastructure** of the towns and the **behavioural, distributional, environmental and economic consequences** of these changes (1st Semester project module - The Complex City)*

In the above example, the sentence starts with “Have thorough knowledge”, which is used as an indicator for cognitive knowledge, it also points at different knowledge domains (e.g. technical with “infrastructures”, and social with “behavioural, distributional, environmental and economic consequences”), their interconnections, changes and impacts of these in social (e.g. social, human, economic) and special (e.g. town) dimensions. The development of this learning outcome calls for system thinking and holistic views from students.

This gives the stair to move to the interdisciplinary aspect of this curriculum, as both courses and project modules of the first semester indicate an interdisciplinary learning environment. The learning outcomes enclose references to effects of urban development on environment, economy and society, like for example:

*Knowledge of mutual dependences between the **nature-geographic/ecological context** of towns, the **built-up environment**, the **social life** and conditions of the inhabitants and the **economic framework** conditions (1st semester course Complexity, Interrelationships, Synergies and Conflicts)*

The ESD calls for interdisciplinarity once it encloses different aspects of the three pillars of sustainability (environment, social and economic) but also an ecological view (*i.e.* interconnections between different elements and processes). This idea is very present along the UPM curriculum and the learning outcomes formulated for the different modules and semesters, especially for the first semester, as the above two examples show.

In the UPM curriculum the interdisciplinary is explicitly stated concerning collaboration. For example, in the overall qualification profile the reference to “interdisciplinary teams”, and in the following example, the reference to interdisciplinary cooperation:

*Can independently start and implement subject specific and **interdisciplinary cooperation** and take a professional responsibility (2nd semester project module Power in Planning)*

On the other hand, in the 2nd semester courses and project modules, the references to different knowledge domains decrease, being the focus mainly in the social sciences. Examples are politics and policy, power, ethics, communication, whereas in the 1st semester, references to different knowledge domains stress environment, infrastructures, land use, economic, behavioural, etc.

Another of the key principles considered is the type of learning, specifically self-directed learning and contextual learning. Self-directed learning lies on the assumptions that students become independent and autonomous learners, which underlies the life-long learning.

All the modules emphasise a life-long learning approach by stating that students should “take a responsibility for own professional development and specialisation”. Furthermore, the 2nd semester course “*Policy, Planning and Governance*” encloses self-directed learning by emphasising independency, as it is stated bellow:

*Must **independently** be able to develop and introduce **new concepts and methods** of analysis in relation to **problems** relevant to own professional standards (2nd semester course Policy, Planning and Governance)*

The learning outcome also contextualises self-directed learning in relation to the so-called process skills. The relevance of such skills (as it is formulated) encloses not only the student ability to learn new knowledge autonomously and independently, but also adaptability and flexibility towards new situations and realities which require new learning.

Examples of indicators for contextual learning are the presence of words like “context”, “profession”, and “field” in the learning outcomes. In this sense, almost all of the courses and project modules touch upon contextual learning; and some even call for contextualisation of a specific situation, and/ or problem, like in the example stated below:

*Must be able to **use international planning theory** in a **practical context** and in relation to the **problems** of planning [...]*

In terms of process-competences, all modules of UPM have references to identification of problems, analysis and new solutions. There is no distinction here between courses and project modules being both problem based.

The same is observed for communication and collaboration competencies, which appear related to discussions of problems and cooperation in interdisciplinary teams, as mentioned above.

In sum, the qualification profiles of courses and project modules for the UPM specialisation enclose visible criteria of PBL, and points also at complexity and interconnection among the different principles, like for example self-directed learning, contextual learning and problem solving skills.

Sustainable Development aspects

In terms of SD aspects, all three pillars of sustainability: social, economic and environment can be found in the modules of the UPM specialisation. Figure 8-3 shows examples of which SD aspects are present in the different semesters.

1 st semester	2 nd semester	3 rd semester	4 th semester
<ul style="list-style-type: none"> • <i>Sustainability and climate</i> • <i>Land use and transport infrastructures</i> • <i>Environmental consequences</i> • <i>Social consequences</i> • <i>Services and facilities</i> • <i>Economic consequences</i> • <i>Ethics and professional responsibility</i> 	<ul style="list-style-type: none"> • <i>Politic and policies</i> • <i>Ethics and professional responsibility</i> 	<ul style="list-style-type: none"> • <i>Ethics and professional responsibility</i> 	<ul style="list-style-type: none"> • <i>Ethics and professional responsibility</i>

Figure 8-3 Example of sustainable development aspects presented in the learning outcomes from the different semesters of the UPM specialisation (<environment>; <social>; <economic>)

As illustrated in figure 8-3, the 1st semester encloses all three pillars of SD, with presence of environment, social and economic aspects. In the 2nd semester the SD aspects are mainly related to social aspects, more specifically power, politics, policies, as it is stated in the following:

*Knowledge of **power, politics and policies** in relation to decision processes based on national and international research (2nd semester course Policy, Planning and Governance)*

Similarly to the overall qualification profile, it is observed the presence of learning outcomes within the field of ethics and professional responsibility. Their presence is in almost every course and project module in the 2nd semester, as the follow examples illustrate:

Knowledge about ethics questions in planning; [...] Thorough knowledge of participation and democracy in planning (2nd semester, course Planning Theory)

Knowledge of professional behaviour codes and ethical frames for the practice of the planner; [...] Knowledge of communication and work with conflicts due to differences in the planning (2nd semester, course The Deliberative Practitioner)

In the above examples ethics, participation, democracy, or professional behaviour codes are formulated as cognitive knowledge and in relation with role of the planner (i.e. professional practice). The relation between practice and ethic values sets the ground for reflection about the consequences, impacts and responsibilities of an urban planner as contributor and constructor of a sustainable society.

8.2 The practiced curriculum

The practiced curriculum is based on results from interviews, observations and project reports, and aim to outline how the PBL and ESD are practiced in UPM education. The interviews, observation and project reports are mainly concerning the experiences of the 2nd semester of the programme.

The interviews were treated anonymously, being given to each interviewee a code for identifications, as it is shown in table 8-2.

Table 8-2 Interviewees identification

Interviewees from UPM	ID code	Interviewees from UPM	ID code
1 st Study Board member interviewed	SB1 _{UPM}	1 st Student interviewed	S1 _{UPM}
1 st Lecturer interviewed	L1 _{UPM}	2 nd Student interviewed	S2 _{UPM}
1 st Facilitator interviewed	F1 _{UPM}	3 rd Student interviewed	S3 _{UPM}
2 nd Facilitator interviewed	F2 _{UPM}	4 th Student interviewed	S4 _{UPM}
3 rd Facilitator interviewed	F3 _{UPM}	5 th Student interviewed	S5 _{UPM}
4 th Facilitator interviewed	F4 _{UPM}	6 th Student interviewed	S6 _{UPM}

I start by presenting the curriculum experienced regarding PBL (section 8.2.1), followed by a specific focus on ESD (section 8.2.2).

8.2.1 Problem Based Learning practiced curriculum

The findings regarding interviewees' experiences of the PBL curriculum are clustered according with analytical variables investigated, as it follows: metacognitive knowledge and interdisciplinary; emphasis of contextual learning; problem analysis, formulation and solving; critical thinking; communication and collaboration.

Metacognitive and interdisciplinary

In the formal curriculum, there is an emphasis on complex cognitive tasks through construction of metacognitive knowledge. Metacognitive and evolutionary knowledge is also pointed by interviewees as being part of the learning process (figure 8-4).

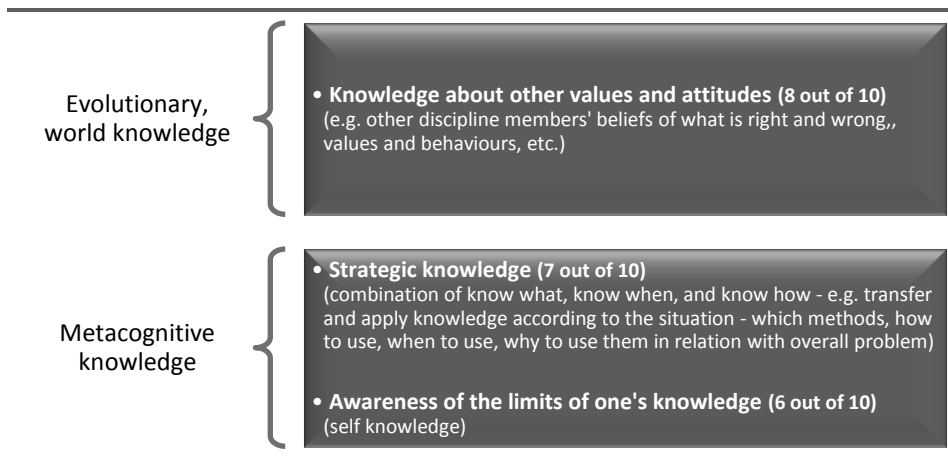


Figure 8-4 Types of knowledge pointed out by interviewees and respective indicators, in which is given the number of interviewees selected the indicator out of the total interviewees that fill the checklist.

All students selected strategic knowledge as indicator for metacognitive knowledge. Student **S1_{UPM}** explains his/ her awareness and importance of this type of knowledge in relation with overall problem solving process, like for example how to structure the process, move back and forth in it, and know when to apply the knowledge:

Strategic knowledge, you know somehow structure the process, you know when you should do what, but at same time you never know. You cannot go from 1 to 2, to 3 to 4, you always jump back and forward all the time. Of course is a knowing when to apply knowledge that you get from theory. (S1_{UPM})

However some of them also pointed for cognitive tasks related with evolutionary knowledge, being the indicator mentioned above the most pointed by the interviewees. However the two remaining indicators are poorly selected. The checklist result is in the appendix 9 (p. 114).

According to lecturer **L1_{UPM}**, supported by **SB1_{UPM}** and **F4_{UPM}**, some of the conditions to construct complex and higher order knowledge are in place in the programme due the fact problems, and project work is based on real situations. This sets conditions to develop different cognitive strategies (leading to different types of knowledge, including evolutionary knowledge) and contextual learning, but also for system thinking and holistic view of the contexts in which problems are formulated and solved.

One of the indicators of evolutionary knowledge is the knowledge shared and cultured in relation to knowledge production, and even though the students did not point to

this indicator in the checklist, almost all of them refer to this when questioned about the advantages of a PBL environment. The main advantage is the “sense” of knowledge they produce through the problem solving process and project work. It is related to other criteria like contextual and self-directed learning and with the knowledge production process as such. The following quote by **S1_{UPM}** is an example of that:

*I think... sometimes it is the feeling, when you are done, that you **create some new knowledge** which hasn't been produced before. It is just from other perspective, that you know that you didn't only learn something, that didn't only read books, and then you went for an examination about those books, but actually be able to do by yourself, to **produce knowledge**. There is **no better feeling** when your supervisor afterwards says 'it is really good what you find out and I've even told some of your results to my colleagues'. That's a really good, nice feeling, to be independent and produce your knowledge. (**S1_{UPM}**)*

This illustrates that the learning experience is considered meaningful for students; not only does learning take place, but they likewise feel they have achieved something by creating new knowledge relevant for others too.

On the other hand, **SB1_{UPM}** generalises, and points for the lack of ability to reflect on one's own knowledge production in more traditional engineering fields:

*In general if you take all traditional engineering education **there is a huge deficit on reflecting in our own practice, your knowledge production** - thinking about why I do this at all, not because the teacher told me to, or the university tell me it is important, but why it is important. (**SB1_{UPM}**)*

Similarly observed to metacognitive knowledge, interviewees also consider the education to be multidisciplinary or interdisciplinary, as it can be seen by the results from checklist D (figure 8-5).

Multidisciplinary	<ul style="list-style-type: none"> • Have knowledge from different disciplines (6 out of 10)
Interdisciplinary	<ul style="list-style-type: none"> • Combines methods and approaches from different disciplines (6 out of 10) • Two or more disciplines which interact and combine their expertise to jointly address and are of common concern (6 out of 10)

Figure 8-5 Type of disciplinary and indicators most chosen by interviewees, in which is given the number of interviewees selected the indicator out of the total interviewees that fill the checklist.

Furthermore, the curriculum analysis shows interdisciplinary cooperation as part of learning outcomes (recall for the overall qualification profile and two course modules from the second semester); however interdisciplinary cooperation is pointed at as a barrier by **F3_{UPM}**. In his experience, it is very difficult to form groups across the programme specialisations, partly due to rigid regulations of the curriculum for group formation, meaning that once students enter in specialisation they can only form groups within the same specialisation, and education:

*The procedural ones are for example: it is very difficult to form **cross functional process groups**. From the time you get in at AAU, from day one until you finish your bachelor, you are in environment, energy and urban, it is the same study. When it comes to the master it splits. So what happens is that you get **shared classes**, that they take, but when it **comes to projects group formation - urban stays with urban, environment stays with environment and energy stays with energy**. What that means is if there is a group in urban planning which is focused on sustainable mobility or something like this, **they look at it with their particularly lenses**. So they see it from the way an urban planner would see it which is very different from the way someone who does energy planning would see it, or someone who works with environmental stuff sees it. I personally tried to structure a group like that last semester and the students didn't like it. (**F3_{UPM}**)*

In this sense the curriculum praises for interdisciplinary cooperation, however, it is not verified conditions in practice for such collaboration. Another challenge mentioned above is the students' resistance, who already carry and identity based on their education background and field. Another reason pointed by the interviewee for students'

resistance is the very specific structure guidelines about what project should contain and deliver in order to get a good:

*[...] the study board guidelines are very explicit about what the delivery of the project should be. And that is not negotiable, so when students deliver a project they **have a series of goals**, and if those goals are not consistent between environment, energy and urban, so the project groups are responsible for delivering because it is 15 ECTS for that. So they are **responsible** and they will be **evaluating based on these criteria**. Actually the structure here is interesting enough in a PBL environment; makes it **almost impossible to create cross functional project groups**. (F3_{UPM})*

This point is supported by F1_{UPM}, stating that before the curriculum changed in 2010, projects module had around 25 ECTS of time allocated. At the moment, they have only 15 ECTS, but students continue to submit similar projects as the one submitted before 2010. This means that students have less time allocated to elaborate on the project content. In this sense, students may become strategic and goal oriented, when it comes to planning and carrying out project work.

Interdisciplinary encloses content, but encounters challenges in practice, especially forming cross programme groups. Another point given by the same facilitator is that it is difficult to engage in other programmes and find a common goal, problem, or project. This may be one of the limitations of PBL process in itself to fulfil all its potentialities, enclosing interdisciplinarity in content, but not in terms of problem solving approach and cooperation. These challenges could be, for example, addressed through the creation of megaprojects, in which students meet in interdisciplinary groups for some parts of the project work. However, the type of problem and intended learning outcomes should also be defined and agreed on among the academic staff (especially facilitators). This approach would not only bring interdisciplinary cooperation among students but likewise among academic staff.

Emphasis on contextual learning

Contextual learning is referred to in the interviews as part of different discourses. The discourses vary from challenges to motivational factors, with links to many other PBL variables considered in this study.

The contextual learning appears associated with:

- Programme characteristics and its link to profession
- The PBL approach and curriculum structure

- Meaningful learning

According to **SB1_{UPM}**, the UPM specialisation encloses a contradiction. It is considered to be contextual, but in some cases the context is also considered detached from the profession. The creation of an education programme is linked to practical reasons, meaning that once there is a profession as urban planners there should also exist an education oriented towards the profession. However, along the years, the UPM specialisation has kind of lost the link to the object of profession, and focuses more and more on processes surrounding the profession:

*UPM it's **too contextual** and there is, if I can be very rude, there is not core of the profession. It started out as what you call a professional education. You say 'you have some planners out in the real world that should plan something - energy systems, road systems, good urban areas to live in and so on. And then you have more and more **people analysing the processes** around the city, e.g. power relations. But what has happened with UPM, as I can see it, is that you totally **lost the object** - what is the object. [...] (**SB1_{UPM}**)*

The problem raised here is that an education can move so much into the contextual sphere that it kind of loses sense of the text (also sometimes referred to as core of field).

Along the same lines, **L1_{UPM}** characterises the UPM specialisation as a broader and generalist education, with no core technical definition as other more traditional engineering fields. In fact, some students corroborate this, like for example **S3_{UPM}**, by pointing out that they learn a bit of everything:

*I think we **have learn a little of everything for skills**. I've learnt during my project to do strategic environmental assessment and stuff like that. **We learn how to understand the tool, we got a lot of knowledge of the way we can use it**. We can do it in different ways, and we can choose within these frames too. I think that is a little bit of everything. (**S3_{UPM}**)*

The PBL learning approach and curriculum structure poses some challenges to lecturers having the perception that once being in a PBL environment everything should be problem based. Facilitator **F1_{UPM}** and **F2_{UPM}** are also UPM lecturers. They say it is in the courses where students acquire the knowledge they apply and use to contextualise their projects. In the lectures they, however, try to exemplify the applicability of the theories in practice as it is explained by **F1_{UPM}** in the following:

*Often it is much easy to start out by introducing the theory and then afterwards give some examples of how to **contextualise**, how that theory might be used, what are the limitations of that theory in practice. [...] The way it is structured at the moment, at least in the course I run, we introduce a theory each lecture, and they get to know the theory and then they can take these theories and use them in their projects. It is more like a resource, and we also create this new thing, at the end of the course we do workshop where the students 'play' with the different theories and apply them to a different case. But as it is now, I suppose the **lectures** are more as **resources** to be used by the students in their **project work**.*
(F1_{UPM})

In the lectures, students are involved in exercises to develop a deeper understanding of the theories and their use in project work, and as facilitator F4_{UPM} poses “project work makes the learning process tangible”. On the other hand, working in a PBL approach does not necessarily take for granted the conditions for contextual learning if the problems and project work are too narrow and well-structured. Student S6_{UPM} shares her experience from the bachelor education in structural and civil engineering, taken at Aalborg University:

*The bachelor is no way near balance, because it is relying on only one thing, which is technical solutions and improvements. I think what I have missed in my bachelor was the balance of what I am **being taught** and **how I can use it**. What they mostly did was to **fire way with all the theories**. [...] In this master I was given the **opportunity to connect**, especially in a course where there was always given an **example**, he would always end by saying this is a planning theory, this is how you can use it, here is a case where it has been used, and we have to present ourselves and **reflect upon and connect to a certain problem**, or area or whatever.*
(S6_{UPM})

Self-directed learning

Self-directed learning is a practiced learning principle in a PBL learning environment, and this is also reflected in the relation between project work and courses. Through the course modules, different theories and approaches are delivered to students, from which they select, and apply in the projects. It is also through the project work that students develop a deep learning on the theory, or approach selected, as it is explained by lecturer L1_{UPM}:

*They are **introduced to different approaches and then they have to dig deeper** in whatever they choose to use in their projects, guided by their supervisors. (L1_{UPM})*

The degree of self-directed learning and how far a student can go depends on individual factors as well as group dynamics. Like student S5_{UPM} experienced, this is very much a matter of communication and work division:

*I have been able to go into depth with whatever **subject I found interesting**. Ok, you always have to kind of find... You are in a group of 4, 5, 6, 7 people, and you have to find **something that you all find interesting**. But I think I have been very lucky, I have always been in a group willing to give and take a bit. All members of the group have always found something interesting in whatever we were doing. Because we can go **into details** (S5_{UPM})*

Facilitator F4_{UPM} corroborates by affirming that it really depends on the students themselves, how far they go digging into the different subjects. According to the above quote, it is up to the students in which theories they choose to develop more knowledge and group individual's level of ambition, personal engagement and interest.

Problem analysis, formulation and solving

Students themselves formulate problems that are addressed in the project modules, and likewise, students identify and analyse the contexts of the problem. The identification and choice of "problematic cases", as it is referred to in the interviews, and from which problems can be formulated, are organised in the beginning of the semester, where both students and facilitators are invited to bring and present cases.

These open curricula in the project modules explain the varied themes found in the students' project reports, from climate change adaptation, to rail road constructions and civic movements. The result of the analysis of the projects can be found in appendix 9 (p. 123).

Nevertheless, students face some challenges in formulating specific problems from open and ill-structured situations as it is explained by facilitator F2_{UPM}.

*I find it for technical engineer, in the field I am working and teaching is... we have to **put a lot of effort in this problem formulation**. And while we*

are very good in **creating the solutions, the problematizing of something**, I find this... sometimes you have really fill them with questions. So this I think is the main obstacle I can see. Well... I think they are very good in the other things. (F2_{UPM})

In the project solving process, students use theory in the problem analysis and formulation, develop analytical framework and, later on in the process, reflect upon the results and limitations of the theory, as it is explained by facilitator F1_{UPM}.

*Students use the **theory to create the problem formulation**, their re-search question phrased in a way where it contains theoretical concepts. Typically, student projects would have an introduction and a problem formulation, and there would be some kind of **theory chapter that goes through the helpful theories**, hopefully that ends out with a kind of analytical framework that students can use to finalise their case study. There may also be some methodology as well, but then they jump to their case study and start to analyse that. And they finalise with some discussion about what they have found and what could be changed, kind of small solutions. **They always go back and always towards the end, they discuss the analysis of the results and implications for the theory.** (F1_{UPM})*

To counter-act on this rather deductive way of creating a problem formulation, the facilitators motivate students to be more explorative, and once they are able to start collecting empirical data they develop a bigger ownership and interest towards the project, as it is explained by F4_{UPM}:

*Sometimes I try to **engage them in an early pile of interviews**, for instance, to go out to the field, to really get a sense of what this is all about. Then they start to develop more **interest**, more **ownership** to their projects. And that can even help them socially wise, if they go together but, of course, that is too relative, but still. So I can see that this is a case of ownership, probably...*

By their turn, students realise the solving process is not a linear process, but rather move back and forward to formulate the problem, collect data, solving and giving the answers, and reflect upon the knowledge used in the problem solving process. Students also develop flexibility and adaptability in the way they solve problems. They know they do not hold all the answers, and there is something new coming out of the learning process, personally or individually, as it is explained by S6_{UPM}:

*I've learnt that, first of all, we **don't have one answer to any problem**, but we can solve it in many ways. I am not sitting here holding all the answers, but I am sitting here, I've **learnt how to reflect**, I've **learnt how to use tools**. And that is something I didn't get from my bachelor, maybe if I was interested in looking into steel beams I would see it, but it is not applicable for the person I am. (S6_{UPM})*

In the above quote, the student also highlights the importance of learning how to reflect upon and use the tools rather than holding all the answers. Once more, it is highlight that different learning outcomes for ESD (such as flexibility and adaptability) can be achieved through a more open and ill-structure project and its alignment with exemplary practice (students are able to transfer skills and knowledge from one situation to another).

Critical thinking

Critical thinking can be defined as “reflective and evaluative thinking which must lead to a reasoned judgement” (Mogensen, 1997), and encloses four perspectives: epistemological, transformative, dialectical and holistic. All these perspectives enclose different views, abilities and cognitive tasks from the student. In the PBL environment, students are able to develop all the perspectives. For example, students in problem analysis and formulation are able to develop an understanding of surrounding world by actively examining and questioning its different contexts and realities, develop visions and strategies to act on it (e.g. epistemological perspective). Along the solving process, for example, students become aware of the level of their own knowledge, possibilities and limitations to act and change the surrounding (e.g. transformative perspective). But PBL is also team based, and students solve problems collaboratively becoming aware of different ways (e.g. culturally and/ or professionally) the group members contextualise information (e.g. dialectical perspective), and that also decisions and actions involve feelings and emotions, not only knowledge (e.g. holistic perspective).

Several interviewees shared experiences that link with these different perspectives of critical thinking such as how they are carried and relates with the learning process.

In the following example, reflection is seen as a continuous activity along the problem solving process, as well as nonlinear. Students are involved in different tasks such as: 1) problem formulation, 2) solving process, and 3) assessment of the solution. Student S1_{UPM} explains in relation to these three tasks that reflecting about your own

knowledge is continuous, and it extends to the different theories and how they link it with specificities of the case, including different actors and systems:

*[...] I think the first one is **when you start creating** it [ref. to problem], but you **start reflecting about** it in the second one, when you **gather the knowledge and information, when you are actually sitting with the case you are working on**. Because that's where you have to be aware of lack of knowledge and you have to be aware of theories that **have to connect together with the case, as well as with different actors and systems**. That's where you start reflecting even though you still have the last part, which obviously would be the one you do. But I think you start doing it in the second phase, and then, in the third phase, you use our reflections to produce that [ref. to solution assessment]. [...] You will never do it just in a logical way, **theories are never 100% and you find out, when you do empirical work, that you miss something, which lacks, limits ones knowledge**. But suddenly pops up and say I was not aware of that, or theories haven't been aware of that. It is actually an interesting area here. (S1_{UPM})*

PBL encloses reflection along the entire process; however, this student distinguishes between reflecting about the theory, use and limitations, and being able to answer the question “why” about the decisions, as the student S1_{UPM} explains:

*I think the challenging part is to **remember to criticise all the time**, in the process you are right now, breaking down into parts and say “**where are we now; why we are here and why we didn't end in the other corner instead?**” I think that is something we learn in the first three years [ref. to the bachelor at AAU] and something that takes even more time to know with students that never tried it before [ref. to international groups in master education]. But I think it can be kind of hard. (S1_{UPM})*

This student had a bachelor in B.Sc. Urban, Energy and Environment Planning, from Aalborg University. She considers herself familiar with the method and how to work with it. She emphasise the need for reflective skills along the process and in relation to what. She recognises somehow the reflective component “disappear” along the education years, however, when groups integrate students with no experience in PBL; she revises and recognises the difficulties in “re-appropriating” such skills towards the learning process. She mirrors her first years as bachelor students in the new master colleagues.

In the interviews, it was also asked about the different critical thinking perspectives through a checklist (checklist E). The checklist is only used with facilitators and students in order to pin point the main tasks along the learning process.

Facilitators tend to emphasise epistemological perspectives, while students tend to emphasise dialectical and transformative perspectives of critical thinking (figure 8-6).

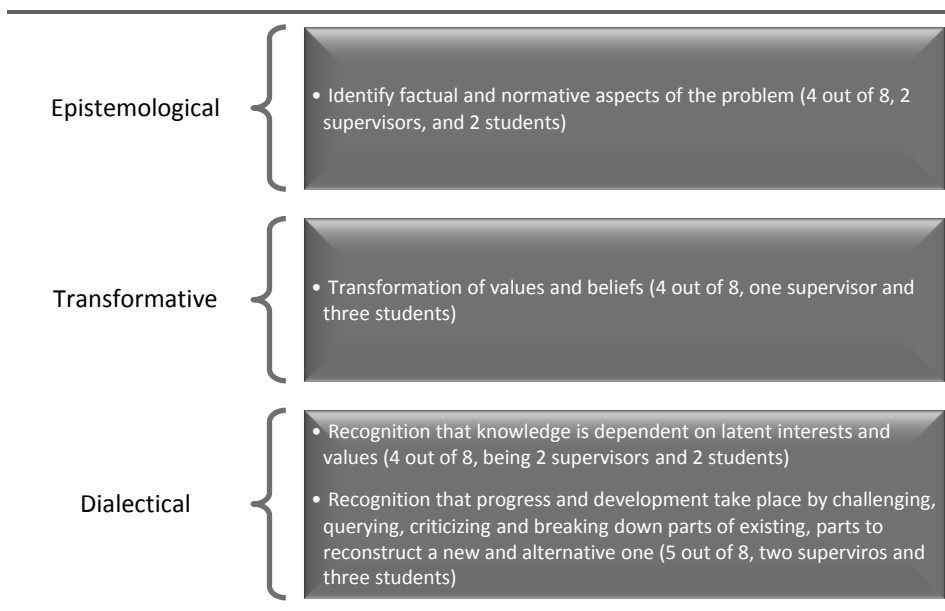


Figure 8-6 Type of critical thinking from checklist E and indicators most chosen by interviewees, in which is given the number of interviewees selected the indicator out of the total interviewees that fill the checklist.

The results from the checklist (towards students emphasis on dialectical and transformative critical thinking) reflect the learning within groups, composed by different students with different interests, backgrounds and personalities, and how to manage it in order to complete the project for the semester. I stress here the choices emphasise the values and beliefs transformed along the learning process, giving a transformative dimension to the learning process. Furthermore, **S1**_{UPM} also points at feelings as part of the learning process, as it is exemplified below:

*[...] your values may change afterwards, but probably help when you work with specific cases [...]. I think **many discussions are based on feelings and reasons why**. [...] I think in many situations **there is a feeling behind it**. In my case it's a mixture of rational thinking saying how it*

should be because it's best for everyone and, of course, depends on the case. There are also feelings involved. (S1_{UPM})

In sum, the PBL approach changes you, how you learn, how you see the world, but also how far you are aware of these different changes and challenges.

Communication and collaboration

In terms of communication and collaboration, different cultural and professional backgrounds posed challenges to group learning and project work. F4_{UPM} explains as in the following:

*Examples of challenges come from experiencing an international environment when it comes to the master degree; groups enclose students from different nationalities, personalities, educational backgrounds, and expectations. So probable challenges I see is that there may be cases of very different cultural backgrounds, and educational backgrounds. So these two different things: the country where they come from, the way they grow up; and **also the planning education is different depending on the country they are coming from.** [...] These different **planning traditions** merge into work in a **specific problem**, in this case was about public participation, collaboration in planning. And the challenge was that people have different ideas, they come up with different perspectives and the one that has the strongest personality trades. (F4_{UPM})*

In the above example, also the diversity of learning environment, and views towards the profession, need to be handled and integrated in project work by students. This constitutes also an example to illustrate a learning opportunity towards a dialectical perspective of critical thinking.

Student S6_{UPM} characterises collaboration as a tool, in which different group members with different educational backgrounds bring different glasses to look into reality. To some extent collaboration is also part of building a community of practice with shared values and understandings, enclosing difficulties to embrace others who are not part of the same community.

Even though AAU education is team based, there is some resistance from students to collaborate across disciplines. As the facilitator F3_{UPM} perceives this it is related to how community of practices are traditionally built in academia. Different community of practices have different conceptual frameworks. If members of different communities

of practice come together, they find difficulties in collaborating because they do not have a “common language” for the same objects:

*When you see research groups that have natural sciences and social sciences, they **haven't had a lot of experience in looking into each other's worlds**. They **simply don't understand each other**. At a fundamental level, what constitutes an empirical fact from a natural science perspective is often perceived as a possible explanatory cause from a social scientist, and vice versa. So here, natural scientist and social science in the presence of so-called evidence and they go 'huff that is not evidence, that is you describing something else'. That **cultural gap in an engineering programme is interesting because that is one of the tensions I find quite fascinating here**. (F3_{UPM})*

According to the above interviewee, AAU has conditions for a more interdisciplinary collaboration between programmes and departments; however, the latter also have a strong cultural discipline identity which poses challenges to the mentioned type of collaboration.

8.2.2 Education for Sustainable Development practiced

The experiences of ESD are concerned its definitions, perceptions and aspects as a result of interviewees responses, project report analyses and observation of status seminar.

Sustainable development aspects

The sustainable development (SD) aspects present in the UPM education are based on the interviewees' responses in checklist B (SD aspects), project report analysis and observation of status seminar.

Through checklist B, interviewees pointed at social sustainability aspects, such as local government, public policy and legislation; local community engagement, impacts assessment and development programmes, as major themes present in the 2nd semester of the programme (figure 8-7). These aspects also overlap with aspects resulted from the formal curriculum analysis for the 2nd semester.

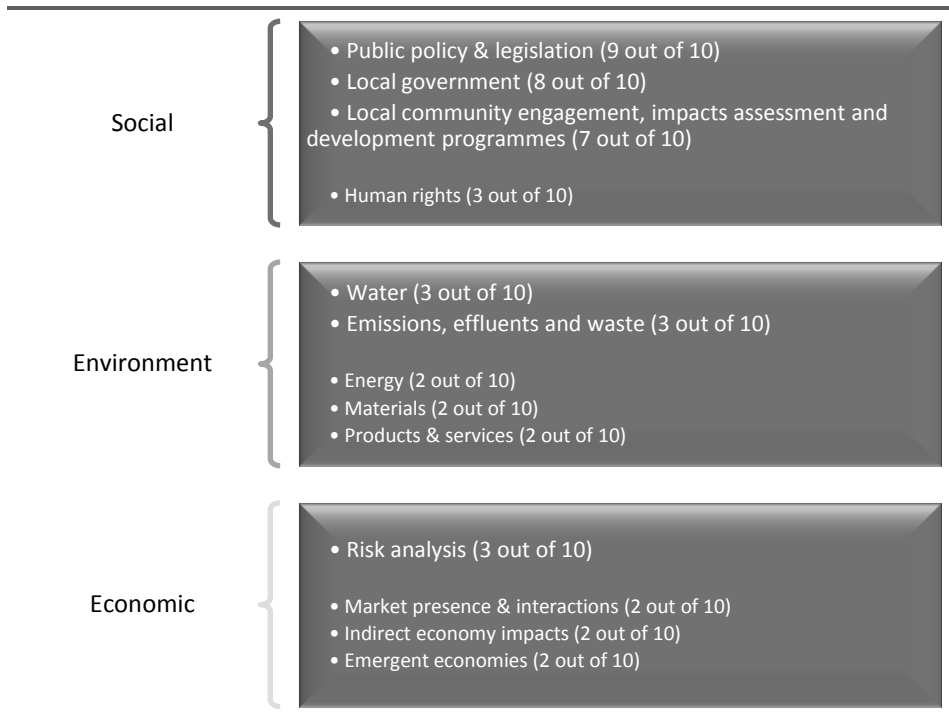


Figure 8-7 Main SD aspects pointed out by interviewees, in which is given the number of interviewees selected the indicator out of the total interviewees that fill the checklist.

The less social aspect pointed out by the interviewees is human rights (represented in the above figure in a smaller font). In fact, the human right aspect is pointed at by the **SB1_{UPM}**, **F1_{UPM}** and **S1_{UPM}**.

S1_{UPM} project is related with civil movements in the city of Hamburg, Germany, and **F1_{UPM}** was the supervisor of the group. In the observation of the status seminar, the students mentioned discrimination, and re-allocation of emigrants as part of the planning rational driven by politic and economic forces, being the civic movements against it.

Environmental aspects of sustainability are pointed out in relation with materials, water and emissions, effluents and waste. The economic aspects are mainly related to risk analysis, market presence and interactions, and indirect economy impacts.

Table 8-3 presents the different students' groups and project titles in the second semester of the education. There is a variety of themes easily linked with social sustainable development aspects pointed through checklist B.

Table 8-3 Students' projects titles

Group	Group formation	Facilitator	Project titles	Main SD aspects
1	S2 _{UPM} , S3 _{UPM} , S4 _{UPM}	F1 _{UPM}	One role to rule them all? A case study of the Hybrid role of collaborative planners in Skive Municipality	Society and economic
2	Four students (not interviewed)	F4 _{UPM}	Bridging Gaps through Community Collaboration – A Case Study from the Regeneration of Groruddalen, Oslo	Society and Labour practice and decent work
3	Three students plus S1 _{UPM}	F1 _{UPM}	A Fight for the Right to the City: The Case Study of an Urban Social Movement and the Fight against Neoliberal Planning in Wilhelmsburg	Human rights and economic
4	Four students plus S5 _{UPM}	F2 _{UPM}	Keeping the discourse on track - An analysis of the light rail project in Aarhus	Environment and economic
5	Two students plus S6 _{UPM}	F3 _{UPM}	Collaboration in climate change adaptation: A case study of Copenhagen	Environment and society

The project reports show mainly the presence of social aspects followed by environment and economic aspects of SD. This shows an overlap between the checklist results, formal curriculum, project reports and observation of the status seminar.

For example, in the project from Group 1 (students S2_{UPM}, S3_{UPM}, S4_{UPM}), there are found some references concerning environment impact assessment, land use, protection habitats of birds. These aspects fall into environment aspects of SD, however, the analysis shows a higher number of references of social and economic aspects of SD. The following is a quote from the project report aiming to illustrate the stated:

[...] “Environmental Impact Assessments are still considered important in making planning decisions. [...] Finally, the state established seven Environmental Centres responsible for the development and maintenance of the EU habitat and bird protection areas. [...] We are now in what can be labelled the Information Age, which includes a new order of economy and society. [...] and since then planning and other public policy arenas have been increasingly characterised by cooperation with actors from the market and civil society [...] (S2_{UPM}, S3_{UPM}, S4_{UPM})

Even though all aspects of SD are present in the education, the focus is clearly in the social aspects, to which the remaining aspects, including environment and economic

aspects, are linked. In the example taken, the project is focused on the planner, his professional role and relations, and how these can touch upon areas such as environment regulations, economies, markets, stakeholders, etc., which are part of the planner context.

This is supported by student **SS_{UPM}**, who explains the presence of sustainable aspects, such as environmental impact assessment, economic factors, as not central in the problem formulation and solving process, but rather part of the overall context:

*There are few elements of it, we **are not discussing sustainability, saying what it is and describing the theory behind**, we are not doing that. But we have something about some climate issues, or something, but we are not describing it because they talk about green transportation, but only have an excuse for something else. (SS_{UPM})*

ESD perceptions and definitions

Beside the SD aspects, interviewees also pointed at the ESD principles (indicators from checklist A) considered present in the education. Here, there is not much discrepancy between academic staff and students, perceiving themselves as being problem solvers; systemic and holistic; flexible and adaptable instead of contextual; participatory in decision making; creative and innovative (figure 8-8).

Problem Solvers	{	• Involve others' perspectives and knowledge in defining and solving complex problems (8 out of 10)
Systemic and holistic	{	• Aware that engineering practice influences, and is influenced by other professional practices (6 out of 10)
Flexibility and adaptability	{	• Accept that there are no guarantees that our solutions will be truly sustainable (6 out of 10)

Figure 8-8 Three main ESD principles identified by interviewees as part of education. These are pointing at indicators in checklist A, in which is given the number of interviewees selected the indicator out of the total interviewees that fill the checklist.

In fact, some of the indicators stated in figure 8-8 relate with the frames of students being educated as urban planners. System thinking and holistic, flexibility and adaptability approach to problem solution was already discussed above regarding curriculum analysis and experienced PBL principles.

Furthermore, the curriculum has space to accommodate all these principles, given by checklists A, as it is explained by study board member **SB1_{UPM}**:

*Definitely, the curriculum **has more space to do things or to develop more skills** than it is represented in the learning goals. That is another thing that you should be aware of, you can look into the learning goals and of course it says something about what you should expect in the end, but what you also experience depends pretty much on **what the individual student does and chooses to do in the project**. Because **projects still drive the education**, what the supervisor is. Of course, they should be living up to the learning goals, but with a good supervisor, a good student can go much more into it than what the learning goals express. (SB1_{UPM})*

Nevertheless, he also stresses that what can be achieved, in terms of these principles, depends pretty much on the type of project and problems chosen by students, and supervisors.

Facilitator **F4_{UPM}** considers the presence of SD as part of the first semester, but regarding the second semester, "things may be a little bit unspoken" as it is also pointed out by **F1_{UPM}**:

*[...] So **Sustainable Development is there but maybe a bit like "unspoken", underlying everything**, so you don't have necessarily to specify that the aim of the project is to come with new ways for sustainable urban development, for example. I think, at least, if the semester project is more, let's say 'this semester about power' so that is where we focus on. This semester could be for example about traffic planning, next semester about land planning or climate change, and then you would **sort out of different perspectives**. (F1_{UPM})*

Some of the SD perspectives are brought into the project, but the clear focus remains in the semester project theme (which is for the 2nd semester a programme on Power in Planning). The different semester themes shape and build different worldviews and understandings in students towards ESD as it is pointed at by student **S3_{UPM}**:

*I think somehow I've seen this as is; I **got a lot of skills and knowledge about Sustainable Development through the bachelor and last semester**. Very much and then now taught how to use that, how to actually*

*with my eyes open go into the world and actually do something about it as much as I can and still acknowledge that we have so many different powers out there, economic powers, political powers, that will **really block us in our pursuits, in our missions** to make **everything right**. [...]* Actually, I think it is fine that this semester has nothing to do with environment, or anything. I feel like they have done a pretty good job teaching us that until now. And so I am ready just to learn how to be an actual planner now. (S3_{UPM})

There is an integration of ESD along the bachelor and master education, however, it is also important to stress that students seek a professional education for practice. This raises the point at the dangerous of integrate “too much” ESD in curriculum, such as making everything about sustainability, leads to decrease the students’ motivation and interest in the programmes.

In the above quote, there is also an emphasis in the environmental sustainability as being perceived as sustainability, with no clear connection to other aspects. S1_{UPM} points out that in her project work it was never considered social to be sustainable, but more what is right and what is wrong:

*I don't think the social aspect so much as the sustainable one even though I know it is there. But when I talked about it in general, it is not what I would define as sustainable. Sometimes, I think probably more about nature than I think of society. We **didn't think of sustainability but we did think that there should be more... there are things in society that are not as equal as supposed to**. Then, of course, you can make the link with sustainability. There is something, or lack of something with regard to the case we work with. (S1_{UPM})*

In student S5_{UPM} experience, it seems that there is no clear and concrete definitions of SD at institutional and programme level, leaving to students the development of understandings and definitions, and how it can be related with other topics, themes, and contexts rather than environmental ones.

*I've been working with sustainability at least two semesters, and I know I have a very clear and comprehensive understanding of what sustainability is, but it would be very interesting if this **institution kind of has its own official understanding of sustainability**. That would likewise have limited us, in some of my projects, because there was this one semester where I, myself, spent a lot of **time describing what sustainability could be in urban planning context**. And I wouldn't have done that if they had an explicit explanation of what it was. Then ... Ok, we may have spent our*

time in something else but, however, this was the way we learnt what sustainability is, or at least how we see it. (S5_{UPM})

In this student perspective, the organisation should create a conceptualisation of sustainability which meets its holistic and overarching principles, but also the context of the different educations.

8.3 Curriculum perspectives for ESD

The curriculum perspectives address the interviewees' views on improving the curriculum and how ESD could be better addressed and integrated.

The perspectives are of two types. The first one is in relation with the practice of the institution and the constraints and limitations of the PBL model. A second type is related with possibilities to do better integration of ESD in education (figure 8-9).

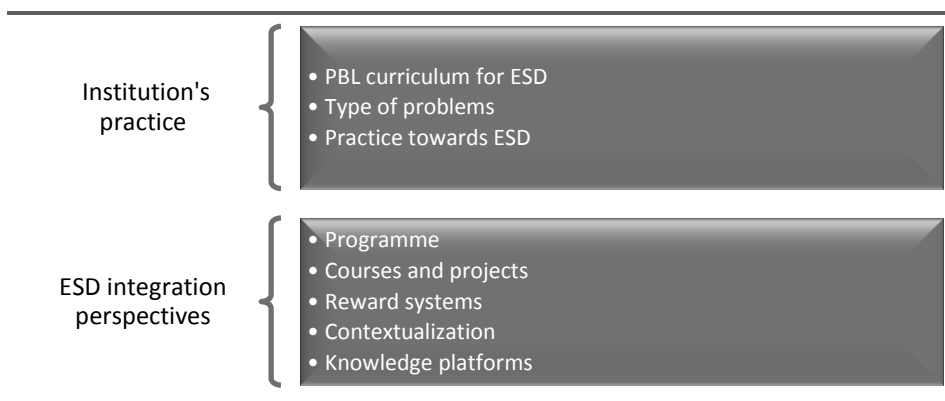


Figure 8-9 Different perspectives addressed by interviewees

Institution's practice

The perspectives towards institution's practice enclose aspects of its mission and vision, education towards ESD and PBL model evolution through time within different programmes.

According to **SB1_{UPM}**, the present PBL model tends to remove the reflective and social components from the education, focusing only on providing technical answers. This puts an emphasis on technical aspects of discipline, living out the "why it is needed to

solve the problem, to whom, how and what are the consequences.” In this sense, the contradiction emerges from the possibility of solving problems without social contextual factors, and its consequences in a broader context:

*If you start out, and have that as a goal I see a contradiction with sustainability. If you start working with PBL, and then have such a **strong focus on solving concrete problems**, you take on all what I call the process of formation [ref. to bildung]. [...] You should just be able to **work problem based with all people, for the people, and you should do this problem**. And afterwards, people wonder why people cannot reflect upon theory of science, sustainability and all that. I can tell you because you take all that part out from the education. That part, and say that you should be very focused on this, and then afterwards say ‘oh! Why I do this and not this...’. In some of the very technical disciplines, you are allowed to ignore society contextual knowledge. You can just specialise and work problem based learning. And that’s why I say from the beginning of education you **start with very detailed problems and then you can get even more detailed**. Even if in paper it may even look like they work very broad, they are also very **detailed and some of the technical core disciplines**”. (SB1_{UPM})*

This calls for a reflection of how problem situations are brought into educations, type of problems formulated (which can be narrowly defined) and, most important, the roles students and facilitators assume in the process. According to the same interviewee, universities should interact with surrounding communities, assuming an active social role. However, it seems that the interaction existent is between AAU and the industry, and carried out in one direction being industry (from industry to AAU). This is becoming one of the weaknesses of AAU model, which is becoming less open and permeable to societal challenges and needs and, consequently, in providing graduates capable to address those challenges and needs.

According to L1_{UPM}, AAU has a tradition in bringing social responsibility towards technological development; however, he considers that there exist limitations when it comes to broaden the concept, and its practice towards sustainable development, as it is explained in the following:

*When it comes to **social responsibility**, we are quite good; when it comes to the perceptions of the university, we are quite ok, and when it comes to the ability to work on energy, and our ability to work with sustainability, it is very bad [...]. This is only a problem if you want to compare us with another university on how sustainable we are, or with another place in the world. You have to translate it somehow. There are a lot **of sustainability factors**, and a lot of studies strongly related with sustainability by the types of **technologies being developed for energy production**,*

*for water savings and treatment, etc., but that may not have an ethos of sustainability embedded, it has been kind of stiffed. You have a general culture of **doing sustainability stuff, but the individuals kind of forgot**, because this stiff tradition of doing these things comes at another earlier stage when their minds start to grow. And obviously, it has been pointed at as a problem, because if you want to have this to continue, having this type of praxis to continue than you need to make the mind sets to change in that direction as well. (L1_{UPM})*

The institutional practice towards sustainable development is mainly focused on technologies to provide sustainable solutions. This point at a technocratic perspective towards the role of technology for sustainability aligned with a strong focus on environmental dimension. The challenge is changing the dominant technocratic view to a more holistic one. Such vision is extended to the programmes, and how students are educated, with the focus on the environmental sustainability content and tools. Inevitably changing the institution practice based on more ESD principles it is needed to revise the type of problem scenarios are brought to education, and how the problem solving process is carried out.

Supporting this assumption, the student perceptions of SD are mainly linked with environmental sustainability. The academic staff has an important role in shaping of and orienting students towards the integrative and holistic practice by example.

Perspectives towards integration of ESD

The interviewees were questioned about suitable initiatives to integrate ESD in education. According to L1_{UPM}, the strategy for integration should enclose multi initiatives, operating at several levels within the organisation. For example, use the curriculum structure, staff development and rewards systems. Figure 8-10 summarises the suggestions given by interviewees.

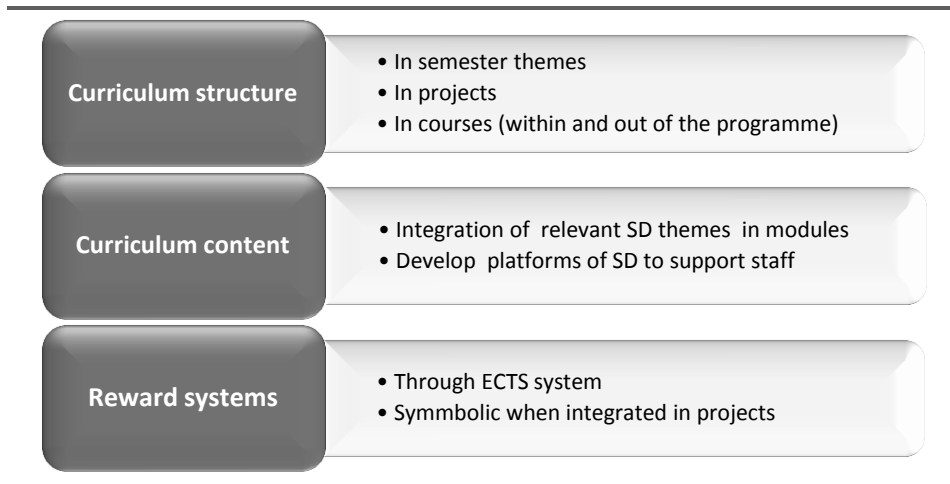


Figure 8-10 Main suggestion given by interviewees concerning integration of ESD in the programme

The integration through projects and courses is unanimous. According to the interviewees, both present different opportunities for ESD.

For example, SD can be used as a project theme. Project work has the point of departure in analysing real and ill-structured situations from which a problem is formulated. This poses possibilities to also analyse the real situation under ESD principles, or link with relevant themes.

Project work encloses several phases (from problem analysis, to problem formulation, solving problem strategy, solutions and discussion of the solutions) and is carried out throughout the whole semester (approximately 3 months). With this structure and time allocated, the project presents several opportunities to integrate sustainability. When questioned about where ESD could be integrated within the project, interviewee **F2_{UPM}** explains that its presence should be made from the beginning, with strong focus on problem analysis and formulation due to its complexity, but also to assure that solution addresses the sustainable issues pointed out in the problem:

*In the **problem formulation**, [...] because it is a **complex problem**, it is not one way, it is not one problem. And, technical universities, and technical engineers and students, they always create solutions. Or they forecast, or they try to, they are able to do so. [...] Of course, then I think, coming back, the created solutions, I think the outcomes of the **problem solution can also be re-framed** in the sense that not having one **problem of sustainable development**. I think this creation of solutions can be proven much wiser. (F2_{UPM})*

According to student **S5_{UPM}**, the problem, its context and elements, shape the solving process and solutions. In this sense, he argues that SD should be present in the beginning, in the problem analysis and formulation, and become part of all reflection and decisions made:

*I think that, it is just me, if I knew from the **beginning** that this project would be about sustainability I think I would **always start with the problem** because sustainability, it is such a huge topic so... and I think I need to describe it, I need to say what sustainability is, and at least what we as a group mean when we say sustainability in our report. So always think of it from the beginning. There could be of course other ways of doing it. [...] And sustainability is not the only one, but sustainability in itself is one of the largest topics you can touch upon... (S5_{UPM})*

Part of the multi initiatives to integrate of ESD is the creation of courses which can provide basic SD knowledge and tools, which can be mobilised and further developed in the project. The interviewees give several suggestions of how these courses could be constructed and related with overall programme progression. For example, **F1_{UPM}** suggests cross programme courses, but whose content also fits the field of study. These allow the development of sustainable development concepts; create platforms for interdisciplinary cooperation among students.

Apart from the curriculum structure, it is also necessary to develop structures to support academic staff. One example is provided by **L1_{UPM}** with development of knowledge platforms for sharing concepts or other resources regarding ESD.

*We have had that, but that would be something which will give you ECTS and would compete with the educations [...]. I think we have to work on a multiple strategy, obviously if you have places where you can integrate, then we don't have to fight for the space. For example, the PV course in the first semester bachelor. In the long run we have to create **platforms and definitions of sustainability integrated in specific studies**, and we have to have it **integrated in the projects**. [...] And then the other thing is that we **should work on making specific definitions of sustainability that fit the different studies**. And it is very important that we don't have a situation where everything goes, and on the other hand, it is very important that we don't push generic sustainability concepts down. (L1_{UPM})*

L1_{UPM} suggests the creation of reward systems as a way to acknowledge those who, by own initiative, integrate SD in their learning and/ or teaching. This is also a form of recognition from the top level of the bottom initiatives. Reward can take several forms, it can be monetary, symbolic or through ECTS.

Nevertheless, from the suggestions provided by interviewees is possible to find some challenges. For example, the curriculum structure, in which the guidelines are clear, and strict, of what a project report must contain and be assessed about. Also when it comes to students getting courses in other programmes, for example, the university office for accreditation and assessment may not necessarily recognise them as part of the overall qualification profile of the programme. In this sense, students would not fulfil the necessary requirements to graduate.

The curriculum structure delivers an education in which students are “close in programme silos” from the day they start the education until graduation. This is very much linked with a reductionist approach to education in opposition of a more holistic, interdisciplinary education.

Final remarks

In this chapter, the PBL principles and ESD aspects in the formal and practiced curriculum of the UPM curriculum have been presented together with future perspectives to point out potentialities and tensions in integration EESD in a PBL environment.

The formal curriculum and experiences enclose an evolutionary and interdisciplinary approach with a strong focus on critical thinking, contextual learning, self-directed learning and project work.

The curriculum of the UPM specialisation furthermore encloses several opportunities for integration of ESD, with key principles already present in practice. Like for example the presence of system thinking and a holistic approach towards problem solution through the development of evolutionary knowledge aligned with interdisciplinarity. It is important to reflect upon the fact whether these principles are a consequent of the interplay between the education characteristics (perceived as general and broad with weak link to profession as it was pointed out by **SB1_{UPM}**), professional identity and curriculum structure (problem themes, type of problems, problem context and their formulation, etc.).

Urban planners' profession involve a multi-system object that is a city, comprising technical dimensions (e.g. infrastructures), social dimensions (services, policies, economy, etc.), and human as well. If it is a consequence of profession identity and nature, engineering education programmes, with strong focus on and identity towards profession, may present barriers and challenges to ESD. In engineering programmes more social oriented may not necessarily face the same kind of challenges.

PBL and ESD principles are varying, and they are even interdependent and interconnected in the learning process, it is very important taking into consideration the landscape of variables investigated in the practiced curriculum. For example, self-directed learning and contextual learning are highlighted by all interviewees as key principles of education.

It seems that these competencies are developed for profession and what is perceived as core of programme. If so, the self-directed and contextual learning support the construction of disciplinary knowledge within engineering field. For example, contextual learning is a principle for ESD, and it has been included in checklist A (ESD principles) to be filled by the interviewees. Very few interviewees identify contextual learning as already part of the education. This is a contradiction considering the PBL learning environment and its principles. The indicators enclose examples like developing solutions locally and culturally appropriate, as well as seek to minimise the negative impacts. It seems that contextualisation is given by the fact that students relate their reality to problem contexts, but do not look into variables and elements that compose the real context of the problem.

Also interdisciplinary presence appears to be limited to diversity of subjects within courses. When it comes to collaboration and diversity of people, these pose a challenge to both students and academic staff. Interdisciplinary cooperation is part of the qualification profile of the programme, but there are several barriers posed to develop such teams. First, it seems that it is not a learning outcome to be developed along the education and assessed. On the other hand, some other barriers like accreditation of elective courses, assessment, resistance from staff and students, and the rigid structure of the curriculum pose also barriers to such development of interdisciplinary cooperation. One example given is the barriers to form cross programme teams.

Also, there is a strong identity of lecturers and students towards PBL environment. Lecturers find it challenging making a normal lecture problem based. For the students, since 2010 the curriculum has less time allocated to project work, but students continue to allocate the same time to project work as before 2010. The crowdedness of PBL curriculum may not be related to the amount of disciplines and theory to learn but rather by the time allocated to projects.

Beside the aspects posed above, the UPM specialisation encloses several PBL principles aligned with EESD principles. Curiously, some principles do not appear formulated in the formal curriculum, like for example system thinking and holistic, or flexibility and adaptability. It is also important to reflect on what leads to practice the mentioned principles (if it is due to the broader nature of programme, profession or type of problems scenarios). Another example is the sustainability definitions and perceptions which are mainly towards environmental sustainability. However students projects themes enclose aspects of social and economic possible to be related with sustainabil-

ity but are not perceived as such. In this sense, it is important to reflect upon whether the programme focuses mainly on ESD tools, such environment impact assessment, missing other relevant aspects, tools and principles for sustainable development.

Table 8-4 synthesises the main conclusions from UPM specialisation towards PBL principles and the possibilities and challenges to integrate EESD.

Table 8-4 Matrix of main findings of M.Sc. Urban, Planning and Management specialisation

	PBL principles	ESD principles
Formal Curriculum	The overall profile encloses meta-cognitive knowledge, whereas some modules even move to the evolutionary level of knowledge. Focus is on complex systems as the city, whereas key PBL principles are interdisciplinarity and contextual learning.	All SD aspects are present in the first semester, while in the following semesters SD is limited to policies, ethics and professional responsibility.
Practiced curriculum	Meta-cognitive knowledge is stressed Critical thinking as a continuous activity along the problem solving process – students tend to emphasise the dialectic dimension whereas the facilitators emphasise the epistemological dimension. There is a clear emphasis on contextual learning based student work on real life scenarios. The curriculum is more a barrier than a driver to foster interdisciplinary student collaboration. In the lectures, the content is presented in a deductive way – presenting the theory, followed by examples. The students seem to mirror that approach in the projects. Intercultural groups of students and staff provide opportunities for interdisciplinarity, but it is a challenge to “look into each other’s worlds”.	Even though the curriculum encloses social aspects of SD, students only include environmental aspects in their perception of SD. In the second semester, social relations seem to be the point of departure in working with sustainability, but students draw in SD knowledge from the first semester when the problem calls for it. The environmental perspectives are related to the urban ecological system. The economic aspects are very limited, both in in the projects and in the dialogue with students and staff. ESD perceptions were related to problem solvers, a systemic and holistic approach as well as flexibility and adaptability. Not too contextual knowledge as could be expected. SD is more seen as a subject, than as a process.

In the curriculum perspectives, interviewees mentioned the dominant institution practices towards SD as technocratic and the focus on the environmental aspects, which to some extent impact how students build their sustainability definitions and perceptions. They also suggest initiatives to integrate ESD. These do not only involve curriculum structure like integration in projects and creation of courses, but also conceptualisation and reward systems.

9 Sustainable Education for Civil Engineers

This chapter presents the main results from the study of M.Sc. Structural and Civil Engineering (SCE) programme. The results are based on the data collected through the content analysis of the formal curriculum, and interviews with study board members, lecturers, and facilitators.

This chapter follows the structure from the previous chapter. Each subchapter looks into PBL and ESD principles, whereas the specific subsections focus on the formal curriculum (9.1.), the practiced curriculum (9.2) and perspectives (9.3). The chapter closes with main conclusions from the programme studied (9.4).

9.1 The formal curriculum

The curriculum analysis is carried out on two levels. On the first level the intended learning outcomes (ILOs) of the overall programme, i.e., the qualification profile, is analysed. This summarises what is expected of students when they graduate. The second level encloses the analysis of ILOs that composes each course and the project modules along the four semesters. The detailed curriculum analysis grid is in appendix 10 (p. 137).

9.1.1 Programme overall qualification profile

The analysis of PBL variables embedded in the ILOs enclose criteria concerning knowledge, disciplinarity, learning and process competencies. Table 9-1 presents the main variables, and criteria stated in the ILOs of the overall qualification profile.

Table 9-1 PBL variables stated in the ILO of the overall qualification profile of the programme

PBL variables	Criteria	Examples of indicators retrieved from curriculum (SES, 2010)
Knowledge	<ul style="list-style-type: none"> • Cognitive • Procedural • Metacognitive 	<ul style="list-style-type: none"> – Has knowledge about... – Excels in the scientific methods and tools... – ...judge quality of results...; Must understand [...] for analysis and design on ...
Disciplinary	<ul style="list-style-type: none"> • Multidisciplinary • Interdisciplinary 	<ul style="list-style-type: none"> – ...loads, materials, structures...; Has knowledge in one or more subject areas [...] within the fields of civil and structural engineering; – ...implement [...] interdisciplinary cooperation
Learning	<ul style="list-style-type: none"> • Self-directed learning • Contextual learning 	<ul style="list-style-type: none"> – Take responsibility for own professional development and specialization – ...select and apply proper scientific theories, methods and tools for their solution; ...work-related complex situations.
Process competencies	<ul style="list-style-type: none"> • Problem analysis & formulation • Problem solving • Critical thinking • Creativity & innovation • Communication • Collaboration 	<ul style="list-style-type: none"> – ...identify scientific problems – ...solving giving problems – ...judge quality of results – ...develop and advance new analyses and solutions; ...work-related situations [...], and which require new solutions. – Can communicate research-based knowledge and discuss... – ...implement disciplines-specific as well as interdisciplinary cooperation.

The programme overall qualification profile encloses indicators that can be linked with metacognitive knowledge, interdisciplinary cooperation and approaches, self-directed and contextual learning, process competencies. Procedural knowledge is strongly represented in the ILOs, and related with specific engineering fields indicated by words such as exemplified in table 9-1.

Interdisciplinarity is considered part of the learning and present in the following ILO:

*The program is based on a combination of academic, **problem-oriented and interdisciplinary approaches**, organised on the following work and evaluation methods that combine skills and reflection. (SES, 2010, p. 6)*

Furthermore, interdisciplinary is also formulated as part of the learning outcomes as interdisciplinary cooperation (table 9-1).

Regarding knowledge domains represented in the ILO, these are mainly under the specific disciplines of the engineering field, such as “construction materials, hydraulics, structure-soil and structure-fluid interactions, etc.”

In reading the curriculum focusing on sustainable development (SD) aspects, the overall programme points at themes that can be related to environment and professional responsibility; however, the core focus is on technical knowledge. SD aspects in the curriculum are very few and mainly related with environmental aspects, product responsibility and professional responsibility.

When it comes to environment, the perspective is limited to physical environments and elements that have an impact on the solution, like for example, wind and wave loads. The following quote exemplifies:

*Has knowledge about **construction materials and soil** regarding their mechanical behaviour and modelling;*

*Has knowledge about loads, especially **environmental loads like wind and wave loads**, and methods for their evaluation. (SES, 2010, p. 5)*

In terms of product responsibility, risk and reliability is highlighted by the following ILO:

*Has knowledge about **risk and reliability** in engineering including **uncertainties** of loads, geometry, material properties, structural response and computational models (SES, 2010, p. 5)*

Dealing with uncertainties is part of the ESD principles, when it comes to engineering education, but in the context of these formulated ILOs, it seems to be related with technical aspects only.

Besides the link to risk and reliability, there is also ILOs related with professional responsibility, as it exemplified below:

*Can initiate and implement discipline-specific as well as interdisciplinary cooperation and **assume professional responsibility** (SES, 2010, p. 6)*

Nevertheless, social factors, and user perspectives, are omitted in the ILOs formulated.

9.1.2 Module qualification profile

The programme is composed of four semesters; the first three semesters are composed of courses and projects, while the fourth semester encloses only one project module to prepare the master thesis. Table 9-2 presents the different courses and project modules that compose the programme.

Table 9-2 Courses and projects modules composing the different semester of the programme

Semester		Module
1 st		Analysis and Design of Load-Bearing Structures (project module)
		Structural Mechanics and Dynamics (course)
		Material Modelling in Civil Engineering (course)
		Fluid and Water Wave Dynamics (course)
2 nd		The Excitation and Foundation of Marine Structures (project module)
		Coastal, Offshore and Port Engineering (course)
		Advanced Soil Mechanics ¹⁾ (course)
		Risk and Reliability in Engineering (course)
		Advanced Structural Engineering ¹⁾ (course)
3 rd	A	Analysis and solution of an Advanced Civil and/or a Structural Engineering Problem (project module)
		Renewable Energy Structures: Wind Turbines and Wave Energy Devices ²⁾ (course)
		Wind Loads on Structures ²⁾ (course)
		Advanced Geotechnical Engineering ²⁾ (course)
		Fracture Mechanics and Fatigue ²⁾ (course)
	B	Traineeship at an Engineering Company ³⁾ (project module)
	C	Study at Other University
	D	Long Master Thesis (project module)
4 th		Master Thesis (project module)
All semesters(*)		Problem-based learning (PBL) and students' responsibility at Aalborg University

1) The student must choose one of the course modules.

2) The student must choose three out of the four course modules.

3) The study board must approve on the content of the Traineeship, before it is commenced.

(*) For students not acquainted with the Aalborg PBL model, this does not have formulated learning outcomes

The programme encloses elective courses in the second and third semesters. Notice that traineeship and study at another university, in the third semester, does not specify ILOs, because students have to make and submit a study plan to be approved by the study board. The "long master thesis" combines the 3rd and 4th semester projects, whereas the ILOs for the master thesis include both modules.

In the following, the main findings from the courses and project module analysis are presented. There is special emphasis on the 3rd semester, as the interviews carried out after the curriculum analysis mainly involved actors from 3rd semester of the master programme. The choice to focus on the 3rd semester was given by study board member **SB1_{SCE}** interviewed, because curriculum, and type of problems students are solving, is more open.

Problem Based Learning variables

The courses and project modules reflect the programme overall qualification profile when it comes to PBL variables.

Figure 9-1 presents the main PBL variables, and criteria explicitly presented in course and project modules, and pin points the present indicators of PBL.

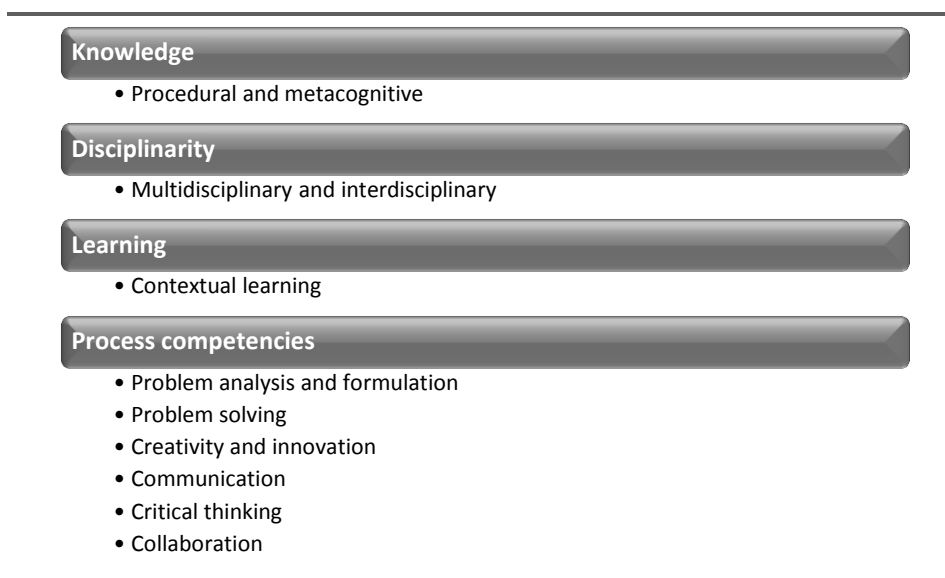


Figure 9-1 PBL variables and criteria present in the ILO from courses and project modules.

In all courses and project modules, there is emphasis on cognitive and procedural knowledge within the specific subjects of the field. Like for example in the following ILO:

Know fundamental theories and methods for analysis of dynamic structural response (1st semester course “Structural Mechanics and Dynamics”)

Almost all ILOs classified as knowledge start by “understanding” followed by discipline, specific knowledge emphasising cognitive and procedural knowledge as exemplified in the following:

Understand the nature of wind: wind profile, mean wind, extreme wind, turbulence, turbulence field – for applications for structures such as buildings, bridges and wind turbines (3rd semester course “Wind Loads on Structures”)

The progression seems to enclose a cumulative construction of cognitive and procedural knowledge, where previously gained knowledge needs to be mobilised.

The metacognitive knowledge is considered when the same ILO involves complex cognitive tasks as for example to evaluate, create, compare, apply, etc., implying a frequent combination of procedural and cognitive knowledge to carry out specific tasks. These ILO are commonly defined as skills and competencies in the courses and project modules:

Be able to apply analytical solution methods based on continuum mechanics for selected static problems (1st semester project module “Analysis and Design of Load-Bearing Structures”)

Must be able to compare and evaluate limitations and uncertainties related to the methods used for solving the chosen problem (3rd semester project module “Analysis and Solution of an Advanced Civil and/or Structural Engineering Problem”)

The notions “limitations” and “uncertainties” are part of several ILOs in project modules. Limitations and uncertainties are related with metacognitive knowledge due to its association with the verbs “compare and evaluate”, used as indicators for this type of knowledge. Nevertheless it is important to highlight that the limitations and uncertainties are strongly related with methods used in solving problems.

Engineering fields are multidisciplinary in content because their fundamental knowledge (Shepard, Macatangy, Colby, & Sullivan, 2009). Therefore, the programme

can be considered multidisciplinary; if it is taken into consideration the different subjects which compose the core disciplines in the structural and civil engineering fundamentals, like physics, mathematics, materials, statistics, energy technology, geotechnic.

However, the interdisciplinary cooperation and interdisciplinary approaches mentioned in the programme overall profile, kind of disappear when it comes to ILO in terms of courses and projects modules.

The contextual learning is associated with problems defined within the specific areas of the disciplines. In fact, it seems that knowledge constructed by students is directed for solving technical problems, missing completely other contextual factors besides a reference to ethics that only appears in the master thesis ILO:

*Have understanding of implications within the related research area including **research ethics** (Master thesis project module)*

Also the self-directed learning has less visibility in the ILO formulated on course and project level compared to the overall profile.

This also shows in the problem solving abilities highlighted in the ILO's, being the ability to solve a problem and provide a solution within specific areas of SCE as a final goal of the learning process. The following ILO exemplifies this:

*Must be able to **apply** advanced analytical and/or numerical and/or experimental methods for **analysis and assessment of the chosen problem** (3rd semester project module "Analysis and Solution of an Advanced Civil and/or Structural Engineering Problem")*

The problem analysis and formulation kind of fade away in the ILO of the courses and projects, and the same goes for the ownership to reach a broader contextualisation of the problem. The broader context and by whom the problems are formulated is not explicit in the ILOs.

Sustainable Development aspects

Figure 9-2 presents the sustainable development (SD) aspects resulted from the SCE curriculum analysis, and in which semesters are present.

The SD aspects are mainly related with environment (e.g. energy, materials, physical environment), with product responsibility (e.g. risk, reliability and safety) and research ethics. These SD aspects are in alignment with the overall profile.

1 st semester	2 nd semester	3 rd semester	4 th semester
<ul style="list-style-type: none"> • <i>Construction materials</i> 	<ul style="list-style-type: none"> • <i>Water level variations at coastal zone</i> • <i>Sediment transportation; scour and protection</i> • <i>Soil</i> • <i>Safety, risk reliability</i> 	<ul style="list-style-type: none"> • <i>Wind and wave energy</i> • <i>Reliability</i> • <i>Fatigue analysis</i> • <i>Reduce risk of fracture</i> 	<ul style="list-style-type: none"> • <i>Research ethics</i>

Figure 9-2 Sustainable development aspects pointed in M.Sc. programme ILO (<environment> <product responsibility>)

Given the above analysis of knowledge and disciplinarity, it is no surprise that the sustainable development aspects are hard to find, with exception of a course in the 3rd semester named Renewable Energy Structures: wind turbines and wave energy devices. Nevertheless, in the ILO of the course, the focus remains on the technical aspects:

Know methods for design of main structural components for wind turbines and wave energy devices (3rd semester course “Renewable Energy Structures: wind turbines and wave energy devices”)

Nevertheless, the use of indicators provided by Global Reporting Initiatives (GRI, 2011) allows to identify potential themes for integrating SD further in courses and project modules as the aspects of environment, product responsibility and ethics can be linked with some of the courses and project modules in the programme (figure 9-2).

9.2 The practiced curriculum

The practiced curriculum is based on results from interviews and aim to outline how the PBL and ESD are practiced in SCE. The interviews are mainly concerning the experiences of the 3rd semester of the programme.

The interviews were treated anonymously, being given to each interviewee a code for identifications, as it is shown in table 9-3.

Table 9-3 Interviewees identification

Interviewees from UPM	ID code	Interviewees from UPM	ID code
1 st Study Board member interviewed	SB1_{sce}	2 nd Lecturer interviewed	L2_{sce}
2 nd Study Board member interviewed	SB2_{sce}	3 rd Lecturer interviewed	L3_{sce}
3 rd Study Board member interviewed	SB3_{sce}	1 st Facilitator interviewed	F1_{sce}
1 st Lecturer interviewed	L1_{sce}	2 nd Facilitator interviewed	F2_{sce}

I start by presenting the curriculum practiced regarding PBL (section 9.2.1), followed by a specific focus on ESD (section 9.2.2).

9.2.1 Problem Based Learning practiced curriculum

In the following is presented the results from the interviewees regarding the PBL practiced curriculum.

Cognitive knowledge and disciplinary focus

The SCE master programme is characterised by study board members as structured and strict, with strong focus on technical knowledge within the engineering field. The main reason, explained by **SB1_{sce}** and **SB2_{sce}**, is that this is a natural extension of the bachelor.

The bachelor education is practice-oriented, with strong focus on developing professional skills rather than deep knowledge of engineering fundamentals. Students who do not want to proceed to the master level can finish at bachelor level and finish with a diploma degree as it is called in a Danish context. Students aiming for a research oriented carrier or more specialised positions pursue a master education. In the bachelor education, there are no separated branches, as students follow the same programme. For this reason, the first semesters of the master programme are focused on developing deep technical knowledge in order to compensate for the practice-oriented approach of the bachelor education. This is the main reason why the curriculum proceeds to stress cognitive and procedural knowledge. This is explained as follows:

*“[...] It is **very strict** what they have to do in the first semester in order to **gain some basic knowledge**, on which they build on in the second semester. The second semester is more free. I think it has three different topics in which they can work on. There is an offshore structure, out in the ocean, and a harbour structure on which students work on. There are **more choices on the second semester**. [...] They **get more and more choices** about the project along the master education.” (SB1_{SCE})*

Even though SB1_{SCE} points out that from the 2nd semester, the curriculum gets less strict and students acquire more freedom to choose the problems to solve, some lecturers claim that there is more need for students to develop more and deep technical knowledge, especially concerning the complex concepts and principles of the discipline:

*“It is difficult to **go to the basic of the problem**, so you don’t have enough time **to learn all the basic things**, only in the surface. [...]. There is a tendency to **cut away those theoretical very difficult things**, and then just give an introduction. Sometimes that is not always sufficient when you have to design very complicated buildings or wind turbines, or other things. You need to know the details also.” (L3_{SCE})*

This emphasis on technical knowledge leaves very little space in the curriculum to address knowledge domains, or broaden areas, and address more ill-defined problems.

This focus on technical and disciplinary knowledge is also characteristic for the way interviewees fill out the checklist C on the type of knowledge and checklist D on disciplinary (appendix 10, p. 173). Figure 9-3 presents the main type of knowledge considered by interviewees to be constructed in the programme. The indicator knowledge of theories, models and structures (factual and cognitive knowledge) and knowledge of subject specific techniques and methods (procedural) are pointed at by the interviewees as being the main types of knowledge developed in the programme. This is in

alignment with the formal curriculum. The indicator knowledge about facts elements and/ or terminology was the third most pointed indicator.

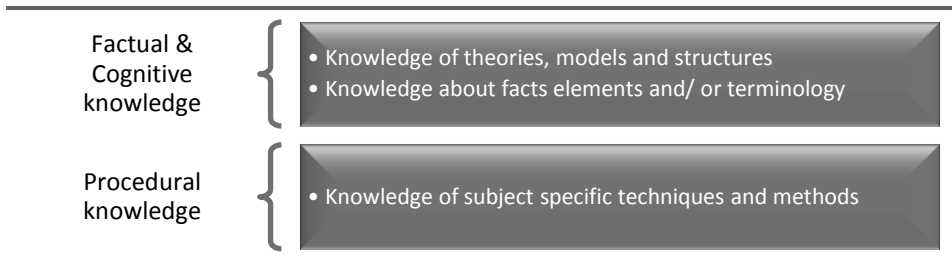


Figure 9-3 Type of knowledge pointed at by interviewees by thick the correspondent indicators on checklist C

Although limited, there were some indicators towards metacognitive knowledge pointed at by some interviewees, like for example, strategic knowledge (three out of seven interviewees). Lecturer **L2_{SCE}** explained that in his/her lecture students get involved in all types of knowledge constructions, including evolutionary knowledge:

I will take them all [ref. to checklist C]. In the course you have to know what you are doing, when you apply each theory... I don't know "know how" and "know who" because when you do it in a system you depend on other being able to do something specific. [...] Because use this technical solution you depend on these technicians being able to do something and continuing doing it so... You actually have to know someone. [...] It is a requirement of quality aspect in it. If you specify what this "type of well done" it is, you need to find someone who have a certificate that says that is able to do like that. If you don't find that you have to choose another solution. [...] If this is linked with know-how and know who, then yes. (L2_{SCE})

However, the interviewee perceived it more in relation with line of supply in technology development rather the impact on social, environmental or economic systems.

In regard to interdisciplinarity, figure 9-4 presents most indicators pointed out by interviewees in checklist D.

Disciplinary	<ul style="list-style-type: none"> • Study of courses related with engineering (mathematics, physics, etc.) • Knowledge within your subfield of engineering
Multidisciplinary	<ul style="list-style-type: none"> • Aware of other discipline works

Figure 9-4 Disciplinary pointed out by interviewees by thick the correspondent indicators on checklist D

The two most ticked indicators are both related to a disciplinary approach, however, multidisciplinary in the sense that the students are considered to be aware of other disciplines works. The priority is the clearly disciplinary content aligned with cognitive and procedural knowledge.

Self-directed and contextual learning

Self-directed learning is one of the most emphasised learning outcomes by the interviewees. First of all, self-directed learning is linked to how students acquire new scientific and technical knowledge. Due to fast technological advance and knowledge production, students should develop the ability of “learn how to learn”, leaving to university the task of develop of basic and fundamentals:

“We can teach the basics to some level and they have to learn by themselves. That’s why say they have to learn how to learn.” (L1_{SCE})

Secondly, self-directed learning is mentioned as a factor in the transition between the bachelor and master education, but also between master and the work environment. According to lecturer L1_{SCE}, the entrance to the work market and practice requires that students enter into a new learning process. In the work place, there are no courses delivering “the right” technological knowledge to solve a problem. In this sense, students should be able to identify the knowledge needed and apply it. This also encloses the ability to recognise who and where to find the expert who can provide the knowledge required. L1_{SCE} explains:

“They are in the master now and you think, if you are an engineer out in the real world, you have to sit down, and you have to find out what is the problem. And when you know what the problem is, and what can solve this problem, you look for it. So we are telling the students ‘you have to recognise the problems and come to us, and say what you need’

*and then we teach, because it is like the real world now. And the students say 'oh no! You have to teach us all that you know, because we cannot find out what we need.' They are quite afraid of this approach to teaching. [...] They have **to know who to contact to solve this problem**, and that's the way we want to teach them. We say 'Ok, you are in the master, you have to see, what do you have to know, what do you need to solve, and **tell your boss in your company - I need to talk to somebody who knows about this, and this, because I don't have the knowledge**. You have to educate this entire people together and make them see that this is the way to solve problems" "We always say - why are you here? You are here **to learn how to learn**" (L1_{SCE})*

This also implies that students struggle with self-directed learning even when they come to the end of programme.

Furthermore, at times there is a time gap between the time the course content is delivered and its use in project work. For example, the content may be delivered in the second semester, and students need the knowledge delivered for the 3rd semester project. Thereby, the course content does not have a direct relation to the project work. This seems to be the case within the 3rd semester, with exception of the course "Advanced Geotechnical Engineering", where the lecturer claims a direct link between the course and the project theme. On the other hand, this course appears to be one of the four optional courses to be selected by students at the 3rd semester (SES, 2010, p. 8).

Another obstacle is that the curriculum model is composed of three courses of 5 ETCS and content has to be fitted into these modules, making it difficult for small thematic courses alongside with project work:

*"You **have to fit in a certain no. of courses that could be useful later, or now**. But you have to **choose SECTS, which is a big chunk**, and that cannot be done on what you need right now because there's more part of it. [...] Therefore on the 3rd semester that kind of goes away, your **courses are different from projects**. And it would be the same in many curricula, in civil and in mechanical. You take courses that are not linked to the rest of the studies. There's something you like to know, but you don't know what it is for. They [ref. to students] make the link if they want to, it's their choice. It may be something **not useful for a project, but is something they find useful in general**." (L2_{SCE})*

It is not that clear if self-directed learning is an educational strategy or it is a consequence of the curriculum model. Nevertheless, self-directed learning is stressed as a

fundamental competence for appropriation of knowledge learned, to be mobilised and applied into new learning situations.

Problem formulation and solving process

The problems to be considered in the first two semesters of the programme are classified by the staff as narrow and fixed, as it is the staff being responsible for choosing the problems students should solve in their project work:

*“I think for structure engineering is quite similar to how we do it, indoor environment engineering, for the 7th semester [ref. to 1st semester of master programme] is **actually fixed what** they have to do, because it is the first semester of the master so we go from being practice oriented to be theoretical oriented so... so it tends to be focused **in a very small problem...** for instance in structural engineering it can be a **plate with a hole, and then analyse in detail.** [...] It is normally on this 7th semester that you do some in detail, you do measurements in detail, you do some analytical work and you do some numerical work. And then combine them and compare them, and so on. [...] This **gives quite a lot restriction on what students can actually chose in this semester because it needs to be something that we can instrument in order to measure,** and it’s also limited to how many different set ups we can actually have.” (SB2_{SCE})*

The main reason for this restriction on what a student can choose is, as pointed out above, the need for students to develop basic fundamental engineering knowledge and assure the quality of the engineers educated in this respect.

This approach is also used in the course modules where students, besides sitting in on lectures and work assignments, also carry out mini-projects. Students have to solve two specific problems, defined by lecturers, through two mini-projects. These are related to, specific content of the course, and set the basis for course evaluation. As noted in the following quotes the mini-projects are also very fixed and teacher-directed:

*“**Courses are basically lectures with assignments for each lecture,** and two mini projects, which constitute the base for the evaluation. And examination is based on the mini projects, why they [ref. to students] do that? Etc. We could also choose a written examination. [...] Almost everything is **given in the mini projects,** is very structured and defined, where students need to apply what they have learned in the course. Like for example, calculate a wind load in a building. **I choose the building**” (L3_{SCE})*

Interviewees stress the use of real technical problems as a mean to engage and motivate students' learning. But the structured and reductionist approach to the solving process seems to be present in courses and projects which may have an impact on how students develop their views towards solving engineering problems, losing some flexibility and adaptability along the education.

According to interviewees, in third semester, the problems are considered to be more open, and the problem solving process is unknown for students as well as facilitators:

*“This **time they don't know; don't have the way to solve the problem.** They have to come to me and say 'is this the way?' In all other semesters we say more 'this is the way to solve', now we are saying 'no, we are not giving it, the way to solve, you have to think yourself'.” (L1_{SCE})*

According to both facilitators interviewed, the facilitator may have an idea of how a possible solution to the problem may look like but do not have the specific answer. But students have more freedom to pursue other details, methods, or specific aspects they find interesting along the process:

*“To some extent **we control the direction projects take, but also students by** find out what is the next step. You should not give them all the answers on the way but, of course, we, perhaps, when we define the **project have an idea of which direction it should go.** We don't tell them the direction, but we try to push them into that direction. If they ask for methods, I try to pull them from that direction. **But, if along the way, they find in the project something detailed and it is very interesting for them, then they should also be free to move into that direction, even when it is not expected when we formulate the project. So they can move relatively freely.**” (F1_{SCE})*

The problem solving progression seems to require from students to rather jump from a more structured problem and staff directed approach to an unstructured and self-directed process. To some extent, students struggle, and have difficulties to make these jumps as it was previously explained by L1_{SCE} (p. 194).

Looking at the 3rd semester project catalogues provided by the semester coordinator, around 40 project ideas are presented by identifying:

- Title;
- Purpose;
- Background (in some);

- Main activities to be carried out;
- Contact person;
- Relative amount of theory, experimental work, and computer modelling

Project proposals provide students examples of how a project can be designed. The project proposals enclose information to guide students in the problem solving process, leaving less space for developing self-directed and self-regulated learning. Therefore, students will rely more on the facilitators' guidance rather than on their own decisions to redesign the project. According to facilitators, in the 3rd semester, students have a higher degree of freedom to redesign their projects based on the project proposal, some do and experiment the mentioned jump and struggle with it. But it is part of the learning process. However, this is not mandatory for all students, and some may remain in the project frames given by the proposal.

Furthermore, from reading the project catalogue, students are more likely to remain within the university's, and laboratory's, walls. The problems presented are relatively narrowed down when the students take over; risking those students will neglect a more holistic view on the problem. The proposed problem solving approach is aligned with the Newtonian reductionist approach, where complex problems are broken down to parts that can be managed scientifically. This approach is mirrored in the following quote:

*"[...] And I think it is important a project motivates them but also the complexity. I mean a big part of **being engineer, I think, is to take a complex problem and then simplifying it down to something you can actually calculate.** And understand, break down in pieces, not so that... it always has to be done in pieces, you can make complex structures and whatever. But you need to be able to understand it and also you need to be able to develop, you could say, the ability to have an overview of the complex project and understand it."* (SB2_{SCE})

The above approach to solve problems seems to neglect contextual factors related to the interaction between science, technology and society. One of the arguments behind this neglect is an overcrowded curriculum, lack of time to properly develop a problem analysis and at the same time formulate and solve a problem, but also that more technical knowledge has been added to the curricula.

"With the new curriculum, we have added so much so they don't really have much time to study and just wonder about something and then investigate, we really... I think... When you have a new curriculum that we did a few years ago, one way of getting everybody satisfied is adding

*a lot more so that everybody gets a little bit more than what they had before. And I fear that has happened a little bit, we have put in more in the courses, we have shortened the projects, we have added a lot of things perhaps. **I don't think we added more to the projects but we have shortened them which are more or less the same so there is less time.** We have changed the first study year also. The first years of the university, when I started, all the different engineering specialties were grouped together, so we could choose among everything. I thought I was going to study acoustics and electronics and I came into groups with students who wanted to become civil engineers and so on. Now, I mean... It is almost that we have made every moment of the studying life filled by something, this task and this task and this task.” (SB2_{SCE})*

The above statement pushes for a more holistic approach, but at the same time, other staff members take the position that too much time is already allocated for problem analysis:

*“Sometimes **too much time is going to define the broad things** [e.g. time allocated to define the problem], which is also important. But there is not much time to learn all **the theoretical, difficult things**. There has to be a balance.” (L3_{SCE})*

The priority, as L3_{SCE} stated, is “to make sure our students build a wall and it doesn’t fall due to the lack of knowledge and understanding of fundamentals”.

Critical thinking

The checklist with critical thinking (checklist E) indicators target facilitators and students. For the SCE programme, only two facilitators, and no students, were interviewed giving a low reliability on the type of critical thinking students actually carry out. Nevertheless, the two facilitators’ responses overlap in the following indicators:

- Explain, understand and questioning the factual and normative aspects of problem (epistemological critical thinking);
- Different point of views on each case (dialectical critical thinking)

However, when staff from SCE elaborates on critical thinking, it is linked with decision making and methodological reflection. Students must be able to explain why they use

certain methods and tools in comparison with others and be critical towards the accuracy of the results obtained as part of the solutions.

*“[...] you are aware of what you are doing and **you make the right choices**, for example, if you have to do a computation about something. You don't just **look up the first random formula** ... but really think about if it is applicable here and what are, you could say... the uncertainties when using this method... Maybe not quantitatively but, at least, you have some idea of the impact of this [...]” (SB1_{SCE})*

Even though staffs recognise the need for deeper knowledge at master level, they also find important the balance between the amount of the content delivered and the time allocated to project work. According to SB2_{SCE}, an overcrowded curriculum like this may lead to students losing their critical sense:

*“I think what will happen first is that the students on paper have been working with a lot of topics, but they really do not understand them fully. So I think, in the beginning we can do that for several years, we can add more and what will just happen is that understanding of... will become less... Maybe that is not a big problem because, I mean, for engineering, of course, you have some **basic sciences that you have to know**, but you also **need to be aware of a lot of things**, to be introduced to a lot of things, and so on. So you have to have knowledge at different levels so it becomes a **problem when we lose their critical sense, when the students lose their ability to be critical, challenge different methodologies, understand a complex area, and been unable to do themselves... familiarise themselves with a new topic**. So actually, if... I think the biggest danger, perhaps, is if we put so much in the curriculum that they don't have time to learn to study because they need to produce small reports for courses, big reports for projects, and working” (SB2_{SCE})*

Different academic staffs have different perspectives towards the curriculum. While some academic staff from lecture, such as L3_{SCE}, emphasise the need for more technical knowledge, or students' weaknesses in understanding deep technical knowledge. Study board members are more sensible to the need to give time for reflection, for students to deal with complex situations, cope and manage them, as part of the learning. Also, these complex learning situations can be generalised to be applicable in future similar complex situations as the exemplary learning principle.

Communication and collaboration

In the **SB3_{SCE}** experience, young engineers have to be able, as part of their professional practice, to present and communicate their projects and solutions to a broad audience to enable public participation:

But that is what we also try to put into the projects and ask the students, and we also.. You know they do a lot of project presentations and they are, to some extent, free on how to do, how they want to do it, but you cannot have a traffic project without being prepared to go out to a public meeting and make a presentation. And after you've done that you should be aware of what kind of questions that would be asked. And they are not necessary asked in a very polite manner, not if you are getting close to peoples' backyards. (SB3_{SCE})

In this sense, a young engineer needs to be aware of the type of audience one is facing when presenting ones project. Frequently, audiences may be composed of other professionals, with no knowledge or background in engineering, like economics, citizens, politicians, etc. The interviewee raises the collaboration, not only among peers, but also with external partners and professional practices.

On the other hand, the facilitator **F2_{SCE}** points at the diversity of students in the master programme, with different educational and cultural backgrounds as one of the challenges to address in the education process as explained in the following:

*“When I am supervising groups, I think the **biggest challenge is when you have people from different systems which come to Aalborg for the master** and you have to teach them a fast introduction to the system, which can be difficult because **they are not used to work in this way. They work more freely and that can have a lot of pros and cons.**” (F2_{SCE})*

The above is also experienced as a challenge for students of the M.SC. UPM, where is given more concrete examples regarding the type of collaboration and communication that would take in the group. For example, students coming from different educational backgrounds have different ways to look into the world, but also different learning experiences and expectations.

9.2.2 Education for Sustainable Development practiced

Although interviewees recognise the need to address sustainable development (SD) in engineering education as a future perspective and as a future requirement in structural and civil engineering association standards, it is not considered a priority, as expressed by one of the lecturers:

*But it's something that is not done very much, I would say because **it is not very relevant for the type of projects they have, so instead...** they could do maybe and here we are focused on technical expertise. Maybe we are more thinking that it is better that they do **learn the technical things here and these other things that they can maybe learn afterwards in real life.** Because they could learn a lot about these things and they couldn't design a building that is not safe. (L3_{SCE})*

The academic staff also seems to encounter difficulties in defining and quantifying ESD, which would make it easier to integrate in the education as it would be aligned with the general approach of the programme as well:

*"What you do are easier things, like calculate the energy consumption in a building to be within a certain level. But now, you move on to the next thing and become a little... The **sustainability word is very hard to put into an equation, which could be a goal.** If you cannot do that, if it doesn't enter in the equation somewhere then you actually **have a hard time to quantify.**" (F1_{SCE})*

It is also indicated that SD is more far from the core of the SCE discipline than it is the case of for example other related disciplines, an indoor environment or water environments, where sustainability is seen as a more natural part of the curriculum:

*"You can say water and environment, and indoor environmental engineering, you can **say in a way they are lucky because it's already integrated and is a very important part...** of course what water environment is about is preserving the environment, reducing pollution and so on. And indoor environmental engineering is something about, "ok, we should put more isolation in our houses in order to, also, save the environment". You **could say that more in the structural part, for example, where I am mostly into, not offshore but more about houses which are good, it is, you could say, more like design, you have to design this so that it can save the loads.**" (SB1_{SCE})*

In accordance with the statement above regarding different perceptions towards curriculum, also academic staff has different perceptions towards the opportunities for ESD. Some educations are seen as more suitable to pursue such goals because it comes naturally in the curriculum, while others such as SCE do not have room for SD contextual learning because its focus is on expertise.

According to L2_{SCE}, the absence of sustainability is not due to the staff resistance towards it, it is more due to the lack of link between the specific content of the course and sustainability frameworks:

*“My part of the course is kind of “be able to do this kind of analysis”, so where it is applied is up to the students. Some are in the project, but not necessarily all. **You don’t put sustainability in your course. It is not because you are against it as framework; it is just because it doesn’t fit.**”*
(L2_{SCE})

Not only is SD perceived to be peripheral and hard to quantify, but it is also seen to be a nice aspect to know which might be added to the working situation. There is a latent expectation that students are able to develop knowledge, broader context knowledge and analysis skills when they finish their education, and start working in real life. At the same time, there is recognition of the lack of ESD at University level which may turn into a weakness in students’ education:

*“Out in practice, **where the way to earn money is to make these kind of links, it is not calculating, because everyone can calculate.** There are a lot of pressures, a lot of programmes, and whatever, so it is where the money is, to connect **the technical, the environmental and economic aspects. Everyone can calculate, but not everyone can make this connection.** For now at the University, we are not very good at making these connections.”* (L1_{SCE})

However, in spite of these barriers for ESD, staff point at aspects of the programme that can be linked to sustainable development, see figure 6-6. The main aspect pointed out as part of the curriculum is risk analysis, followed by materials and energy. The master programme has a course regarding risk analysis in the second semester of the programme. However, the main focus of the course is on probabilistic methods.



Figure 9-5 Main SD aspects pointed at by interviewees through checklist B

SB2_{SCE} recalls some tools that used to be part of the project work and of the curriculum like Life Cycle Assessment (LCA), but nowadays, these are not so visible in the engineering curriculum.

But I think it is... when I was educated in this, 15 years ago or whatever, we did life cycle analysis (LCA): Looking at the energy for running a building, energy for building a building and so on. And actually Denmark was fairly advanced at that point; we get some fairly advanced calculations and so on. But at that point, it turned out that energy for constructing the buildings corresponded to one, or two, years of running the building. So it didn't matter. And now, it actually becomes important again because the energy for running the building is a factor of 10 perhaps, or 20, and the amount of materials that you use in order to reduce the energy is increasing, so now they are.. The energy of constructing of the building corresponds more or less to the energy for running the building. (SB1_{SCE})

L2_{SCE} points at another tool for students to consider: Lifetime Analysis (LTA) of the materials used in designing their project work. Furthermore, **SB1_{SCE}** argues that is part of the profession to look into this when designing or constructing a building, as it is explained in the following:

“And also that you don't waste, for example, materials. You just use what should be used, and then you don't overdesign [...]” (SB1_{SCE})

The study board member above pointed at the difficulty to integrate ESD in the SCE curriculum because it “doesn't come naturally”, however, here is presented an eco-design approach by saving resources as part of the practice. These points at *praxis* that underlies professional practice but it is not linked with SD principles.

This consideration is extended by **SB2_{SCE}** regarding the users, and impact, into the overall goals of a project. **SB2_{SCE}** tells the story of a research project of which the aim was to reduce the energy consumption in old buildings, however, it was not taken into consideration aspects of culture and how people make use of buildings in the summer and winter, leading to some project failures in full filling the project's goals.

*I think, **we have seen too many bad examples of solutions to appear to be good that really wasn't.** I mean classical example of energy renovating Danish houses... you have a lot of this buildings where you have some kind of... what's called... you have this outdoor space and it is actually not added to the facade, it is actually more or less embedded in the front. A large project, we spent many money and many years of renovating by closing this by glassing, using glassing to close this so it could be a interior space so that it would **reduce the heat lost from the building**, or from the apartment, but what happened was that the people thought "Oh now we can use it so we put an electrical heater and we just got a bigger apartment. So it was really.. I mean... **Good intentions but a disastrous solution.** (**SB2_{SCE}**)*

In the above, it is also recognise that sustainable technology by itself does not secure sustainable solutions and lifestyles Therefore other contextual elements are needed to be integrated in the project, such as the users' perspectives and behaviours, and this is something students also need to learn to handle and be aware of in their projects if they aim to mirror the professional practice.

Another example of a link between SD and SCE is given by **SB3_{SCE}**, explaining that students have to take into consideration impacts caused by traffic planning and infrastructures, for example, in relation to society and local communities.

Through checklist A, it is also possible to point out practices in education that can be linked with pedagogical principles of ESD. figure 9-6 presents the indicators pointed at by interviewees. The most pointed out is the problem solving principle. This comes with no surprises due to the PBL environment in which they educate, and were educated.

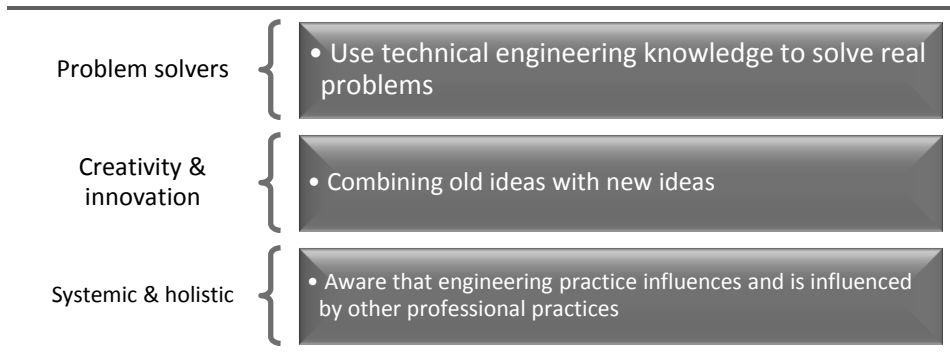


Figure 9-6 Main ESD principles pointed at by interviewees through checklist A indicators

However, all though it can be argued that the problem solving approach is a driver for ESD, it does not necessarily secure integration of ESD. This is very much depending on the extent of which the problem is seen in a broader context. In this case, the interviewees remain technical in their approach to solve problems and in their way of thinking about SD, rather than moving to broader societal and environmental aspects that evolve from contextualisation of technical problems.

9.3 Curriculum perspectives for ESD

As previously stated, Education for Sustainable Development (ESD) is recognised for its importance and therefore, it is seen as future part of the engineering education and practice. Lecturer L1_{SCE} considers that the curriculum has the conditions to address almost, if not all, of the indicators mentioned in checklist A (ESD principles) as well as most of the aspects in checklist B:

I agree we have the basis to do this [ref. to competencies for ESD in checklist A], *but we are not doing as much as we could do. It's not a priority. [...] Things are changing and... specially because we have lot of pc's and computers and whatever, and a lot of what we are teaching you can do if you understand these programmes, so we need to fill a little bit more to put into these context lines* [ref. to integration of ESD an principles listed]. (L1_{SCE})

So the potential for integrating SD exists, but at the same time, staff also refer some barriers. The focus on doing calculations and technical competences may decrease the students' motivations to learn about sustainability during their study. For example,

L2_{SCE} points out the students' lack of interest in engaging in elective courses related with economics, which may be of great interest for an engineer in their future practice. However, students present very little interest in enrolling in courses which provide additional knowledge and skills to their qualification profile.

*"They [ref. to students] are **so busy in learning the technical discipline** of their trade, so if they have time to spend they will try to keep supervising on that. They are **hard to take these things around them**, which could be useful. There's quite a lot, economics is very useful - how a company runs? How to obtain finance? How to take it out in society? - but they do not take such courses" (L2_{SCE})*

Also, there is a great emphasis on the assessment towards the technical aspects, and its scientific correctness, this may lead to students to put effort in learning what is more valued in the assessment. As L2_{SCE} puts it, "otherwise why bother" if there is not reward afterwards.

Furthermore, comments from staff imply that the trust in PBL and the positive feedback from industry might have been a "sleeping pillow" in the sense that staff does not feel it necessary to reflect further on the competencies students are to develop:

*I think one of the problems at the moment with the new curriculum is that we have not really, at least for a period of time, we have just told ourselves the students become **very good by doing PBL**, they become really good engineers, we know we get good feedback from the industry and so on. But we **have really not sat down and really specified the competences that they get from doing this**, which means that when we do the curriculum, and just the curriculum, there is a **tendency that these things that we didn't put on words which can be neglected somewhat**. We think it will stay there no matter what we do... (SB2_{SCE})*

However, when the interviews started to reflect *in situ* on the way ESD could be integrated in structural and civil engineering (SCE), they mainly stressed integration in the project work, and seemed more reluctant to integrate it more into courses:

*"I think, for our case, it **would be in the project**. Hum... because **we haven't got that number of courses that we would like to have**. And really we have, you can say this course in road administration and road management, or what would you call it, we can take it in various parts, but my feeling is that we should not put more.. Taking in the administration of law of roads is enough for the students for that course. And I know that our colleagues have another course where they look at this ethics on environment in open areas: They do that at the water supply ...*

and it would be relevant for us to actually have the same course, but then we will have to replace by something else and..." (SB3_{SCE})

It is also argued that the projects would be best suited for integration of ESD due to the work on real life problems, which can make learning for sustainability meaningful:

*"You have **the perspective when using real problems**, in this PBL learning, where they can go out and see '**yes, we have problems with climate change. Yes, we have an interaction with economics. Yes, people are starving because for this and this**'. This could be a way we can make it interesting. Having it in projects [and make it also technical], because they can relate to their lives, out and with what they see daily in television". (L1_{SCE})*

The staff also reflects on when in the project it would be appropriate to focus on ESD. **SB1_{SCE}** points at integration at the end of the project report, when students are writing their conclusions and reflect on the methodologies used as well as possible impacts of solutions developed:

*"[...] you could say, it gets **more technical when you progress** [along the bachelor and master programmes] **but something like this** [ref. to relation between society, technology and sustainability - STS] **should be more included than it is now, than maybe it could be a good idea they make a technical project and, at least, make some reflections about how it will impact on other areas without making very detailed analysis, but just be aware of the fact that if you build a giant structure somewhere it could impact on other things in society and so on.**" (SB1_{SCE})*

But **L2_{SCE}** also points at the need of integrating sustainability in the beginning of the project, where the problem is defined, and then returns to it at the end for final considerations in relation to the impacts of the decisions made:

*"When solving a problem, or whatever they do, **they have to assess the impact of what they are doing, the social, economic, sustainable, whatever, and decide if they still want to participate in that.** Ah! All go back to engineers and physics that made the atomic bomb almost by accident and then have a bad conscious about that. In that category, it has to be part of every project. But students don't think like that these days. I had some students doing something to a sniper gun, and I ask them 'How is your conscious about this? Do you have any? No... it's just taking a problem'." (L2_{SCE})*

In either case, it is stressed that ESD should not be an add-on but integrated and related to the technical practice to be meaningful learning for students:

*“If it is **just an add-on it is not useful**, it should interfere [ref. with technical knowledge as aspects of the field]. You choose something, or something else, with that argumentation alone. This is sustainable, this is not. Because if it is an add-on they [ref. students] **will never have interest in it**, any consequences, so why bother.” (L2_{SCE})*

One of the possibilities to work within a technical frame of mind and yet be involved in more holistic interdisciplinary approaches is according to **SB2_{SCE}** to develop projects and establish groups across programmes and departments as stated:

*[...] I would like to be able to do a mixture, so that some semesters they are working, just engineers, working on the core and use of it. I mean, you also need to have some kind of foundation understanding your own method, your own field in order to be able to **work efficiently together with other people**, so you need a strong basis. And then I would like to do some more cross disciplinary work, where they actually use their own skills together with others students' skills to do a project. I mean I like this... The Technical University of Denmark (DTU) have just participated in a competition where the task is to build a low energy building, or a zero energy building, or a energy producing building and I mean that is a project where I can see how engineers, students from architecture and design, mechanical engineering work together. We have at the university the car racing at the energy department, where you also have cross-disciplinary work. You have the satellite people from electronics, developing satellites over a period of years. (SB2_{SCE})*

However, such rather far reaching perspectives like more cross-disciplinary work and more integration of SD might be depending on staff taking the first steps, as the study board members refer, students look up to their lecturers and supervisors as role models.

Final remarks

The above presents the main findings of the analysis of the formal as well as the practiced curriculum and further perspectives for ESD in the Structural and Civil Engineering (SCE) master programme.

The intended learning outcomes (ILOs) formulated for courses and projects are aligned with the ones pointed out during the interviews, and show that the SCE programme is centred on cognitive and procedural knowledge within the specific subjects of the field. The formal curriculum presents, as part of the programme overall qualification profile, ILO related with interdisciplinary approaches and cooperation. However, the courses and projects ILOs, as well as in the practiced curriculum, show very little room for development of these. Also the curriculum structure and type of problems driving the learning processes are considered by interviewees as strict and structured. This raise some questions whether the problem scenario analysis, problem identification and solving process are more controlled by staff than guided. Problems are considered fixed and structured by interviewees for the first semester of the curriculum, as the main aim is for students to develop technical knowledge. For the following semesters, problems are claimed to be more open. Anyway, when looking into the project catalogue for the 3rd semester, the descriptions include information like the relative amount of theory, modelling and laboratory work is needed to include in project work. However, students can use this as a point of departure to design their projects, but they can move and pursue other directions, redesign their projects in accordance with their interests.

The approach to ESD is aligned with the overall educational approach, and when staff addresses interdisciplinary, self-directed learning, contextual learning, and critical thinking, it is closely related to professional development within a pure technical perspective. In other words, broader contextual factors related to science, technology and society do not take up much space in the approach to PBL.

In this sense, it is worth to reflect upon how far the expertise of an engineering programme poses challenges to integrate ESD, and from which factors the challenges are dependent. Some appear to be related with the curricula design. The interviewees characterise the curriculum as overloaded leaving not enough time allocated for project work, and integrating more technical content considered as fundamental for the master education. This view of the curriculum seems to influence how the curriculum is organised (e.g. time gap between courses and project work), the course contents delivered (through mini projects and solving structure defined by staff) and the type of problems addressed. Table 9-4 summarises the main findings from the SCE programme.

Table 9-4 Matrix of main findings from M.Sc. Structural and Civil Engineering

	PBL principles	ESD principles
Formal curriculum	<p>The overall qualification profile encloses, ILOs emphasise procedural and metacognitive knowledge, multidisciplinary and interdisciplinary cooperation.</p> <p>Regarding the semester modules (projects and courses) it is emphasised procedural and metacognitive knowledge. The knowledge domains are mainly STEM disciplines specific for field, therefore, it is considered multidisciplinary. There is no reference to interdisciplinary cooperation.</p> <p>Contextual learning is indicated through the problem formulation and solved within the engineering field.</p>	<p>In the overall qualification profile, SD aspects enclose environmental sustainability such as soil, and construction materials; and social sustainability through product responsibility such as risk, reliability and uncertainties, and professional responsibility.</p> <p>The programme has a course module related with sustainable energy structures such as “Renewable energy structures: wind turbines and energy devices” (3rd semester), nevertheless, the course is not compulsory to all students. The programme also has a course in “Risk and Reliability in Engineering” (2nd semester). Furthermore, the programme has courses and project modules regarding civil engineering in specific contexts, such as marine environments (2nd semester).</p> <p>Environment, product responsibility and ethics are main SD aspects indicated in modules ILOs.</p> <p>The environmental sustainability aspects are present in three of the four semesters, product responsibility in 2nd and 3rd semesters, and ethics in the 4th semester, related with research carried out in the master thesis.</p>
Practiced curriculum	<p>Academic staff emphasise cognitive knowledge within the engineering field fundamentals as a need for a quality of education and with effect in the curriculum structure. The curriculum is characterised as narrow and structured in the first two semesters which implies students have little freedom to redesign the projects.</p> <p>Self-directed learning and contex-</p>	<p>Interviewees pointed at environmental (materials, energy and products), economic (risk analysis) and social sustainability as part of the curriculum. Environment is emphasised over the other spheres of sustainability. Furthermore, there is a “tacit” practice towards LCA, LTA and eco-design, but these are not included in the formal curriculum</p>

	PBL principles	ESD principles
	<p>tual learning is highly emphasised but it's directed for need appropriation of technical knowledge for professional practice.</p> <p>The same is extended to critical thinking, which falls in decisions towards technical "formulas" and knowledge applied in the problem solving process.</p>	<p>ILOs.</p> <p>There is recognition from the academic staff of ESD in becoming part of the professional practice through its integration in civil engineering associations' standards. Nevertheless, its definitions out of mathematical equations make it difficult and the priority of education is only in the technical knowledge. The "other aspects" may be learned out in real life.</p> <p>It is also recognised the value of a young graduate to be able to contextualised the technical knowledge and practice with other spheres of society, however, the priority of education at the moment is not moving in that direction.</p>

In spite of these barriers, possibilities for thinking the curriculum differently are also taken into consideration. One example is a call for more interdisciplinary cooperation in cross disciplinary groups.

The academic staffs also recognise sustainability as a part of the future civil engineering education and profession. Staff can see the relation between SD principles and themes and the technical discipline, and find opportunities for integrating SD at the beginning and the end of project work addressing real life problems. However, presently, it is not a priority.

10 Discussion and recommendations

Engineers are called to develop innovative technologies at a rapid rate, with economic value (Felder, Woods, Stice, & Rugarcia, 2000). On the other hand, sustainable development problems, originated partly from contemporary unsustainable patterns of living and consumerism, call for engineers to contribute to a more sustainable and fair future through development of technologies. The integration of sustainable development in engineering education is highly stressed by research (see for example (Shepard, Macatangy, Colby, & Sullivan, 2009; Broadbent, 2012), accreditation bodies (see for example Engineering Council, 2004; ABET, 2010), and engineering organisations (see for example (see for example National Academy of Engineering, 2004; Doods & Venables, 2005; Bourn & Neal, 2008). From a theory perspective, Problem Based Learning (PBL) can support integration of Education for Sustainable Development (ESD) by having similar principles with the latter, and by developing the knowledge, skills and competencies stressed by the above references.

This chapter discusses findings regarding in which ways PBL can support the integration of ESD in engineering education and it closes with recommendations made by the experts and practices investigated.

10.1 Discussion

The discussion brings together practice, experts and the theoretical perspectives. The theoretical perspective pointed out variables (chapter 4, p. 76), to be investigated from an expert (chapter 5, p. 81) and a practice perspective (chapters 8, p. 147, and chapter 9, p. 183). The expert perspective gives an broad and holistic overview of integration of ESD, such as curricula structures, examples of learning outcomes, learning pedagogies, roles of different actors, but also challenges and future perspectives for ESD in general, and in particular for engineering education for sustainable development (EESD). In the practice perspective, two engineering programmes from Aalborg

University (AAU) were investigated, the M.Sc. in Urban Planning and Management (UPM) and M.Sc. in Structural and Civil Engineering (SCE). In these, the PBL principles practiced, such as metacognition, interdisciplinarity, critical thinking, contextual learning, problems solving skills, show similarities with ESD principles. Furthermore, the differences of PBL practiced in both programmes also show different supports for ESD integration.

1. Multi rather than interdisciplinary cooperation

Metacognition and interdisciplinarity are two core principles of Education for Sustainable Development (ESD). ESD is characterised as “*interdisciplinary*”, it can not be claimed by any discipline, but is constructed through contribution of all, promoting “*high-order thinking skills*”, such as metacognitive knowledge (UNESCO, 2005).

Steiner and Posch (Steiner & Posch, 2006) argue that interdisciplinarity requires disciplinary expertise as its corner stone, but also construction of knowledge regarding other disciplines. The knowledge regarding the different disciplines should be more than just factual and declarative knowledge, but rather understood, applied, evaluated, synthesised or contested, *i.e.* be metacognitive. Interdisciplinarity can also be constructed through cooperation. Interdisciplinary cooperation makes it possible to combine traditions, cultures and methodologies of different disciplines as a means to construct new discourses and interpretations of reality. Therefore, interdisciplinarity encloses both content and collaboration (Steiner & Posch, 2006). Furthermore, the combination of metacognitive reasoning with interdisciplinarity allows the development of system thinking (Stauffacher, Walter, Lang, Wiek, & Scholz, 2006; Steiner & Posch, 2006).

In both practices investigated (UPM and SCE), the formal curricula enclose intended learning outcomes (ILOs) for construction of procedural and metacognitive knowledge within different disciplines and interdisciplinary cooperation.

In UPM, the formal and practiced curricula enclose content within different disciplines from different knowledge domains. For example, knowledge about land use, transport infrastructures (technical/scientific domains), their interconnections and complexities in relation to social, behavioural, environmental and economic consequences (social domains) (chapter 8, p. 151). In SCE, the formal curriculum encloses content within different disciplines, but mainly from technical/scientific domains. SCE is multidisciplinary rather than interdisciplinarity which is also supported by interviewees who considered the programme multidisciplinary and disciplinarity (chapter 9, p. 191).

On both practices, interdisciplinary cooperation is part of the overall qualification profile of formal curricula. In the UPM practiced curricula, this is pointed out as a barrier

due to strict curricula guidelines for group formation and assessment; and a challenge to accommodate different professional identities and cultural diversity in group work (chapter 8, p. 156). For example, the facilitators and students interviewed pointed to the diversity (professional and cultural) of new and international students entering in the programme as one of the challenges of PBL. It seems also that students already carry with them a strong professional identity which poses barriers for group work. However, the students interviewed referred that even though this poses as a challenge, it also provides opportunities to reflect on your own knowledge and your problem solving approach and support those who may not be used to a PBL approach (chapter 8, p. 168).

SCE presents a strong focus on disciplinary knowledge within engineering fundamentals to deepen students' expertise (i.e. STEM disciplines), with no room for interdisciplinarity at the content or cooperative level. The academic staff expects students to learn "that stuff" afterwards, in real life, when they finish their education (**L3_{SCE}**, chapter 9, p. 202). However, study board members (such as **SB2_{SCE}** and **SB3_{SCE}**) recognise that a part of engineering practice is also being able, for example, to communicate with the general public and explain, for example, why a certain solution is adequate and what are the consequences of others (chapter 9, p. 201).

Nevertheless, there is general a recognition of the need for interdisciplinary cooperation across departments and educational programmes. It is seen as a way to enrich students' learning by integrating and understanding how other disciplines work, and how they may influence their own field.

Furthermore, the curricula are problem based and project organised. Project work is carried out in groups which present possibilities for more interdisciplinary learning. The groups could enclose more diversity and promote more cross-multidisciplinary knowledge by forming cross-programmes groups. Even though the academic staffs is aware of these possibilities, it also encounters some resistance, mainly from students and from formal curricula guidelines (**F3_{UPM}**, chapter 8, p. 168).

Interdisciplinarity can be promoted different levels, such as:

- Cross-programmes groups, within the same department (cross expertise);
- Cross-department groups, within the same faculty (cross disciplines/fields within engineering);
- Cross-faculty groups: social sciences, engineering, economics, etc. (cross-knowledge domains).

Through the above possibilities, students would be able to construct knowledge in different disciplines and knowledge domains through peer learning. The learning goal

here is not to replace the disciplinary expertise, but rather bring it to a broader context with other fields of expertise.

Furthermore, such interdisciplinarity learning experiences could be one part of the curricula. For example, at TU Delft (Netherlands) and University of Cambridge (UK), students have the possibility to choose elective programmes or NGO's projects (e.g. Engineers without Borders), in which they form cross-disciplinary groups to solve sustainability problems (chapter 5, p. 87).

It is likely that each of the above possibilities encounter different challenges and of different nature, such as different disciplinary cultures and traditions; different understandings of PBL, problem definitions and solving approach, etc.; administrative and accreditation.

The interdisciplinary cooperation is not only a learning possibility for students, but also could be for academic staff. This would compose a good and inspirational example for students. For example, at Arizona State University (U.S.), in each department and school, a senior sustainability scientist is nominated and an internal network for EESD is formed among academic staff. The senior sustainability scientists come together, collaborate, and develop strategies to move further in the integration of ESD in the different schools and faculties of the university, including engineering education. In the same university, students from different schools and faculties collaborate to solve real problems. However, students find difficulties to find a common conceptual language; therefore, they are engaged in exercises aiming to develop a common understanding and conceptual ground (see chapter 5, p. 91).

2. Challenge to balance different contexts

PBL creates conditions for contextual and meaningful learning through the use of real problem scenarios to foster learning. According to Jonassen (Jonassen, 2011), context is one characteristic of problem scenarios and is defined as situations (social, political, cultural, environmental, technical, etc.) in which the problem scenario is embedded. Problem context is also analysed in order to identify and formulate problems (chapter 3, p. 50). The context is related to the complexity and structuredness of the problem. The more ill-structured, the more complex the problem scenario is in its context. Also, this increasing complexity of the problem scenarios is addressed in the PBL five basic models. See for example model four (PBL for transdisciplinary learning) and five (PBL for critical contestability) in which problems scenarios are characterised as dilemmas, multidimensional and open respectively. While in model one (PBL for epistemological competence) and model two (PBL for professional action), the problem scenarios are limited to solutions already known, and real-life situations respectively. The latter

problem scenarios are narrower, disciplinary-oriented, with less contextual elements in comparison to former models (model 4 and 5 for example) (Savin-Baden, 2000, 2007) (chapter 4, p. 69). By solving real problems, students' disciplinary and theoretical knowledge acquires concrete meaning in relation to the context (Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005). If the context is limited to the disciplinary and professional context, the problems tend to be narrower and with less societal contextual elements. In this example, students remain within the disciplinary and professional contextual boundaries.

The problem scenarios are more likely to include more societal contextual elements when too complex, ill-structured or multidimensional. Such problems scenarios require students to mobilise and construct knowledge from vary disciplines. At the same time, the boundaries between practice and theory, as well as between professional and societal contexts, may get blur.

In both practices investigated, students' disciplinary knowledge acquires meaning in relation to professional context, and it is not explicitly related to societal contexts. Also, problem scenarios mainly regard development of professional skills and knowledge which also enables students to build a strong professional identity. In the UPM programme, the study board member **SB1_{UPM}** explains the creation of the education as a consequence of an existent profession. Also, the programme focuses the first semester learning on the object of profession, such as town, its planning and development. In the second semester, focus is on the professional role and relations of an urban planner. An urban space encloses several types of systems and contexts, from social to economical, technical, environmental, etc. **SB1_{UPM}**, pointed out as well that UPM programme can be characterised as being very contextual, focusing on processes of the object of profession rather on their products, *i.e.* focus on analysing the reasons and analysis of a "problem" rather than providing solutions (chapter 8, p. 160).

In SCE, professional context is also highly valued and stressed through several mechanisms. For example, the first semester problems are real, but narrowly defined to develop and deepen the engineering fundamentals. Also, courses enclose small project assignments in which students have to solve problems defined by the lecturers. Furthermore, learning outcomes assessed in projects and courses are regarding technical content and aspects of the problem solving process and solutions, reinforcing students' focus on technical aspects of the problem, and less on societal contextual elements (chapter 9, p. 196).

A curriculum for ESD should support the interconnection between professional and societal contexts (e.g. economic, environmental, social, political, cultural, etc.), in order to solve sustainable problems (Bransford, Brown, & Cocking, 2000; Habron, Goralnik, & Thorp, 2012).

In one hand narrower problem scenarios, which emphasise professional contexts, lead to contextual learning for engineering expertise (professional contextual elements). On the other hand, ill-structured, complex and multidimensional problem scenarios allow students to contextualise theoretical knowledge within professional and societal contexts. PBL environments allow bringing different problem scenarios to educational programmes, supporting two types of contextual learning: professional expertise and contextualisation of the expertise in broaden society (societal context).

However, such approach to contextual learning must be promoted by the academic staff and paid attention in formal curricula.

Historically, PBL learning goals are related with knowledge, skills and competencies for professional practice (see for example Dolmans, Grave, Wolfhagen, & Van der Vleuten, 2005). Epistemologically, such principles determine how PBL is practiced in relation with the discipline and professional practice, posing barriers to a paradigm shift for a more holistic and broad contextual education without losing the professional and practice principle of PBL.

Both programmes face a challenge of balancing the core of expertise and contextual elements which can be brought into education. This constitutes one of the core prejudices of ESD for engineering education. Integration of ESD does not imply the removal of professional core and expertise from the education, but rather use the disciplinary domains as platforms for integration of broadened contextual aspects whenever it is relevant in the curriculum. As pointed out by, for example, Dr Karel Mulder, Dr Francisco Lozano, Dr Rodrigo Lozano, Dr Roger Hadgraft and Dr Richard Fenner, it is necessary that students develop deep technical knowledge that is integrated with sustainable development education (chapter 5, p. 88).

In sum, real problem scenarios do not secure the integration of three pillars as part of contextual learning. These have to be part of the learning goals and balanced between the core (professional expertise) and the professional and societal contexts of learning. The problem scenario supports a more holistic construction and view on the profession by establishing a relation between expertise, professional practice and societal contexts.

3. Different problems, different relations to ESD

Engineers are traditionally seen as problem solvers, but the type of problem (more or less structured), its context (narrow or broadly defined) as well as students' and academic staff's roles determine different approaches to problem definition and solving processes.

In both practices investigated, two distinct problem solving approaches emerge as result of the different approaches to problem scenarios

In UPM and SCE, course and project modules are problem based. In the course modules, real problems are used to illustrate a theory and carry out assignments. However, in the project modules, students have to analyse a problem scenario, identify, formulate and solve a problem within a timeframe of approximately five months. It is in the project modules that the different approaches to solve problems emerge.

In UPM, in the beginning of the semester, students have the possibility to choose between problem scenarios to elaborate their project proposal. For this reason, students' project reports present a variety of themes (e.g. climate change adaptation, rail roads and civil movements), enabling them to move into more real and broad contexts and relate these to the semester theme and professional field. Even though the academic staff brings other problem scenarios as possibilities for project proposals, students also have the freedom to bring problem scenarios into education. This promotes a meaningful learning and allows students to build and explore their own professional profile (chapter 8, p. 163).

For example, student **S5_{UPM}** addressed topics such as environmental impact assessment, social and economic causes and consequences in his project about rail road construction in a municipality in Denmark. He explained that is not because the project is specifically about such topics, but because they are part of an overall context and relate to the rail road theme. This is supported by another group, students **S2_{UPM}**, **S3_{UPM}**, **S4_{UPM}**, who explained that in their project report, environmental impact assessment is a tool used for decision making in urban planning, but it does not compose the core of the project. In this sense, UPM students deal with more societal context as part of the problem, how these are interconnected with and influence each other, engaging students in a more holistic and systems-approach to problem solving.

In SCE, for project work, students are also presented with problem scenarios for project proposals. These are gathered by academic staff, some in collaboration with companies (external partners). The information enclosed in the project proposals is focused on technical aspects and narrower professional contexts. The problems are real, but they are brought into the educational programme by the academic staff, or via collaboration with companies. It appears that the students' degree of freedom to "go out" and bring more multi contexts problem scenarios into their educational programme is quite limited. Even though students choose to bring a problem scenario out of the academic staff's proposals, the assessment of the project outcomes falls mainly within the technical aspects. Furthermore, the academic staff characterised the SCE curriculum as very strict, with problems narrowly defined by them, as a means to control the construction of learning outcomes on technical knowledge (chapter 9, p. 196).

Interviewee **SB1**_{UPM} explained that in more technical programmes have removed societal contextual elements from the problem identification, analysis and formulation. Solving the problem focuses only on providing technical solutions to a given problem, and lacks the reflective components in which students address questions such as: why it is a problem? Who has the problem? And what are the consequences of the problem and its solutions? (chapter 8, p. 175). This is supported by the student **S6**_{UPM}, with B.Sc. in Structural and Civil Engineering from Aalborg University, who characterised the education as reductionist because the focus is on learning how to break a complex problem into smaller and simpler parts to be solved, losing the sense of interconnection with reality. Real problems are not simple, and when they are simplified, non-technical contextual elements are removed. In this sense, the problem solving approach becomes reductionist.

The view of reductionist problem solving approach is part of the engineering tradition; which is supported by the experts interviewed (chapter 5, p. 88). This is also pretty much aligned with the current Newtonian-Cartesian paradigm, in opposition to a more holistic and systemic paradigm (chapter 5, p. 95) (Sterling, 2004).

Furthermore, Dr Richard Fenner (Cambridge University, UK), supported by Roger Dr Hadgraft (RMIT, Australia) points to the need to think about problems differently and by that essentially try to add to the traditional approach a more holistic and broader view (chapter 5, p. 88)

A PBL environment promotes a more or less systemic and holistic learning based on the types of problem scenarios and learning goals defined in an education. The relation between theory and practice should also enclose the profession in a broader social, environmental and economic context.

In this sense, problem scenarios brought into more technical programmes, such as SCE, should enclose non-technical contextual elements (such as social, economic, environmental and political) in order for students to identify and formulate problems with these dimensions as well as return to them when it comes to decision making. Through this process, the problem solving approach becomes more holistic rather than reductionist and technocratic, without losing the professional expertise and identity. Two examples are given by Dr Yona Sipos (University of British Columbia, Canada) and Dr Mark Henderson (Arizona State University, US) through community based learning and humanitarian engineering, respectively. Community based learning claims for a more open and “beyond the university walls” education. The education process and institution acquire a more system thinking quality by allowing students to use community and social problems as scenarios for learning (chapter 5, p. 89) (Lucena, Schneider, & Leydens, 2010).

A PBL approach such as this should not be seen as diminishing the technical expertise or removing relevant technical knowledge from the curriculum, but rather as creating opportunities to equip students with the ability to deal with complexity and uncertainties of technologies, and provide better solutions for local communities.

4. Problem based learning as a critical and transformative process

Critical thinking and reflection starts by questioning in order to examine and interpret how the world is, and how our knowledge is shaped by what surrounds us (Tilbury, 2007). They are cognitive acts carried out by students individually, collaboratively within domains of knowledge, and for action (Barnett, 1994). In PBL, problem analysis and identification take point of departure in questioning a given problem scenario as a means to understand and formulate a problem to be solved. Critical thinking and reflection is considered a process competence developed by students in a PBL environment (Savin-Baden & Howell, 2004).

In case study, critical thinking is highly emphasised in both programmes investigated as an important learning goal, however, there are differences.

In both practices, critical thinking and reflection is examined at two main levels:

- Problem solving process and within the disciplinary field (on both programmes)
- Transformative learning (students learning process involve transformation of views, feelings, concepts of right and wrong, etc.)

In UPM and SCE, there is great emphasis on developing critical thinking within the discipline field. For example, SCE students should be able to reflect on “what” are the proper methods, formulas, etc., for solving a problem, and justify “why” it is so (chapter 9, p. 199).

Furthermore, SCE seems to deal with a “paradoxical dilemma” regarding the development of critical thinking. On the one hand, the programme struggles with an overcrowded curriculum in which too much time is spent on problem analysis and formulation, rather than on focusing on complex detailed knowledge (**L3_{SCE}**, chapter 9, p. 204). On the other hand, interviewee **SB2_{SCE}** recognises that too much content on the curriculum may lead students to lose their critical sense (**SB2_{SCE}**, chapter 9, p. 206).

Students question and reflect on disciplines’ knowledge, professional practices, when doing problem analysis, formulation and solving processes. Through questioning and

reflecting students put professional contexts and practices into perspective, which enables them to revise, contest and reconstruct them. These activities constitute a step for a transformation of the individual student, his/her views and perspectives, which Barnett (cited by Savin-Baden & Howell, 2004, p. 63) defines as critique, and Mogensen Mogensen, 1997, p. 434) as transformative perspective.

Nevertheless, critical thinking and reflection are considered present, and carried out throughout the entire problem solving process. This is emphasised by students and facilitators.

Student **S1_{UPM}** does not only support the statement above, but also extends reflective acts on self-knowledge to different theories and how they link with specifics of the problems. Students contextualise the discipline in broadened contexts, including in relation with different actors and systems of urban planning (**S1_{UPM}**, chapter 8, p. 170).

Critical thinking is a step towards transformative learning understood as a process of effective change of students' frames of reference (*i.e.* worldviews) (Moore, 2005) and a core principle of education for sustainable development (ESD) (Sterling, 2004). Transformative learning does not involve only cognitive dimensions of learning, but also emotional and social dimensions, leading to a reorganisation of the assumptions underlying students' worldviews (e.g. knowledge, culture, value of attitude, judgments and beliefs of what is right and wrong, etc.) (Cranton, 1996; Mezirow, 1997; Sapos, Battisti, & Grimm, 2008).

The students' responses provided support for the existence of critical thinking, and a first step towards transformative learning by questioning other practices as well as involving feelings, beliefs and values. **S3_{UPM}** gives an example by point out the existence of many "powers" which influence her role as a professional and block her in doing things right (**S3_{UPM}**, chapter 8, p.177).

Supporting the transformative dimension on PBL learning process is also a statement from student **S1_{UPM}**. Even though she does not consider her project social as part of a sustainability frame, she points that "*there are things in society that are not as equal as they are supposed to*" (**S1_{UPM}**, chapter 8, p. 178). Furthermore, the same student also stresses that the PBL process transforms values, and group discussions are mainly based in feelings and reasons why things are as they are.

In a transformative learning perspective, students critically think about the disciplines, their culture, and contextualise them into sustainability frames and principles (Barnett, 1994; Cranton, 1996). This implies that they become aware that their professional practice is part of a bigger picture, and also contributes to develop and construct a more sustainable future. Nevertheless, their practice, frames, culture and knowledge need to be contested and reframed towards a more sustainable development

(Mezirow, 1997). It is the learning experiences which will enable students to revise these frames of disciplinary culture and practice and contest them and reconstruct their frames of reference towards sustainability (Moore, 2005; Sipos, Battisti, & Grimm, 2008).

Experts emphasise the need for transformative learning for ESD (chapter 5, p. 92). The students interviewed emphasise on the transformative perspective of critical thinking, emphasise the PBL support for transformative learning (chapter 8, p. 171).

In the SCE programme, focus is on developing critical thinking for disciplinary practice and procedural knowledge. However, the learning conditions can be created to step further towards a transformative learning for ESD through, for example, type of problem scenario, interdisciplinary cooperation, and assessment of solutions' impact on societal context.

5. Systemic and holistic views on “safe” engineering ground

As discussed in the introduction (chapter 1, p. 12) and in the similarities between PBL and ESD (chapter 4, p. 76), engineering education research, and accreditation bodies and societies point in the same direction: develop knowledge, skills and competencies capable of addressing contemporary challenges, including sustainability crisis. Engineering Education for Sustainable Development (EESD) underlies sustainability and education for sustainable development (ESD) principles. These have been elaborated by engineering education research (see for example (Engineering Education for Sustainable Development, 2004) and societies (Doods & Venables, 2005; Bourn & Neal, 2008) in competencies young engineers should be equipped with. These different EESD principles and guidelines were compared and clustered into six main principles to be investigated in practice (see, for example, appendix 7, p. 60). The six principles are: systemic & holistic; flexibility & adaptability; contextual; problem solvers; participatory & decision maker; creativity & innovation.

In both programmes investigated, the main principle pointed out by interviewees is *Problem Solvers*, which emphasises the view of the learning environment (as PBL) and professional practice. Traditionally, engineers are seen as problem solvers (Lucena, Schneider, & Leydens, 2010), and a PBL environment does not make the exception.

Through “*Problem Solvers*”, UPM emphasises the involvement of other’s perspectives and knowledge in defining and solving complex problems (chapter 8, p. 172), while all interviewees in SCE emphasise the use of technical engineering knowledge to solve real problems (chapter 9, p. 206).

Both programmes also emphasise the “*Systemic and holistic*” principle as well. In the SCE programme, most of academic staff are aware that engineering practice influences and is influenced by other professional practices. However, integration of sustainable development in programme is not a priority (chapter 9, p. 202). Nevertheless, the potential already exists in written intended learning outcomes (ILOs) where some aim for students to develop abilities to deal with uncertainties and risks.

In the UPM programme, “*Systemic and holistic*” is highly emphasised by students in comparison with academic staff. For example, three out of four students selected awareness that engineering practice influences and is influenced by other professional practices, while only three out of six academic staff interviewed selected the same indicator. In comparison, the same is observed for the criteria “*Flexibility and adaptability*”, where all students accept that there are no guarantees that solutions will be truly sustainable. While students stress sustainability as more than being problem solvers, only two of the academic staff interviewed share the same view. Even though the “*being problem solvers*” is stressed in the UPM programme, “*flexibility and adaptability*” also gives to students the awareness of the limitations of solutions of the problem, and uncertainties for the future in terms of sustainability. Student **S6**_{UPM} explained that a problem can be solved in many ways, and she is not holding all the answers, but she is able to reflect and use the proper tools to solve it (chapter 8, p. 172).

In opposition, academic staff emphasises “*Participatory & decision maker*”, or “*Creativity and innovation*” as part of the programme while only one student considered the same (chapter 8, p. 172).

With much less attention is the contextual aspect of ESD for both programmes. This principle stresses the importance of developing solutions that are locally and culturally appropriate, minimising negative and maximising positive impacts of solutions both locally and globally. Even though in both programmes, students learn through solving real problems, there is not much emphasis on the societal contexts in which technical solutions are applied, supporting the dominant view of professional education.

In the two previous discussions, UPM students and academic staff emphasised different aspects of critical thinking and EESD principles. Students interviewed emphasised aspects aligned with ESD principles such as transformative approach to solving process, flexibility and adaptability or systemic and holistic view of education.

When it comes to critical thinking, students considered it present through out all the PBL process. Furthermore the reflection and critical thinking involves feelings, values and beliefs which align with transformative learning. While academic staff emphasised the use of theoretical elements for problem formulation, development of a methodological framework for problem solving and for further questioning and reflecting on solutions. For example, **SB1**_{UPM} considers that students are losing the capability of

reflecting on their own knowledge production in relation to societal context (*i.e.* being critical beings). However, students characterise the feeling of producing new knowledge as “no better feeling” (chapter 8, p. 160).

On both practices investigated, the academic staff characterises students as: goal oriented, strong identity towards field (e.g. students just want to do calculations); do not engage in free or elective study activities (for example, chapter 9, p. 206). Also, academic staff points for several struggles that students face along their learning process such as difficulties in linking theory with practice, formulating problems or mastering complex concepts and theories.

Education for Sustainable Development (ESD) aims for participation by and empowerment of students to be change agents for a more sustainable society. Dr Rodrigo Lozano claims that all actors should be involved in integrating ESD in higher education: students, academic and administrative staff, top and middle management. Furthermore, students should be empowered and have a central role on the process of the integration of ESD throughout their academic life. For example, at TU Delft (Netherlands), the committee established to develop a strategy to integrate ESD included students. Others emphasise the involvement of student bodies and NGOs as platforms to integrate ESD (see for example RMIT, Australia, and University of Cambridge, UK) (chapter 5, p. 91).

6. Challenge to obtain a comprehensive SD approach

Sustainability is an integrative concept because it brings together environmental, social, cultural and economic aspects into one framework (Stauffacher, Walter, Lang, Wiek, & Scholz, 2006). Engineering is not the exception profession, it being out of the integrative framework of sustainability. Engineers are producers (by developing new technologies with, for example, need for resources to operate, with impacts on environment and social life, and economically valued), but they are also citizens.

The integration of sustainable development (SD) in engineering education does not only enclose principles regarding the learning process and principles, but also content (Roorda, 2013). Several strategies for integration of sustainability in higher education have been reported by the experts interviewed in chapter 5 (p. 81). For example, stand-alone courses or embedded/integrative courses with relevant themes of sustainability are appropriated and integrated in subject-specific courses (Rusinko, 2010; Lozano, 2011a).

In both programmes investigated, the content for sustainable development is related to the following levels:

- Stand-alone courses with sustainable development as content;
- Concepts that can be related to pre-existing disciplinary-oriented courses;
- Concepts that can be related to problem solving project work and reporting.

The SCE programme has a course named “*Renewable Energy Structures: Wind Turbines and Wave Energy Devices*” in the second semester (SES, 2010). Even though it is related to renewable energy structures, the written intended learning outcomes (ILOs) do not enclose further references to sustainable development or/and sustainable energy production. The course focuses essentially on technical aspects of renewable energy structures and does not relate this to broader, integrative contexts of sustainable development. Nevertheless, this existent course in the formal curriculum provides a ground to move further in integration of sustainable development as content.

The UPM programme does not enclose courses explicitly entitled for sustainable development (SADP, 2010), but the programme’s overall qualification profile encloses ILOs with reference to three pillars of sustainable development and climate change adaptation. Furthermore, the project work for the first semester, entitled “*The Complex City*”, can also be related to three pillars of sustainability. But there are no further explicit references to sustainable development as content.

In the formal curricula, UPM encloses aspects of the three pillars of sustainability, with a dominance of social sustainability in the second semester, while SCE encloses aspects of the environmental sustainability dimension.

In the practiced curricula, UPM mainly presents aspects of social sustainability, but the students’ projects enclose aspects of three themes of sustainability. All projects enclose social sustainability aspects as point of departure, but which are extended and relate to other pillars of sustainability. Take for example the project of student **S6**_{UPM} about climate change adaptation (environmental sustainability), in which students went out to interview households and municipality representatives (chapter 8, p. 169). Students work with real problem scenarios in their projects in which they have to “get out” of the university in order to understand and solve the problem. This allows students to touch upon the complexity of the real societal contexts in which projects’ problems or cases are immersed, and therefore bring other pillars of sustainability to the project work.

Even though students who work with societal contexts mingle with their professional contexts, they define sustainability in relation to environmental aspects, such as environmental impact assessment. However, their project proposals are address perspectives of what is right or wrong in social contexts, giving the students the opportunity to investigate, report and point out solutions to “*make things right*”, as students **S1**_{UPM}

and SS_{UPM} mentioned. Remarkably, students do not link the social dimension of urban planning investigated in their problems as part of sustainability.

In SCE, the aspects of sustainability with potential for the profession is materials, energy, products and services (environment sustainability), risk analysis, economic performance (economic performance) and product responsibility (social sustainability) which are commonly the ones related with common definitions of sustainable development in engineering education (chapter 5, p. 98) (Broadbent, 2012).

Lucena *et. al.* (Lucena, Schneider, & Leydens, 2010) gives several examples of engineering practice integrating social and economic dimensions for sustainable community development that moves beyond the environment by including social, cultural and economic aspects.

Clearly, there is a need to bring better understanding of how the dimensions of sustainability can be brought into the engineering curricula, but also to construct clear and shared sustainable development definitions, frameworks and tools. This calls for an institutional definition of sustainability, frame of action and relation to different practices/educations, but also collaboration across different departments. This is something also claimed by student SS_{UPM} (chapter 8, p. 177)

Such a view towards sustainable literacy is supported by Dr Francisco Lozano (ITESM-Monterrey, Mexico) and Dr Richard Fenner (University of Cambridge, UK) (chapter 5, p. 99). There is a need to provide academic staff and students with an integrative, holistic view of sustainable development to be related with professional contexts, but also integrate transformative, critical and contextual learning principles.

7. Prejudices towards Sustainable Development

Integration of ESD should happen through learning principles and content (e.g. tools, perspectives, frameworks, etc.). It is important to be careful in claiming a presence of ESD just based on one of the learning principles, or just the content. An alignment between learning principles, sustainable development content, learning goals and assessment of those is needed to integrate ESD. In this sense, ESD in engineering education becomes a visible part of the formal and practiced curriculum. Nevertheless, the use of what is already in the context of the institute, constitute a good platform as point of departure. In the practices investigated, some prejudices and tacit practices related to sustainable development emerges, especially in the SCE programme.

In the SCE, academic staff recognises the importance of integration of sustainable development; however this recognition comes with prejudices such as: difficult to bring into a technical programme, subjective and complex concepts that cannot be

defined in a mathematical formula (**F1**_{SCE}); the metaphor “if something new comes into curriculum, something essential needs to get out” (**L3**_{SCE}); the nerdish identity attributed to students who only want to do calculations (**SB1**_{SCE} and **L2**_{SCE}). In this sense, making use of already existent expertise on structural and civil engineering, combined with sustainable development, is essential to bridge prejudices and possibilities for practice for ESD (chapter 9, p.206).

Such prejudices are common in other engineering education contexts in relation to ESD. For example TU Delft (Netherlands), Arizona State University (US) or University of Cambridge (UK) point out some resistances towards ESD because it is not “real engineering” (chapter 5, p. 97).

However, the SCE academic staff is aware that sustainable development will become part of the new engineer professional profile, and those who have knowledge, skills and competencies to work within technical expertise and sustainable development have an advantage when entering the labour market (**L1**_{SCE} chapter 9, p. 210). By his turn, interviewee **SB2**_{SCE} recognises that to provide sustainable solutions, along with technical expertise is needed (chapter 9, p. 212).

SB2_{SCE} stresses that around 15 years ago, Aalborg University’s engineering programmes had Life Cycle Assessment (LCA) as part of the design processes taught to students, being quite advanced for the time. Even though it is no longer present in the formal curriculum, it is part of the practice of some academic staff. It seems that there was a step back regarding the use of sustainable development tools such LCA as part of the technical education. Also **SB1**_{SCE} explains that in the profession, you “just use what should be used, you don’t overdesign”, and **L2**_{SCE} points out that in mechanical engineering courses, students have to carry out Life Time Analysis (LTA) in their projects and studies (chapter 9, p. 202).

L1_{UPM} also points out that AAU is quite good when it comes to “social responsibility” and development of technologies for sustainable energy production as part of several research programmes (chapter 8, p. 175); however, a systematic presence of sustainable development content in technical curricula seems to be scarce.

On the other hand, sustainable development in engineering education is highly focused on development of sustainable technologies and environment, pointing aside the other two pillars of sustainability (chapter 5, p. 21). It is important to stress that there is a strong focus on sustainable technologies and environmental sustainability as if these alone is equal to engineering education for sustainable development.

10.2 Recommendations

The recommendations examined in this subchapter are presented from a top-down approach, i.e. take the point of departure of the organisation's role and vision and move towards teaching and learning practices. The aim is to provide an overview of the university as a system with many layers and interconnections.

1. The University's role and vision for ESD

An education towards sustainable development advocates for a holistic and transformative approach within the institution, involving all levels, mission and vision, programmes, research, etc. And the initiatives and view towards ESD from top level should meet the ones carried out at bottom level (Sterling, 2004).

The examples of integration of ESD into higher education presented in chapter 5 (p. 81) highlight the importance of involvement of top level management (e.g. directors, heads of schools and faculties, etc.) envisioning and supporting initiatives to integrate ESD. See for example ITESM-Monterrey (Mexico), Arizona State University (US), TU Delft (Netherlands). Furthermore, Dr Yona Sipos (University of British Columbia, Canada) refers to the use of mission and vision to gather and develop a staff development programme for ESD with middle management support.

Faculty of Engineering and Science, AAU, have in their mission and vision statements reference to sustainable development (chapter 6, p. 117). However practice should mirrors missions and visions for ESD should, and not be centred in technologies as solutions for sustainable problems, falling into a naïve and technocratic approach to deal with sustainability crisis.

The Faculty of Engineering and Science has a long tradition of collaborating with external partners, especially industry. According to **SB1_{UPM}**, the university assumes the role of a provider of technical solutions for the industry problems; narrow it down its requirements. The role of university should be also questioning what overall society challenges and needs, and help to address them. By acting as an open and integrative system in the overall society, the university would create conditions for transdisciplinary learning and collaboration. In a transdisciplinary approach, academia (students and academicians) would learn to collaborate with practitioners from outside university to solve complex problems (Steiner & Posch, 2006). Notice that these practitioners include others than just industry partners, moving PBL to a more community based learning.

In a reductionist problem solving approach, social and economic pillars of sustainability will tend to be removed from problems' contexts and learning approaches. Therefore, it is important to turn the already existent vision and missions more integrative towards sustainable development. Visions and missions can operate as integrators throughout the existent faculties, departments, programmes and research centres. In this way, all the different levels of practice of institution would integrate ESD and will be under the bigger umbrella of the institution vision for ESD.

Also, experts pointed out the campus' operations as part of initiatives to integrate sustainability at the university, but also with students' involvement and empowerment. On the Green AAU webpage, there is not explicit reference or "corner" for students' active participation and initiatives; it is extended to all communities of the university with contact names for suggestions and ideas (Aalborg University, 2013).

The Green AAU mission includes campus operations, educational programmes and research, however, it encloses very much a perspective of environmental management with aim to reduce the university's impacts on the environment and contribute to a more sustainable campus.

From an environmental management perspective, students are perceived as "products" of the educational processes, and when educated under sustainable development principles and frameworks, they carry out in their professional practice the sustainable mission and vision of institution. Also, there is a latent practice related with social responsibility and research on development of sustainable energy production (for example chapter 8, p. 175).

Also, when questioned about the point of departure for integration of ESD in engineering education, experts pointed out the key role of the top management through: nominating committees and academic staff with vision to integrate ESD and support the latter initiatives (chapter 5, page 91).

2. Problem Based Learning and learning strategies

In their considerations for learning processes for ESD, experts emphasise learning strategies such as problem based and project organised learning, but they also suggest others which can be included under PBL curriculum. It is relevant to stress that learning should be active, empowering, participatory, transformative and involve multi-criteria decisions (for example, chapter 5, p. 89). To some extent, in the previous sub-chapter, the transformative PBL character was already addressed, but the latter is a bit "unspoken" in the curricula. Furthermore, **L2_{SCE}** stresses that when solving problems, students should be able to assess the solutions' impacts at social, environmental and economic level and make decisions based on the outcomes. This is a form of empow-

erment possible to take into technical programmes, enabling student to become socially responsible (chapter 9, p. 212). Dr Mark Henderson, from Arizona State University, U.S., points to the need of PBL models for EESD which sustainable development principles are explicit and addressed as learning goals (chapter 5, p. 101).

At AAU, the interviewees point out that integration of ESD also calls for a revision of PBL practices within institution, and their evolution through time. The type of problem scenarios and interplay of its characteristics (e.g. context, structuredness, complexity, etc.) shapes the worldview; type of knowledge; skills and competencies that students develop in the learning process. Projects, problem scenarios and proposals brought into programmes should be defined so they can be aligned with intended learning outcomes formulated for ESD. Examples are problem contexts related to technical, social, cultural, economic, political, environmental dimensions (**SB1**_{UPM}, chapter 8, p. 178), and problems that also enclose higher complexity and integration of several knowledge domains mirroring not only real life, but also the engineering practice in the bigger picture (Scholz & Tietje, 2002; Steiner & Posch, 2006).

SCE academic staff considers that programme has the basis to integrate SD aspects (chapter 9, p. 204) and to address the EESD principles (chapter 9, p. 206). But at the moment, they are a priority in the programme, as well as integration of sustainable development. Furthermore, the full integration of ESD principles and their formulation as educational goals would enclose modifications on the formal curricula, facilitation and academic staff prejudices towards ESD.

SB2_{SCE} adds to this that maybe it should be time to stop and research the type of competencies in fact engineers have when they are educated and not just rely on the feedback of the industry.

3. Curriculum for sustainable development: structure and content

In chapter 5 (p. 87), it is presented several possibilities to integrate ESD at the curricular level. Examples are add-on strategies (e.g. stand-alone courses for SD), integrative strategies (e.g. SD integrated in all the relevant discipline-specific courses) and minor and full master's programmes in sustainable engineering. These strategies call for innovative and student-centred learning approaches, and many face challenges to also change the learning towards more innovative approaches, aligned with ESD principles.

At AAU, curricula are problem based and project organised. Half of each semester is allocated to solving a real problem through a project. For the interviewees, project modules constitute the natural strategy to integrate sustainable development (SD) in

the programmes. SD has two possibilities to be integrated in a project: through semester themes, which is enclosed in the formal curricula and turns compulsory the integration of sustainable development in problem and project report. A second possibility is to make it part of projects reports as part of the final reflections of the problem solving approach (chapter 8, p. 177; chapter 9, p. 206). The mentioned suggestions work as integrated and add-on strategies for the project modules. In this perspective, most of the interviewees suggested SD to be part of the problem identification and formulation in order to guarantee its presence and a meaningful learning since the beginning of the solving process. **L2_{SCE}** argues that add-on strategies (both at course and project level) do not have a deep impact on students' learning. It is not enough to know theories to have an impact and interfere in students' life and views, it should be integrated. And it is through projects that students' learning is tangible and contextualised. **SB2_{SCE}** adds that projects enable students to work collaboratively in bigger projects, across departments and programmes. This is observed to in other departments and universities, but the interviewee cannot explain why it is not being done in his department.

Besides the possibilities given by projects modules, the interviewees also argue that stand-alone courses are needed to expose students to tools and basic knowledge within SD in order to be mobilised and contextualised in the projects. Here, SCE is reluctant with one more change in the curriculum, which implies removing more essential engineering knowledge from the programme, consequently leading to a decrease of quality of education.

L1_{UPM} also argues that the sustainability framework is flexible enough for all programmes and professional educations to be able to find their place in such. This is achievable by pinpointing relevant themes for both sustainable development and field of education. Several examples are found in literature in relation to such strategies. Furthermore, experts also share the same view as **L1_{UPM}**.

Integration of sustainable development should also be cautious and not make everything about sustainability risking losing the visibility of the professional education as core part of the programme.

4. Role of actors: students and academic staff as drivers

In this perspective, the importance of having students involved for integration of SD in their educations is revised, but also the academic staff.

The students involvement in greening campus initiatives has already been mentioned, but also the value of sustainable development as part of their professional profile as engineers. This should not overshadow their professional identity, but rather make part of it. Experts suggest bringing individuals that are both experts in the field and in

sustainability, alumni and/or industry representatives into the university (chapter 5, p. 91).

At Aalborg University, the students interviewed emphasise different aspects of education when comparing with academic staff, indicating different positions in relation to ESD in engineering education. These outcomes raise questions if students are in favour of integration of ESD in the educational programmes.

Experts also advice staff development in sustainable development so they can act as bridges between the sustainability experts' community and the discipline field expertise. Some are nominated as ESD champions (chapter 5, p. 91).

L1_{UPM} suggested staff development as part of the perspectives, but also constructions of knowledge platforms as support for academic staff who are interested in integrating SD in their teaching and learning. This is carried out at Cambridge University with support of organisations such as the Royal Academy of Engineering and MIT Cambridge Institute.

5. Recognition systems and other resources

Another way to facilitate the integration of ESD in engineering education at Aalborg University is through the creation of reward systems. These can be of different types and should also address students and academic staff.

Voluntary integration of SD in project work should be rewarded by academic staff as part of the formal assessment supplementing the focus on just technical aspects. This type of reward has strong impact on much focused students for taking the better grades. At the same time, it is a signal of recognition from the academic staff.

Other suggestions are made as part of reward systems by L1_{UPM}, like for example symbolic rewards and awards as external recognition for students.

Even though is not mentioned by the interviewees from the case study, it is important to extend the reward systems to academic staff who integrate sustainable development in their teaching and learning. As an example, University of British Columbia took such as example by giving certificates to academic staff as part of recognition of integrating sustainable development. On the other hand, TU Delft certifies master students who participate and take minor degrees in sustainability (for example, chapter 5, p. 93).

From the above discussion, the following recommendations can be summarised:

- Top level management should envision integration of ESD. Vision and missions for ESD should include the three pillars of SD and be connected through institutions' initiatives and strategies to integrate ESD. Top level should also support initiatives for ESD across the different levels of organisation through, for example, allocation of resources and recognition system.
- Higher Education Institutions (HEIs) can assume relevant social roles for ESD through, for example, environmental management systems (EMS). Different HEIs should look into possibilities for more collaboration towards ESD. The collaboration should be fostered creating interdisciplinary and transdisciplinary community of practices. For example, Aalborg University may attempt to establish external partnerships beyond industry, and contribute for community based projects.
- For institutionalised PBL practices, the transformative learning character of PBL should be visible in learning processes, by promoting collaborative learning and critical thinking. This depends on types of problems scenarios, student's ownership and visibility in formal curricula. Transformative learning can be fostered by, for example, creating mega-projects aiming to solve multidimensional, open and complex problems. The mega-projects are carried out by students from different educational programmes and even faculties. Once more, the collaboration should be promoted across disciplines and different actors, such as academic staff and students. In Aalborg University, group work and facilitation processes present possibilities by joining co-supervisors and students from different areas in a mega-project.
- Problem scenarios contextualise knowledge in engineering professional contexts, but also in societal contexts. The contextual learning provides an opportunity for engineering education and ESD, as well as a new relation between practice and theory. PBL curricula can include problem scenarios to develop engineering expertise and, later on, develop a holistic understanding of profession in broader societal contexts. PBL practices can include and challenge students through different types of problem scenarios to foster different levels of contextual learning.
- Assessment and reporting teaching practices have an important role in the integration of ESD. These activities also acknowledge what is practiced, who practices and how practice forms a platform to integrate ESD. Furthermore, they can be used to develop new initiatives and involve new actors.
- At a practice level, it is highly stressed the students' involvement in top and middle level initiatives to integrate ESD, such as greening campus operations projects. Furthermore, this involvement can constitute a form of empowerment by actively change and transform the learning places.
- For academic staff, it is highly recommended the creation of staff development programmes for ESD, where the academic staff should experiment the same learning environment and conditions as students. For example, the programmes can promote transformative collaborative learning and contextual learning,

through cross department collaboration for ESD. Furthermore, these programmes can also promote a better understand of PBL and its support to the integration of ESD.

- The recommendations also include the creation of recognition systems. The recognition systems are extended to students and to academic staff, in relation with their own initiatives to integrate ESD. Regarding to students, the recognition can be made through formal assessment on ILOs. In Aalborg University, ILOs can be formulated for project modules and addressed in the formal curricula. Regarding to academic staff, those who integrate ESD could be recognised through tenure systems and symbolic nominations such as ESD champions. The recognitions systems differ in examples provided by experts; however, they are developed according with context and culture of organisation. Furthermore, the recognition is for different levels and targets different actors.

As a final remark, the above recommendations compose a multi initiatives strategy to integrate ESD in engineering education, especially for Faculty of Engineering and Science, Aalborg University, supported by other international examples and recommendations.

11 Conclusions and closing reflections

Engineering education institutions are being challenged to integrate education for sustainable development (ESD) in their educational programmes. Engineering education research, accreditation bodies, and organisations point in the same direction, and give guidelines in the type of qualifications engineers should have to address the sustainable crisis.

This chapter presents the main conclusions of the study by answering the research question from the three perspectives investigated. The perspectives provide different layers of analysis and comprehension of Problem Based Learning (PBL) and Education for Sustainable Development (ESD) for engineering education. The theoretical perspective discusses and compares the learning theories behind PBL and ESD, their similarities and constructions for change and practice (PBL support to integrate ESD). The integration of ESD advocates change at an organisational level based on holistic, systemic and transformative principles. The experts' perspective analyses the integration of ESD by examining and comparing the institutional strategies, challenges and perspectives of change. The third perspective examines different PBL practices in engineering education and their support of ESD integration.

The following starts by answering the research question from a theoretical perspective followed by experts' and practice perspectives. In each perspective, it is addressed mutual relations emphasising a comprehensive approach to research.

11.1 Answering the research question

This study aims to investigate the following research question:

In which ways can PBL support the integration of ESD in engineering education?

In the following, this research question is answered according to the main outcomes of the three investigated perspectives.

From a theoretical perspective

The theoretical perspective aims to investigate the similarities between PBL and ESD principles and defines learning dimensions in which ways PBL can support the integration of ESD.

The ESD literature review presented in chapter 2 (p. 25) gives an overview of the different interpretations and responses to ESD.

Integration of ESD in higher education institutions (HEIs) calls for a change involving all levels of the organisation. HEIs show different levels of response which include different levels of organisational learning towards ESD. These different levels of responses and learning include transformation of the educational paradigm (level 1 or top level), institution's management, curriculum design and development (level 2 or middle level), teaching and learning practices (level 3 or bottom level). ESD learning is contextual, self-directed, collaborative, transformative, experiential, constructivist/ cognitive.

PBL learning process is characterised as interdisciplinary, contextual, self-directed, participatory oriented, and based on learning theories such as constructivism and experiential learning. Through the PBL process, students develop, for example, high metacognitive reasoning, critical thinking, problem solving skills, teamwork, and communication skills. However, different problem scenarios lead to different learning outcomes. The five basic PBL models discussed in chapter 4 (p. 69) provide an overview of different combinations of problem scenarios, learning goals, knowledge, disciplinarity resulting in a landscape of practice.

PBL can support the integration of ESD by creating learning conditions to promote the different states of ESD (i.e. education **about**, **as**, or **for** sustainable development). The five PBL basic models present dimensions, such as knowledge learning goals, and problem scenarios, similar to ESD. The combination of the different dimensions lead to

different PBL models, which can promote the development of metacognition, interdisciplinarity, critical thinking, problem based, collaborative, self-directed and contextual learning for ESD.

It is important to stress that PBL supports integration of ESD at different levels by bringing different problem scenarios to drive the learning process aligned with different learning goals and leading to different learning outcomes. For example, if the problem scenario is narrower and disciplinary oriented (PBL model for epistemological competence), the learning goal is mainly to develop knowledge in a disciplinary area. This model can be claimed to support an education about sustainable development, rather than an education for, or as, sustainable development. Education towards sustainable development which claims for more interdisciplinarity, or transformative education, is more suitable to be fulfilled by dilemmas, or multidimensional and open problem scenarios (PBL model 4 and 5 respectively) (chapter 4, p. 75).

The comparison between PBL and ESD principles allowed pointing some variables investigate PBL and ESD in engineering education practices. The PBL variables represent different ways in which PBL can support the integration of ESD (figure 11-1).

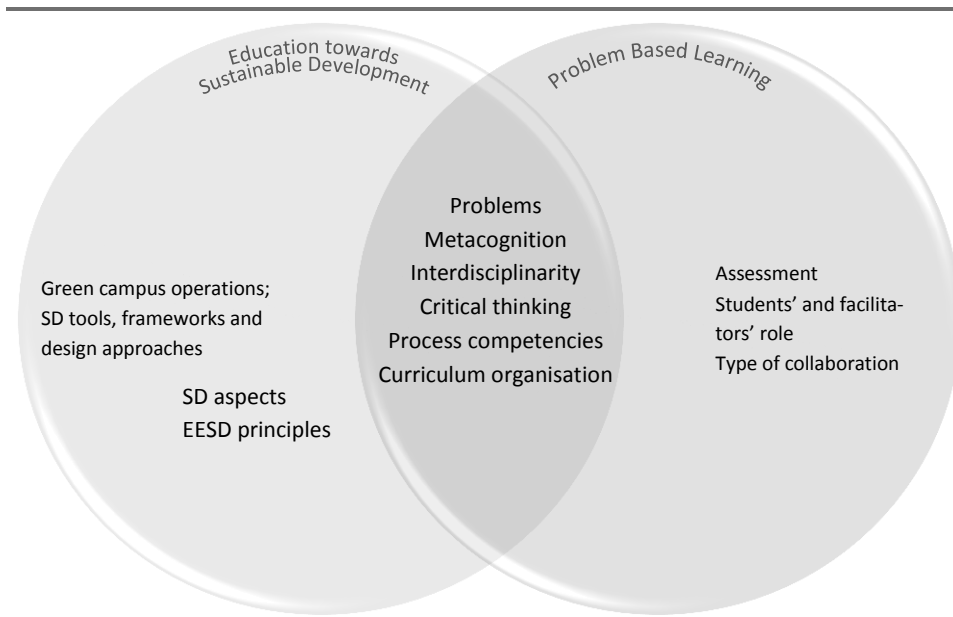


Figure 11-1 PBL dimensions which can support the integration of ESD in engineering education.

The variables are problems (e.g. narrow or ill structured problem scenarios), knowledge (e.g. metacognition), disciplinarity (e.g. interdisciplinarity), critical thinking

(e.g. transformative critical thinking), process competencies (e.g. problem analysis, communication) and curriculum organisation (e.g. project organised) (figure 11-1). However PBL does not necessarily support the integration of ESD if sustainable development is not part of the learning goals, therefore other principles of ESD, specifically for engineering education, and SD content have to be added as content for ESD. PBL can support the integration of ESD principles in engineering education but a close relation to SD content is needed.

The integration of ESD is more detailed when investigated through experts' interviews and bring examples of strategies, drivers, barriers and challenges for change, actors' roles and involvement, learning practices, future perspectives for ESD. These are elaborated in the following section.

From the expert perspective

In order to respond the research question from an expert perspective, seven experts in education for sustainable development (ESD) and engineering education for sustainable development (EESD) were interviewed. The experts' interviews aim to analyse the integration of ESD in higher education, with emphasis on engineering education, in its strategies, drivers, barriers and challenges, pedagogies, role of different actors, future perspectives. The results, presented in chapter 5 (p. 81), are organised in elements of integration; challenges and future perspectives (figure 11-2).

The integration of ESD involves change of different elements: curriculum structures, formulation of EESD learning outcomes, learning processes, actors, resources and facilities. Furthermore, ESD encounters challenges and barriers such as institutions' culture and context, staff and students' resistance, collaboration among academic staff and cross disciplines (figure 11-2).

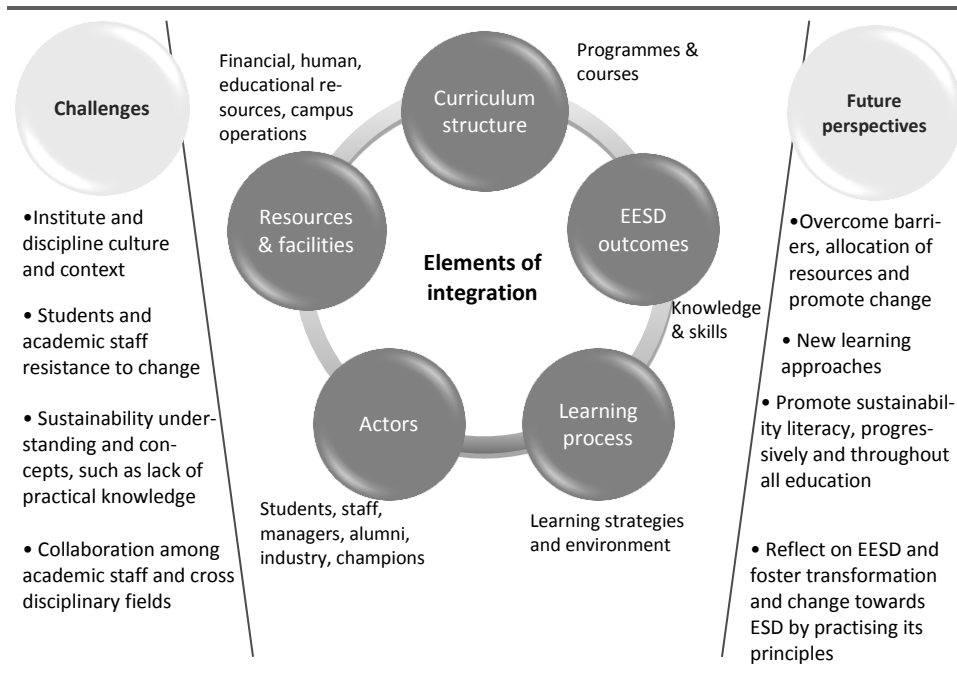


Figure 11-2 Elements of integration for EESD, challenges and futures perspectives of integration of ESD in engineering education

Experts also stress learning outcomes and learning processes for ESD in engineering education. The learning outcomes, such as system thinking and holistic solving problem, combine ESD and engineering expertise. PBL supports the development of ESD outcomes by letting real problems foster the learning process. Solving real problems promote contextual learning and mirror the complexity of reality. These conditions allow students to construct interdisciplinary knowledge and a broader view of problems' contexts and their solutions. Furthermore learning processes for EESD are based on transformative, collaborative, and self-directed principles to empower students. As it was discussed in the theoretical perspective, different problem scenarios can provide a base for the learning process including the EESD principles. Furthermore PBL is also team based which means that students solve problems collaboratively. The collaborative dimension of PBL also poses other possibly for ESD, which is form cross disciplinary groups (such as example provided by Dr Mark Henderson from Arizona State University).

Experts also claim for innovative learning strategies by combining old and new strategies. A suggestion made by the experts is developing the PBL models a step further and include ESD principles. PBL thereby can support the development of new and innova-

tive pedagogies for ESD through research and benchmarking of best practices of PBL and ESD.

Regarding the resources needed for ESD, staff development programmes assume an important role in terms of the integration of ESD. These programmes also work as platforms for staff to develop new learning and innovative pedagogies aligned with the ESD and their field. They are contextual which means academic staff contextualises sustainable development in both societal and professional contexts. Examples of staff development programmes, such as University of British Columbia (Canada), combine both understanding of learning principles and content for ESD. PBL can support the design of staff development programmes for ESD by allowing the construction of a common understanding of PBL and ESD learning principles.

PBL can provide support at these different levels, but it is important to be aware of limitations of constraints.

At institutional level, the integration of ESD implies a systematic change of curricula, in its formal and practice forms. This can be supported by a simultaneous process of change for a PBL curriculum to integrate ESD.

From an institutional point of view, this “double process” of change for PBL and ESD is likely to meet the challenges mentioned in figure 11-2 (p. 241). The use of PBL to integrate ESD should also include an understanding of PBL learning principles at practice and organisational levels. This calls for a holistic view on PBL learning processes in opposition to a fragmentation and multi-conceptualisation of PBL and ESD practices.

The following answers the research question from a practice perspective.

From the practice perspective

The curricula of the two engineering programmes investigated, M.Sc. Urban, Planning and Management (UPM), and M.Sc. Structural and Civil Engineering (SCE) are problem based and project organised. The curriculum organisation is explained in more details in chapter 6, in the introduction to Aalborg Case (p. 105).

The findings of the case study, presented in chapters 8 and 9 (p. 147 and p. 183, respectively) have shown two PBL models practised in the programmes studied, one in each programme.

The practices investigated show that PBL supports the integration of ESD as it promotes:

- Metacognition and interdisciplinary cooperation for systems thinking by fostering high complex reasoning tasks (e.g. reflect, evaluate, synthesise) and group-work across different disciplines.
- A holistic problem solving approach by analysing multi-contextual and ill structured problem scenarios;
- A balance between professional and societal contexts by including elements from both contexts in the problem analysis, formulation, and solving processes.
- Transformative learning by fostering transformative collaboration and critical thinking
- Different learning outcomes for ESD by bringing different problem scenarios into education
- Comprehensive integration of SD content by using different opportunities to integrate SD such as project's themes, sustainable design and environmental management tools, and relevant courses.

Even though PBL supports the integration of ESD in several ways, they are not free of limitations. For example, the combination of metacognitive reasoning and collaboration within a disciplinary field (e.g. SCE), or within several disciplinary fields (e.g. UPM), leads to a more disciplinary expertise, or to a cross disciplinary and system thinking, respectively. Even though the academic staffs from both programmes are aware of the importance of cross disciplinary and system thinking as important for students' learning, they also encounter several constraints. Some pose by curricula guidelines, other by students' resistance to work in just diverse teams. This constitutes an example in which organisation, and educator developers, should support and create conditions for interdisciplinary education. Good examples are given by experts' interviews such as the use of mega projects, and student associations (such as Engineers without Borders).

In both PBL models investigated, the problem scenarios brought into the education, and by whom (student or academic staff) do not only create conditions for development of metacognitive reasoning across disciplines, but also determine the contexts students analyse for problem identification and formulation, and the problem solving approach. Here, SCE and UPM oppose, for example, SCE problem scenarios are narrower, without societal elements as the students' contextual learning within the core and boundaries of the disciplinary field.

In opposition to the UPM programme, the problem scenarios are multidimensional making the programme contextual, meaning that students' contextual learning loses the sense of the disciplinary boundaries, and the professional object. However, this allows UPM students to develop more holistic problem solving approaches by integrat-

ing broader societal elements. But likewise these outcomes do not aim, or relate directly with ESD, but with professional practice.

Also different problem scenarios enclose different relations with ESD by supporting the development of different outcomes, but they should be formulated and assessed as learning outcomes for sustainable development.

Both PBL models investigated face some challenges regarding the disciplinary culture and prejudices towards ESD in engineering education. In SCE, for example, academics point at some problems of integrating ESD such as overcrowded curricula, students' lack of motivation. However, PBL principles such as exemplarity and self-directed learning, in which students seek, create, apply and generalise knowledge and skills from one problem solving process to another, would allow challenging students to analyse very complex, and ill structured problems at upper levels in their education (such as the master education). In the UPM study, students emphasise the need for an institutional definition and framework for sustainable development. Surprisingly, these students also emphasise different aspects of the PBL education such as its transformative process by reflecting, criticising, and contesting different objects and subjects along the solving process. Examples are practices, beliefs and feelings.

This constitutes a relevant topic for future investigation in order to understand how critical thinking and peer learning promotes transformative learning and which kind of problem scenarios ought to promote a sustainable education in their whole principles.

SCE falls more into a PBL curricula for professional action (model II), focused on procedural knowledge, real life situations and testing competencies for workplace. Such curricula emphasise the disciplinary and technical contexts, narrow the problems and limit the integration of ESD. The UPM programme, which presents a quite opposite profile, it falls into the PBL of learning interdisciplinarity understanding (model III). This model promotes metacognitive knowledge, interdisciplinarity, knowledge to act and interact, assessment focus on skills and contextual knowledge. This programme encloses characteristics which praise some of the core principles of ESD.

The following synthesises in which ways PBL can support the integration of ESD in engineering education from the three perspectives investigated.

Synthesis

Problem Based Learning (PBL) can support the integration of ESD in engineering education by:

- Promoting system thinking if groups are formed across faculties, departments, education programmes and students develop metacognitive reasoning through interdisciplinary collaboration;
- Fostering transformative learning if key actors open up for critical thinking in relation to established paradigms and practices;
- A holistic problem solving approach if problems are characterised as multidimensional, complex and ill-structured;
- Relations between theory and practice for ESD if the knowledge constructed for professional and societal contexts are related to SD concepts.
- Comprehensive integration of SD if learning goals for ESD are considered throughout the curriculum and if SD is explicitly stated and assessed as such.
- Providing diverse pedagogical opportunities to obtain the learning goals if to SD is given a role in, for example both stand-alone lectured based courses and project work.

The study also allows making some recommendations regarding the PBL support to integrate ESD in engineering education. The main recommendations are:

- Top level management should envision and support the integration of ESD. The ESD vision and missions should be included in the organisation profile, and be practiced at all levels. To secure ESD practice, top level can develop recognition systems to support bottom up initiatives.
- Institutions should assume new social roles. Examples are to take responsibility for institutional impacts by implementation of an audit environmental management system (EMS) or to take responsibility for regional development by collaborating with industry, alumni or NGO's on community based projects.
- For institutionalised PBL practices, the transformative learning dimension should be more visible. For example, interdisciplinary collaboration should be promoted through the creation of projects across department and faculties (mega-projects). Also students should have more ownership over their problems and projects by allowing them to choose problem scenarios and formulate learning outcomes for education and for ESD.
- A culture of continuing assessment and reporting on PBL and ESD initiatives should be promoted.
- The students' involvement in strategies to integrate of ESD should be increased. For example, students can use the greening campus operations as project themes.
- Academic staff should be motivated to collaborate across department. In PBL environment co-supervision constitutes a good platform to bring together academic staff from different programmes, departments and faculties. The co-supervision could be used, for example, in mega-projects, in greening campus projects or community based projects.

The following presents the closing reflections, methodological reflections and proposals for future investigations.

11.2 Closing reflections and methodological considerations

The closing reflections do not only regard the content of the last chapter, but also my life as a researcher. It has been three years of struggles, doubts, and ups and downs. But it was also three years of support, learning, growing, reflecting, and, of course, achievement. I cannot write in detail about these three years because these pages are not enough. However, I can, and shall, focus on the key reflections towards the research process, methodologies, and decisions which led to this thesis.

Throughout the research process, I encountered several cross roads, where each path decided shaped the research process and its outcomes. For example, the PBL, ESD and engineering education research themes I have decided to work with as well as the perspectives and analytical variables defined.

I have taken my point of departure in a comprehensive literature review, and define key concepts of common learning principles of PBL and ESD. I have also used the literature review to develop and construct instruments for data collection and criteria for analysis. This process allows me to comprehend, for example, what we mean by critical thinking, limits of critical thinking, which are frequently referred to in literature, but not further elaborated on. The literature and concepts I constructed, I also aimed to observe in practice. I could have headed for another road, and rather let the academic staff and students define them to me. But doing so also imply to formulate and investigate other research question, such as how PBL practitioners define education for sustainable development in their engineering field.

The research design and tasks carried out (e.g. the sources of literature review chosen, case selection, case study, data analysis and reporting, etc.) enclose limitations and a certain degree of subjectivity. Along the research process, I have applied strategies to minimize the subjectivity, or biases, that my study may enclose. For example, the concepts of interdisciplinarity, the type of knowledge may be different in different research communities; therefore, I have tried to reduce such by using triangulation of sources of evidence in the case study, and furthermore support the case study conclusions with EESD perspectives and literature. Also, even though Aalborg University was

most suitable for case study, I made the choice supported by a screening study of other institutions which combined PBL and ESD in engineering education at institutional and programme levels. Also I have addressed the question of quality of the research in chapter 7 (p. 141) through arguments to attest study validity, reliability and generalisation.

The outcomes of the study are mainly suitable for Aalborg University, due to its strong contextualisation, and furthermore, for specific programmes investigated. However, the theoretical and experts perspectives, data collection and analysis procedures, are constructions which support the case findings and can be adapted to investigate PBL and ESD in other institutions.

This study also sets the ground for further investigations within the areas of PBL, ESD and engineering education. Some examples are:

- In which ways the facilitation process promotes the integration of ESD
- What kind of group formation and problem scenarios are needed to foster critical taking and transformative learning?
- What characterises holistic problem solving approaches?

This is the closing chapter of a PhD study, but it is also the ground for further research within the area, collaborations, and learning experiences.

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