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**Industrial Design and Engineering Transition
to Radical Innovation for Sustainability in Tertiary Education:
*Concept Design Strategies based on a New Zealand Study***

A thesis presented in partial fulfilment of the
requirements for the degree of

Master of Philosophy

in

Product Development

at Massey University, Albany,
New Zealand

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Abstract

A UN Decade of Education for Sustainable Development (UNDES) is currently in progress from 2005 – 2014. The importance of Sustainable Development (SD) and Sustainable Product Design (SPD) has been recognized by the professional bodies for industrial design and engineering, and promoted within tertiary education. A consensus gained from a literature review revealed that *radical innovation* is now necessary to achieve Factor 4 (i.e. reducing resource use to a quarter of the total), or Factors 10-20 (reducing resource use to a 10th – 20th of levels in the present production/consumption model) in upholding global environmental and social integrity. Design and engineering are seen as “core catalysts of change” towards radical innovation for sustainability, and therefore essential that industrial designers and engineers be appropriately educated. The motivation and main aim of this research was therefore to develop an educational framework for mainstream industrial design and engineering in SD/SPD at tertiary level. This should be based on the key concepts of SD/SPD towards *radical innovation*, successful international examples of industrial design and engineering curricula, as well as any pertinent information derived locally from the New Zealand design and engineering scenario. The latter was derived via a survey of industrial/product design, mechanical/mechatronics engineering students in their final year of undergraduate study in New Zealand.

These research strands were synthesized and further refined, using a 4-year undergraduate degree structure (combined years 1-2 for a 3-year design degree programme). The *Conceptual Educational Framework and Guidelines* are intended as an aid and underlying structure towards embedding *radical innovation for sustainability* in Industrial Design and Engineering curricula. Together, they provide a draft, a roadmap of essential and important concepts, to combine with discipline-specific core content of Industrial Design and Engineering undergraduate degrees

The NZ survey results proved similar to international studies: an overall discrepancy between the high ratings of the importance of sustainability and low values in actual knowledge, with definitions of ecodesign (eco-efficiency through reduction and/or minimization of harmful environmental impacts), rather than eco-effective, beneficial sustainable design (comprising environmental, economic and social considerations). The key recommendations are documented within four concepts: 1. *Emphasis on the Social Element of SD/SPD*, 2. *Transition towards Systems Thinking via PSS (Product-Service Systems)*, 3. *Complementary Sustainable Design Strategies* and 4. *Transition towards Strategic Design*. These concepts advocate emphasis on the social element of SD/SPD through context and creativity; systems thinking via PSS; eco-effectiveness and *Cradle-to-Cradle design principles (C2C)*, followed by eco-efficiency for optimization; and all governed by strategic design. The design intent of the *Conceptual Educational Framework and Guidelines* is to maximize beneficial, eco-effective systems, sustainable behaviour, equity, quality of life, and connecting design, technology and human behaviour.

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Table of Contents

Abstract	iii
Acknowledgements	iv
Table of Contents.....	v
List of Figures.....	viii
List of Tables.....	x
List of Appendices.....	xi
Glossary of Terms	xii
1. INTRODUCTION.....	1
1.1 Motivation and Rationale for this Research	2
1.2 Definitions of SD/SPD.....	3
1.3 The Importance of SD/SPD Concepts in Tertiary Education	5
1.3.1 <i>International SD Tertiary Education</i>	5
1.4 Sustainability Guidelines of Professional Bodies	7
1.4.1 <i>SD/SPD and Industrial Design Accreditation</i>	7
1.4.2 <i>SD/SPD and Engineering Accreditation</i>	8
1.5 Ecopreneurs – Change Agents of the Future?	10
1.6 Purpose of this Research	12
1.6.1 <i>Research Aim and Objectives</i>	12
1.7 The Scope and Contribution of this Research.....	13
1.8 Overview and Structure of Thesis	15
2. LITERATURE REVIEW OF KEY CONCEPTS OF RADICAL INNOVATION FOR SD/SPD.....	17
2.1 Overview	17
2.2 Concept 1: Emphasis on the Social Element of SD/SPD.....	19
2.2.1 <i>'Wicked' Problems are User-Centred in Systems Design</i>	19
2.2.2 <i>The Human Factor as Part of the Whole, within Systems Thinking</i>	21
2.2.3 <i>Symbiotic Effects between Ecosystem Services and Human Well-being</i>	25
2.2.4 <i>Technology needs to be linked to Human Behaviour</i>	27
2.2.5 <i>Human Factors and Understanding Consumption</i>	29
2.3 Concept 2: Transition towards Systems Thinking via PSS (Product-Service Systems).....	35
2.3.1 <i>Overview</i>	35
2.3.2 <i>Broadening of Scope from Products to Systems</i>	36
2.3.3 <i>PSS (Product-Service Systems)</i>	44

2.4	Concept 3: Complementary Sustainable Design Strategies.....	49
2.4.1	<i>Eco-efficiency / Cradle-to-Grave</i>	49
2.4.2	<i>Eco-effectiveness / Cradle-to-Cradle</i>	51
2.5	Concept 4: Transition towards Strategic Design.....	59
2.6	Complementary Professions of Industrial Design/Engineering	65
2.7	Educational Perspectives	71
2.7.1	<i>Differences between Design and Engineering Courses in SPD Education</i>	71
2.7.2	<i>SD/SPD and Industrial Design Curricula / International</i>	75
2.7.3	<i>Academic Design Research Projects – Case Studies</i>	76
2.7.4	<i>DEEDS (Design Education & Sustainability)</i>	78
2.7.5	<i>SD/SPD and Engineering Curricula / International</i>	80
2.7.6	<i>SD/SPD in Curricula / Interdisciplinary</i>	90
2.7.7	<i>Prior SD/SPD Frameworks/Surveys in Design & Engineering Curricula</i>	94
2.8	Key Conclusions of Literature Review	101
3.	RESEARCH METHODOLOGY	103
3.1	Research Methodology and Design Process of this Thesis	103
3.2	Rationale for Key Concepts of Radical Innovation	105
3.3	Rationale for using a Survey	107
3.4	Design of Survey Questionnaire	110
3.4.1	<i>Questionnaire Composition and Design</i>	110
3.4.2	<i>Drafting the Survey Questionnaire</i>	111
3.5	Pilot Study of Survey Questionnaire.....	113
3.6	Final Survey – Nature of Survey Sample	115
3.7	Ethics Considerations.....	115
3.7.1	<i>The Human Ethics Committee at Massey University.....</i>	115
3.7.2	<i>Ethics Procedures – Low Risk Notification</i>	116
3.8	Distribution of Survey Questionnaire	116
3.8.1	<i>Schedule of Distribution</i>	116
3.8.2	<i>Summary of Survey Characteristics</i>	117
4.	SURVEY RESULTS AND EVALUATION.....	119
4.1	Overview	119
4.2	New Zealand Survey Results	120
4.3	Differences between NZ and International Studies / T-Test.....	123
4.3.1	<i>Rationale for using a Statistical T-Test</i>	123
4.3.2	<i>Evaluation of Studies for Sustainable Development Concepts.....</i>	127
4.3.3	<i>Evaluation of Studies for Environmental Issues</i>	129
4.3.4	<i>Evaluation of Studies for Policy, Standards and EMS</i>	132

4.3.5	<i>Evaluation of Studies for Tools, Technologies and Approaches</i>	134
4.3.6	<i>Comparison of Studies for Ratings of the Importance of SD</i>	137
4.3.7	<i>Evaluation of Open-ended Questions in New Zealand Survey</i>	138
4.4	Summary of Evaluation of NZ and International Studies.....	144
5.	EDUCATIONAL FRAMEWORK AND GUIDELINES.....	147
5.1	Overview	147
5.2	Strategic Design Cycle Model	150
5.3	Guiding Principles of Radical Innovation for Sustainability	153
5.3.1	<i>Guiding Principles for Emphasis on the Social Element of SD/SPD</i>	153
5.3.2	<i>Guiding Principles for Transition towards Systems Thinking via PSS</i>	155
5.3.3	<i>Guiding Principles for Complementary Sustainable Design Strategies</i>	156
5.3.4	<i>Guiding Principles for Transition towards Strategic Design</i>	157
5.4	Core Structure underlying Framework, using Design Process	159
5.5	Conceptual Educational Framework	160
5.6	Educational Framework Focus – Years 1-4	162
5.7	Educational Framework Guidelines	163
6.	CONCLUSIONS	169
6.1	Overview	169
6.2	Limitations of this Study.....	174
6.3	Future Research	174
6.4	Executive Summary and Recommendations.....	175
	References	177
	Appendices	

List of Figures

Figure 1: Diagram of the concept of sustainable development (Szymkowiak, 2003).....	4
Figure 2: Diagram of how Sustainable Design is attained (Charter, 2001)	4
Figure 3: Thesis Structure and Content.....	16
Figure 4: A model for design and 'well-being', (Fuad-Luke, 2007, p. 24).....	22
Figure 5: Differentiation of innovation types and their sustainability potential (Tischner, 2008, p. 162)....	35
Figure 6: Hierarchy of waste management (Cooper, 1994), cited in (T. A. Bhamra, 2004, p. 560)	37
Figure 7: Brezet's four stages of product improvement to innovation (Brezet, 1997),.....	39
Figure 8: Structure of service system and environmental strategies (Jackson, 1996), cited in (T.A. Bhamra, 2004, p.561).....	40
Figure 9: Environmental strategies and temporal scales (Bras, 1997)	41
Figure 10: Conceptual model of ecodesign process	43
Figure 11: Evolution of the Product-Service System concept (Baines et al., 2007, p. 1546)	45
Figure 12: Product-Service continuum (Kotler, 1994), cited in (T. Bhamra & Lofthouse, 2007, p. 126).....	45
Figure 13: Differentiation of PSS categories and sub-categories (Arnold Tukker, 2004, p. 248).....	48
Figure 14: An integrative framework for Industrial Ecology, LCM and Supply Chain Management	50
Figure 15: Eco-effectiveness strives to generate an entirely (100%) beneficial impact (Braungart, McDonough, & Bollinger, 2007, p.1343)	51
Figure 16: Fractal tile, used to visualise C2C concerns (W. McDonough & Braungart, 2003, p.150)	52
Figure 17: Material flows in the context of an Intelligent Materials Pooling community	53
Figure 18: Back view of ' Mirra' chair (Berry, 2005, p. 229).....	58
Figure 19: Generative principles in design thinking (Buchanan, 2001, p. 76)	59
Figure 20: The relationships within the product design process for ISDPS concept.....	61
Figure 21: Wheel of options for product enhancement, (Parsons, 2009, p. 83)	62
Figure 22: Model of ecodesign innovation, (Charter, 1997), cited in (Sherwin & Evans, 2000, p. 113)	67
Figure 23: Model of integrating Ind. Design and Design Engineering (Sherwin & Evans, 2000, p.116)	68
Figure 24: EMUDE research process (Jegou, 2008, p. 180)	76
Figure 25: From ecodesign to Design for Sustainability (Spangenberg et al., 2010, p. 1490)	78
Figure 26: Adapted from Charter, Tischner et al, 2000, see Figure 2 (Ramirez, 2006, p. 199)	95
Figure 27: Double diamond design process (Design Council, 2007)	103
Figure 28: Sustainable Development Concepts, NZ Survey 2010	120
Figure 29: Environmental Issues, NZ Survey 2010.....	121
Figure 30: Environmental Product Policy (EPP), NZ Survey 2010	121
Figure 31: Standards and Environmental Management Systems (EMS), NZ Survey 2010	122
Figure 32: Tools, Technologies and Approaches, NZ Survey 2010	122
Figure 33: Ratings of the Importance of Sustainable Development, NZ Survey 2010	123
Figure 34: Comparison of Studies for Sustainable Development Concepts.....	127
Figure 35: Comparison of Studies for Environmental Issues	129

<i>Figure 36: Comparison of Studies for Policy, Standards and EMS.....</i>	<i>132</i>
<i>Figure 37: Comparison of Studies for Tools, Technologies and Approaches</i>	<i>134</i>
<i>Figure 38: Comparison of Studies for Ratings of the Importance of Sustainable Development</i>	<i>137</i>
<i>Figure 39: Strategic Design Cycle - model of complementary but sequential SPD Strategies</i>	<i>151</i>
<i>Figure 40: Core structure underlying framework, using diverging/converging design process</i>	<i>159</i>
<i>Figure 41: Conceptual Educational Framework, a structure to combine with discipline-specific courses ..</i>	<i>161</i>

List of Tables

Table 1: Summary of Maslow's hierarchy of needs (T. Bhamra & Lofthouse, 2007, p. 57)	29
Table 2: Max-Neef's satisfiers of human needs (Max-Neef, 1992),.....	30
Table 3: Ecodesign principles & strategies (van Hemel, 1998), cited in (T. A. Bhamra, 2004, p. 562)	42
Table 4: The 12 Principles of Green Engineering.....	56
Table 5: Parameters for MBDC's materials assessment protocol	57
Table 6: Herman Miller Design for Environment assessment criteria	58
Table 7: Reframing our perspectives on sustainable design (Walker, 2002, p. 9)	59
Table 8: Design activities (Sherwin & Evans, 2000, p. 114)	67
Table 9: Pedagogic comparators in engineering and design (Morris et al., 2007, p. 138)	71
Table 10: SCALES core principles (Spangenberg et al., 2010, p. 1492), source (Blincoe et al., 2009).....	79
Table 11: 3-tier SD framework at DUT, (K. Mulder, 2004, p. 281; K. F. Mulder, 2006, pp. 138,141).....	83
Table 12: Clusters of various topics on SD courses (K. F. Mulder, 2006, p. 141)	84
Table 13: Overview of ethical viewpoints (Zandvoort, 2008).....	85
Table 14: Ethics framework at DUT, including the MSc Joint Venture teaching model (JV).....	88
Table 15: Essay topics of the MSc Joint Venture teaching model (JV) (Zandvoort et al., 2008).....	89
Table 16: Scenarios for general and specific energy-saving measures (Uiterkamp & Vlek, 2007, p. 182)....	91
Table 17: The TEOs of the interdisciplinary Ijssel project (K. F. Mulder, 2006, p. 140)	92
Table 18: Programme on backcasting in the Netherlands (K. F. Mulder, 2006, p. 141).....	93
Table 19: Pilot study and Final survey participants	113
Table 20: Distribution schedule of final year student survey in New Zealand, 2010	116
Table 21: Summary of significantly different Data between Studies	125
Table 22: Evaluation of Studies for Sustainable Development Concepts / T-Values	127
Table 23: Significantly different Data for Sustainable Development Concepts	128
Table 24: Evaluation of Studies for Environmental Issues / T-Values.....	129
Table 25: Significantly different Data for Environmental Issues.....	130
Table 26: Evaluation of Studies for Policy, Standards and EMS / T-Values.....	132
Table 27: Significantly different Data for Policy, Standards and EMS	133
Table 28: Evaluation of Studies for Tools, Technologies and Approaches / T-Values	135
Table 29: Significantly different Data for Tools, Technologies and Approaches	136
Table 30: Final Year ID / Eng. Student Definitions of Sustainable Design, New Zealand, 2010	139
Table 31: Design and Engineering Taught Courses / Papers with Sustainability Components	140
Table 32: SD/SPD Topics requested by Final Year ID / Eng. Students, New Zealand, 2010	141
Table 33: Sources of Inspiration and Motivation for Final Year ID / Eng. Students	143
Table 34: Curricula Guidelines for Emphasis on the Social Element of SD/SPD	164
Table 35: Curricula Guidelines for Transition towards Systems Thinking via PSS.....	166
Table 36: Curricula Guidelines for Complementary Sustainable Design Strategies.....	167
Table 37: Curricula Guidelines for Transition towards Strategic Design	168

List of Appendices

- A. *PSS Screening tools developed in SusProNet*
- B. *Tools and Approaches for Eco-efficiency*
- C. *Tools and Approaches for Eco-effectiveness*
- D. *Backcasting*
- E. *Draft Survey Questionnaire for NZ Final Year ID and Engineering Students*
- F. *Final Survey Questionnaire for NZ Final Year ID and Engineering Students*
- G. *Massey University – Human Ethics Committee - Low Risk Notification*
- H. *Extended Table of NZ and International Studies with T-Values*
- I. *Synthesis of Expert Views*
(integrated in the Conceptual Educational Framework)

Glossary of Terms

<i>ABET</i>	<i>Accreditation Board for Engineering and Technology (US)</i>
<i>APEC</i>	<i>Asia-Pacific Economic Cooperation</i>
<i>ASEE</i>	<i>American Society of Engineering Educators</i>
<i>BDes</i>	<i>Bachelor of Design</i>
<i>BDVA</i>	<i>Bachelor of Design and Visual Arts</i>
<i>BE</i>	<i>Bachelor of Engineering</i>
<i>C2C</i>	<i>Cradle-to-Cradle</i>
<i>COP</i>	<i>Conference of the Parties</i>
<i>CSR</i>	<i>Corporate Social Responsibility</i>
<i>CUAP</i>	<i>Committee for University Academic Programmes (in New Zealand)</i>
<i>DEEDS</i>	<i>Design Education & Sustainability (part of the EU Leonardo programme)</i>
<i>DF</i>	<i>Degrees of Freedom</i>
<i>DINZ</i>	<i>Designers Institute of New Zealand</i>
<i>ECTS</i>	<i>European Credit Transfer Accumulation System</i>
<i>EE</i>	<i>Environmental Education</i>
<i>EESD</i>	<i>Engineering Education for Sustainable Development</i>
<i>EMS</i>	<i>Environmental Management Systems</i>
<i>EMUDE</i>	<i>Emerging Demand for Sustainable Solutions (EU programme)</i>
<i>EPP</i>	<i>Environmental Product Policy</i>
<i>ESCD</i>	<i>Engineering and Sustainable Community Development</i>
<i>ESD</i>	<i>Education for Sustainable Development</i>
<i>EU</i>	<i>European Union</i>
<i>FCCC</i>	<i>UN Framework Convention on Climate Change (or UNFCCC)</i>
<i>GNP</i>	<i>Gross National Product</i>
<i>HEE</i>	<i>Humanitarian Engineering Ethics</i>
<i>ICSID</i>	<i>The International Council of Societies of Industrial Design</i>
<i>OECD</i>	<i>Organisation for Economic Cooperation and Development</i>
<i>IP</i>	<i>Intellectual Property</i>
<i>IPCC</i>	<i>The Intergovernmental Panel on Climate Change</i>

<i>IPENZ</i>	<i>The Institution of Professional Engineers New Zealand</i>
<i>IUCN</i>	<i>The World Conservation Union</i>
<i>NGO</i>	<i>Non-Governmental Organization</i>
<i>NIS</i>	<i>National Innovation Systems</i>
<i>NPD</i>	<i>New Product Development</i>
<i>NZQA</i>	<i>New Zealand Qualifications Authority</i>
<i>OAS</i>	<i>Organization of American States</i>
<i>PBL</i>	<i>Problem-Based Learning</i>
<i>PC</i>	<i>Personal Computer</i>
<i>PD</i>	<i>Product Development</i>
<i>PDP</i>	<i>Product Development Process</i>
<i>PSS</i>	<i>Product-Service Systems</i>
<i>R&D</i>	<i>Research and Development</i>
<i>SADC</i>	<i>South African Development Community</i>
<i>SCD</i>	<i>Sustainable Community Development</i>
<i>SD</i>	<i>Sustainable Development</i>
<i>SME</i>	<i>Small to Medium-Sized Enterprise</i>
<i>SPD</i>	<i>Sustainable Product Design</i>
<i>STS</i>	<i>Science, Technology and Society</i>
<i>SusProNet</i>	<i>Sustainable Product Development Network (part of the EU Fifth Framework Programme)</i>
<i>TEO</i>	<i>Tertiary Education Organization</i>
<i>UN</i>	<i>United Nations</i>
<i>UNCED</i>	<i>United Nations Conference on Environment and Development (The Earth Summit)</i>
<i>UNDESD</i>	<i>United Nations Decade of Education for Sustainable Development</i>
<i>UNEP</i>	<i>United Nations Environment Programme</i>
<i>UNESCO</i>	<i>United Nations Educational, Scientific and Cultural Organization</i>
<i>UNFCCC</i>	<i>UN Framework Convention on Climate Change (or FCCC)</i>
<i>VITA</i>	<i>Volunteers in Technical Assistance</i>
<i>WCED</i>	<i>The World Commission on Environment and Development</i>
<i>WWF</i>	<i>World Wide Fund for Nature (formerly the World Wildlife Fund)</i>

1. INTRODUCTION

This chapter defines the global framework of the United Nations Decade of Education for Sustainable Development (UNDESD, 2005–2014; (Fien, 2003, p. 7). This global focus consequently strengthens the listed sustainability requirements of international bodies and emphasizes the importance of Sustainable Development (SD) and Sustainable Product Design (SPD) within tertiary education. Sustainability guidelines of the professional bodies for industrial design and engineering were examined, as well as the scope for ecopreneurship (entrepreneurship combined with ecological concerns) within New Zealand SMEs (small to medium-sized enterprises).

The purpose of this research is given, which is further formulated within the research aim and objectives. The scope and contribution of this research is clarified, with a listing of all preliminary and advanced research outcomes. Finally, an overview and structure of the thesis is given. For clarity, this is then presented graphically before commencing with the main body of work (see *Figure 3*). This simultaneously shows the *design process of this research – from complex to simple*, and the extent of this author's contribution to the literature. Items considered noteworthy and important have all been italicized by this author.

1.1 Motivation and Rationale for this Research

Within business there exists a gap between the current understanding of sustainability (an understanding rooted in a linear economic system driven by efficiency that allows only for relative improvements in ecological and social well-being) and the need to shift emphasis to a more radical position that encompasses the societal case and the natural case, operating within the Earth's carrying capacity, alongside a more cyclical economic model (Xiao & Wang, 2007), cited in (E. L. Dewberry & Monteiro de Barros, 2009, p. 29).

Design and engineering are seen as "core catalysts of change" (E. L. Dewberry & Monteiro de Barros, 2009, p. 29) towards *radical innovation*, recognized as now necessary to achieve improvements towards sustainability, see above. Target improvements have been formulated as Factor 4, reducing resource use to a quarter of present levels, or extending this analogy to Factors 10-20, i.e. a reduction of resource use to a 10th – 20th of levels in the present production and consumption model (Weizsaecker, Lovins, & Lovins, 1997), (<http://www.factor10-institute.org/index.html>), accessed 19.01.10.

Sustainable issues have been well understood since the 1960s, with the early critics of Carson, Papanek, Schumacher et al, yet very little has changed. The professions of industrial design and engineering have been slow to respond, even with pressure from policy and legislation, so that they now lag far behind politics and law. There are now huge gaps between expert knowledge in the field of sustainability, and what is currently practiced in *mainstream* tertiary education of industrial design and engineering. This is highlighted by the fact that the professional bodies for these two disciplines promote sustainability for practising designers and engineers, as well as for tertiary education. Sustainability is also included in accreditation criteria for TEOs (Tertiary Education Organizations) in New Zealand, see 1.4. This presents a problem, but also an opportunity.

It has therefore become essential to provide current and future leaders in industrial design and engineering with the right knowledge and skills, with education seen as a

major vehicle towards future progress and global integration of Sustainable Development (SD). Hence the motivation and rationale for this thesis: to focus on tertiary education for industrial design and engineering at undergraduate level, and to motivate the future professionals confronting the issues of sustainability in the design and manufacture of products. *Sustainable, mainstream education in industrial design and engineering is necessary for a transition to radical innovation for sustainability.*

This research therefore investigated the LITERATURE, for *key concepts of radical innovation for sustainability*, examined TEACHING, to gain information about *successful practices in international tertiary education for design and engineering*, and also looked to the students themselves, in LEARNING. The latter would uncover the present status of awareness and knowledge of sustainability issues through a final year student survey in industrial design and engineering in New Zealand, and uncover any gaps in knowledge (see 1.6). The resulting knowledge from these research strands would enable the design of a draft educational framework, with this thesis as the foundation for steps towards improvements at *undergraduate level* for these two disciplines. This research has the intention of finding synergies and positive connections, for a *mainstream*, multidisciplinary, shared educational model. It encompasses design processes of divergence (analysis) and convergence (synthesis), see 3.1, with all advanced research outcomes detailed in *Chapter 5*.

1.2 Definitions of SD/SPD

Sustainable Development

The term *Sustainable Development* (SD) first became known in 1987 when it was used by Norwegian Prime Minister Gro Harlem Brundtland: "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (WCED, 1987, p. 40). It took into account that socio-economic factors needed to be included in environmental protection efforts, which had previously not been the case.

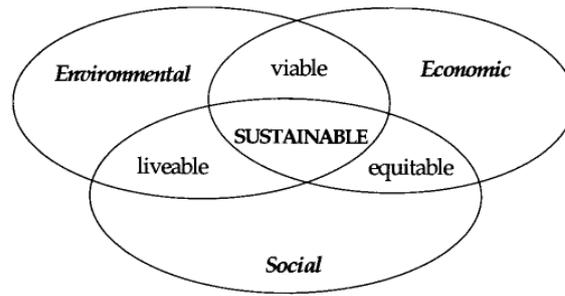
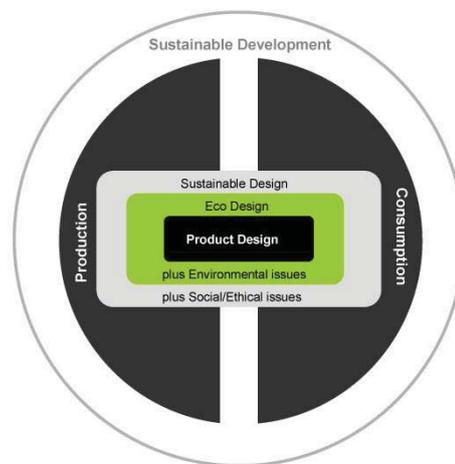


Figure 1: Diagram of the concept of sustainable development (Szymkowiak, 2003)

Sustainable Design and Sustainable Product Design (SPD)



(Charter 2001)

Figure 2: Diagram of how Sustainable Design is attained (Charter, 2001)

Sustainable Design, which comprises *Sustainable Product Design* (SPD), evolved with deeper understanding of problems and effects. Overall, there is a broadening of scope, culminating in *Sustainable Design*.

1. *Green design* has a single-issue focus, perhaps incorporating the use of some new material, such as recycled or recyclable plastic, or considers energy consumption;
2. *Ecodesign* adopts the life-cycle approach, exploring and tackling all or the greatest impacts across the products life cycle; and
3. *Sustainable design* would take a more broad and holistic approach, including questioning/addressing needs, concern for ethics and equity, services and leasing, dematerialization, empowerment, caring and sharing, as well as incorporating ecodesign best practice (E. Dewberry & Goggin, 1996), cited in (T. A. Bhamra, 2004).

For the purpose of this thesis, the terms *Sustainable Development* (SD), and *Sustainable Product Design* (SPD) will be used. The ultimate benefits to society, as formulated in SD, are linked to people, therefore necessitating a focus on the social element. This should also be inherent to product design, with the goal of SPD also taking an holistic approach that benefits society, with wider gains also for the environment and economy.

1.3 The Importance of SD/SPD Concepts in Tertiary Education

1.3.1 International SD Tertiary Education

When SD is applied to scientific education and industry, (Szymkowiak, 2003), Szymkowiak, 2003, sees this as encompassing:

- recognizing that there cannot be long-term economic growth that is not ecologically and socially sound;
- accepting that the design of products, services and methods must not jeopardize the ability of future generations to satisfy their needs;
- creating an open dialogue with the different stakeholders (notably those representing local authorities), so as to determine expectations, potential problems and opportunities, and to come up with suitable solutions involving developmental synergies;
- motivating employees through incentives other than salary, especially by developing skills and favouring the upward movement of information about themes such as environmental policy and the organization of work, health and safety;
- giving preference to anticipation through innovation and voluntary commitment, rather than responses to imposed regulations; and
- adhering to and propagating ethical principles, especially in the case of firms that work in developing countries, which could represent a positive aspect of globalization (Szymkowiak, 2003, pp. 179-180).

The call for Education for Sustainable Development (ESD) originated at the United Nations Conference on Environment and Development (UNCED), known as the Earth Summit, in Rio de Janeiro in 1992. The Rio Declaration documented a set of 27 non-legally binding principles from this conference. Its aims were formulated in the Summit's task list of *Agenda 21* and the United Nations Decade of Education for

Sustainable Development (UNDESD – 2005-2014). Fien, 2003, identified four key lessons that have been learnt:

1. The nature, scope, and purpose of education for sustainable development represent a new vision of education;
2. The importance of basic education;
3. *The need to refocus many existing education policies, programmes and practices*; and
4. The importance of lifelong learning, including adult and community education, appropriate technical and vocational education, higher education, and teacher education (Fien, 2003, p. 7).

In lesson 3 of this report, above, and of interest to this research, is the call for:

- *Interdisciplinarity* and cooperation across the arts, sciences and humanities, in order to approach problems in new ways;
- *Student-centred learning*, which is holistic and creates deep learning and enthusiasm through means of “Resource-based teaching, enquiry and discovery learning, values clarification and analysis, problem-based learning, simulation games and role play, and learning through community problem solving” (Fien, 2003, p. 11); and
- *Futures education* through envisioning human cultural development and setting future scenarios (Fien, 2003).

Therefore it can be seen that new approaches in education and new ways of thinking will be necessary to solve complex problems. This resulted in many regional and world conferences, and professional bodies revised their code of ethics in respect of SD. The global importance of SD means there is also a strong need for Tertiary Education Organizations (TEOs) and professional bodies in New Zealand to encourage and promote the integration of SD/SPD issues at tertiary level education for design and engineering.

The curricula of selected international TEOs were chosen for investigation of SPD educational practices, from EU countries identified as ‘frontrunners’ in the area of SPD (Arnold Tukker et al., 2001). These were The Netherlands, Germany, Austria, Sweden and Denmark, described as “advanced in method development and rather advanced in education and dissemination” (Arnold Tukker et al., 2001, p. 151). A later group were identified as Belgium, France, Finland, Italy, Spain, Portugal and the UK.

At that time, ecodesign was already being taught in specialized courses in The Netherlands, France, Austria, UK and Italy. Therefore the Netherlands, UK and Italy were selected for investigation of successful international SD/SPD within design and engineering curricula, with many notable researchers originating from these countries.

1.4 Sustainability Guidelines of Professional Bodies

Concern for SD issues is explicitly expressed through international and national professional bodies for the disciplines of design and engineering. Sustainability is part of the accreditation criteria for TEOs within New Zealand tertiary education for these disciplines, which particularly emphasizes the importance of integrating SD/SPD into design and engineering curricula. Therefore there is relevance and a need for an educational framework for *radical innovation for sustainability*.

1.4.1 SD/SPD and Industrial Design Accreditation

The International Council of Societies of Industrial Design (ICSID) is the international professional body for industrial designers. SD and SPD are promoted through articles III and IV of the Code of Ethics, reproduced below:

Article III –protect the earth’s ecosystem

- a) Advocacy for safe products and services;
- b) Protection of the biosphere;
- c) Sustainable use of natural resources;
- d) Reduction of waste and increasing recycling;
- e) Wise use of energy; and.
- f) Use of new technology.

Article IV –enrich cultural identity

Industrial designers acknowledge that the environments, objects and services created as a result of the design process, both reflect and help to define the cultural identity of their nations and distinct societies within nations. Designers shall strive to embody and further the cultural

traditions of their national societies while incorporating the best characteristics of international design principles and standards. Icsid code of professional ethics, p.2-3: (http://www.icsid.org/resources/professional_practice/articles1165.htm), accessed 12.05.10.

DINZ (Designers Institute of New Zealand) is the national professional body for design in New Zealand. However, DINZ is not responsible for accreditation. Instead, design TEOs in New Zealand are *Government accredited*. Sustainability education for designers in New Zealand is therefore governed by the accreditation agreements between individual TEOs and the Government.

.. the qualifications are accredited by the Government, through either the New Zealand Qualifications Authority (NZQA) or the Committee for University Academic Programmes (CUAP), (www.dinz.org.nz), accessed 12.08.10.

Specific references to sustainability could not be identified within the present NZQA or CUAP websites: (<http://www.nzqa.govt.nz/>), (<http://www.nzvcc.ac.nz/aboutus/sc/cuap>), but one can hope that future definition and visibility will occur: (<http://www.nzqa.govt.nz/studying-in-new-zealand/nzqf/nzqf-policies/>), accessed 13.08.10.

Whilst DINZ is not directly responsible for sustainability within accreditation of design TEOs, they promote sustainability through *Sustainable Design New Zealand*, created to promote the growth of sustainable design in New Zealand. In June 2009 they held a *National Education & Professional Development Forum* in Auckland, New Zealand, to generate discussion between academics and professionals, and recommendations to the NZ government (<http://www.sustainabledesign.org.nz/projects/forum.html>), accessed 13.08.10.

1.4.2 SD/SPD and Engineering Accreditation

The International Engineering Alliance is the international engineering professional body, and *The Washington Accord*, 1989, "recognises substantial equivalence in the accreditation of qualifications in professional engineering, normally of four years duration" (<http://www.washingtonaccord.org/>), accessed 16.12.10.

Knowledge profile

- comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic, social, cultural, environmental and sustainability;

Design/development of solutions

- Design solutions for *complex* engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations;

The Engineer and Society

- Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice;

Environment and Sustainability

- Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development;

Ethics

- Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice; and

Protection of society

- Recognise the reasonably foreseeable social, cultural and environmental effects of complex activities generally, and have regard to the need for sustainability; recognise that the protection of society is the highest priority.

(<http://www.washingtonaccord.org/IEA-Grad-Attr-Prof-Competencies-v2.pdf>), accessed 16.12.10

IPENZ – The Institution of Professional Engineers New Zealand – is the national professional body governing the engineering profession and is *directly responsible for accreditation of engineering curricula in New Zealand*, with the following SD graduate competency profile:

Personal Foundations: *The Engineer and Society*

Attribute: Be aware of the role of engineers and their responsibility to society by demonstrating understanding of the *general responsibilities* of a professional engineer.

General responsibilities of an engineer include:

- Social responsibilities including ethics, health and safety and other legislation;
- Cultural responsibilities including, in New Zealand, the Treaty of Waitangi;
- Environmental responsibilities including the need for sustainable development and design and legislative responsibilities; and
- Life-long learning (http://www.ipenz.co.nz/ipenz/Education_Career/accreditation/), accessed 16.12.10.

1.5 Ecopreneurs – Change Agents of the Future?

The current SME definition (small to medium-sized enterprise) in NZ is the following: "97.2% (463,278) of enterprises employ 19 or fewer people", accessed 14.02.11 via (<http://www.med.govt.nz/upload/74417/SMEs%20in%20New%20Zealand%20Structure%20and%20Dynamics%202010.pdf>) - SME Business Demographics, February 2009. Therefore industrial design and engineering graduates will very likely become part of New Zealand SMEs.

SMEs are driven by individual entrepreneurs, or ecopreneurs. The latter are seen as the modern entrepreneurs as first defined by Schumpeter, who claimed this innovation to be a 'process of creative destruction' (Schumpeter, 1949), cited in (Beveridge & Guy, 2005, p. 668), but now combining ecological with entrepreneurial concerns. Beveridge and Guy, 2005, identified the rise of ecopreneurs to be enabled through:

- The skills and beliefs of the individual;
- Their environment; and
- The relationships combining the two (Beveridge & Guy, 2005, p. 671).

According to Beveridge and Guy, 2005, (Beveridge & Guy, 2005, p. 669), Wally and Taylor (Walley & Taylor, 2002) identified four ideal ecopreneur profiles, influenced by *hard factors* such as regulations and economics, or *soft factors* such as family and friends, personal networks, experience, and *education*:

1. Innovative opportunists – reacting to hard factors such as regulations and recognising a niche to make a profit;
2. Visionary champions – equally reacting to regulations but seeking to be more environmentally friendly within their sphere;
3. Ethical mavericks – reacting to soft influences, being true to their *values* within a small business or SME (small to medium-sized enterprise); or
4. ad-hoc enviro-preneurs – *also reacting to soft influences but focussed on economics* and profits rather than values (Beveridge & Guy, 2005, p. 669).

Profiles 3 and 4 above are therefore of special interest to educators. Values, sustainability knowledge and economics can combine to become a driving force, made especially strong with 'Blue Ocean Strategy' (Kim & Mauborgne, 2005), to find sustainable market niches in uncontested 'blue oceans' rather than over-run 'red oceans' competing on price etc.

Beveridge and Guy recognized that the literature readily documents barriers and hindrances towards ecopreneurship, *but does not identify positive influences and triggers*. They say that investigation is necessary in the three areas cited: "*the skills and beliefs of the individual*, the environment within which they are embedded and the relationships between these two dimensions" (Beveridge & Guy, 2005, p. 671). Marketing and branding are also important to create a message to oneself and others, and can contribute to changing behaviour and habits (Eckstein, 2003), cited in (Beveridge & Guy, 2005, p. 675).

Thus internal motivation, beliefs and values are seen as significantly important, and intrinsic to the success of ecopreneurs. It would therefore be of great value to assess *the skills and beliefs* of final year students in industrial design and engineering, and to identify potentially strong drivers towards *radical innovation for sustainability*. To know what are especially motivating and inspiring factors towards SD/SPD could reveal how New Zealand tertiary education could contribute towards creating future ecopreneurs, and to integrate such knowledge into an educational framework.

1.6 Purpose of this Research

The purpose of this study was to clarify and *simplify* the complex factors that contribute towards radical innovation for Sustainable Product Design, and to illustrate the interrelatedness of these things. This research aimed to provide an holistic viewpoint to SPD, to show the bigger picture across fragmented disciplines, and how existing frameworks and expert views relate to each other. It had the *final aim to bring all elements together within a Conceptual Educational Framework*, as an underlying structure for integrating components for transition to *radical innovation for sustainability* in industrial design and engineering.

1.6.1 Research Aim and Objectives

Research Aim

Develop an educational framework with supporting guidelines, combining knowledge gained from Objectives 1, 2 and 3 below. This is intended as an aid and underlying structure for curricula builders towards embedding radical innovation for sustainability in Industrial Design and Engineering curricula.

Research Objectives

1. Show the *key concepts of radical innovation for sustainability* through a review of the literature;
2. Highlight *international examples of successful practices within industrial design and engineering tertiary education*; and
3. Investigate *NZ final year students in Industrial Design and Engineering*:
to measure current awareness, understanding and knowledge of SD/SPD and compare New Zealand and international studies, as sustainability is important for accreditation of Bachelor undergraduate programs in NZ.

1.7 The Scope and Contribution of this Research

The value of the present research and the main contribution to the literature was to develop a draft educational framework and guidelines for industrial design *and* engineering curricula. The rationale lies in the fact that the core issues of SPD need to be integrated into mainstream industrial design *and* engineering, the two professions that are ideally placed to bring about *radical innovation for sustainability* (E. L. Dewberry & Monteiro de Barros, 2009). Not only does sustainability need to be central to tertiary education for these two disciplines, but needs to be taught in a cohesive, integrated way. Graduate designers and engineers need to have the skills for designing sustainably, as promoted by the professional bodies of DINZ and IPENZ, and part of accreditation criteria, as detailed in 1.4. Graduate designers and engineers also need to communicate and collaborate with each other. For this they need a common ground of SD/SPD knowledge, and an understanding of each other.

The scope of this research was therefore to develop the *core structure* of a syllabus or curricula for both disciplines, but not the *actual* curricula in defined terms. The latter depends on further refinement according to individual faculties of TEOs, accreditation requirements and blending with core content of existing industrial design and engineering curricula, all activities seen as extra to the present thesis.

The objectives of this research provided the means to gain a comprehensive base of sustainability knowledge to design a conceptual educational framework. This was namely through articulation of *key concepts of radical innovation for SD/SPD*, through the LITERATURE REVIEW, which culminated in a *Synthesis of Expert Views, Appendix I*. The key concepts are of major significance, and are projected into the research outcomes of this thesis.

Equally, successful elements of international tertiary education practices for industrial design and engineering are investigated. Again, it was important to look across

disciplinary boundaries, and to search for successful, motivational examples. These presented a second source of knowledge, namely the pedagogy used for TEACHING.

A third source of knowledge was provided by the students themselves, through a final year New Zealand student survey from industrial design, product design, mechanical and mechatronics engineering. This was to provide information regarding LEARNING. This aim of the survey was to capture information about gaps in knowledge, what inspires and motivates them towards SD/SPD, and to compare against an international survey (Azapagic, Perdan, & Shallcross, 2005).

The knowledge was therefore gained from the three sources described above, namely LITERATURE REVIEW, TEACHING and LEARNING. These were synthesized and refined through a number of processes. For clarity, this is presented graphically in 1.8, to highlight the design process of this research, the structure and the extent of this author’s contribution to the literature. The latter comprises the following:

<u>Preliminary Research Outcomes</u>	<u>Chapters 2, 3 and 4</u>
LITERATURE REVIEW	Chapter 2
• <i>Key Concepts of Radical Innovation for Sustainability</i>	
• <i>Synthesis of Expert Views, Appendix I</i>	
TEACHING	Chapter 2
• <i>Successful Practices in Tertiary Education</i>	
LEARNING	Chapters 3 and 4
• <i>New Zealand Final Year Student Survey Results and Evaluation</i> (Industrial Design and Engineering)	
<u>Advanced Research Outcomes</u>	<u>Chapter 5</u>
• <i>Strategic Design Cycle:</i> <i>Model of complementary but sequential SPD strategies</i>	
• <i>The terms 'design-max' and 'eco-max' as design intent</i>	
• <i>Guiding Principles of Radical Innovation for Sustainability</i>	
• <i>Core Structure underlying Framework, using Design Process</i>	
• <i>Conceptual Educational Framework</i>	
• <i>Educational Framework Focus – Years 1-4</i>	
• <i>Educational Framework Guidelines</i>	

From the literature, the individual components of sustainability have previously been taught in isolation within design and engineering curricula. This research contributes to the literature with the rationale that is mirrored by the *Synthesis of Expert Views, Appendix I*: to bring complex elements together which had previously been separated, to simplify them under the headings of 'key concepts of radical innovation for sustainability', and to integrate them into a simple and coherent *Educational Framework, with Guidelines*.

1.8 Overview and Structure of Thesis

Prior research in SD/SPD has mostly been conducted within the individual disciplines of design and engineering, and also explored separately in *Chapter 2, Literature Review*, for continuity and clarity. This provides an holistic viewpoint of SD/SPD, both historical through to the present day. *Chapter 3, Research Methodology*, presents the design and execution of the survey questionnaire of the present research for both disciplines. *Chapter 4, Survey Results and Evaluation*, will discuss all findings and evaluate SD/SPD knowledge of final year industrial design and engineering students in New Zealand. Distinctions and comparisons are made between the New Zealand and international survey results of Azapagic et al (Azapagic et al., 2005). Finally, the strands are reunited to construct connections between major themes and topics within *Chapter 5, Educational Framework and Guidelines*.

The *Conceptual Educational Framework*, together with supporting *Guidelines*, comprises the major contribution of this research. It combines elements of the three objectives: the key concepts of *radical innovation for sustainability* from a review of the literature, highly successful international examples from industrial design and engineering tertiary education, and the evaluation of the survey of final year industrial design and engineering students in New Zealand. This resulted in the following outcomes:

2. LITERATURE REVIEW OF KEY CONCEPTS OF RADICAL INNOVATION FOR SD/SPD

2.1 Overview

It is necessary to have ecological literacy to achieve *radical innovation for sustainability*, which has driven this comprehensive literature review of the key concepts of SD/SPD. This is viewed from the perspectives of industrial design and engineering, the two professions recognized as being ideally placed for future *radical innovation* in the products they design and manufacture (E. L. Dewberry & Monteiro de Barros, 2009). Therefore *both* professions are central to this research; to explore how industrial design and engineering can positively influence a transition to *radical innovation for sustainability* through tertiary education.

Designing for sustainability requires skilled communicators who can, through artefact rhetoric, conceive effective arguments for how a group of people should live in the context of their environment. The greatest challenge is that sustainable living will mean different things to different people, depending on their local customs, needs, and ecosystems... In order to help develop a sustainable society, designers first should *focus on developing their own ecological literacy* (Stegall, 2006, pp. 63, italics by this author).

The purpose of the literature review was therefore to investigate areas that are often separated, and to *bring all information together* to provide a base of SD/SPD knowledge that is holistic, fusing many perspectives. Important theories and expert views were covered, with both historical and many recent publications from both design and engineering perspectives - see *References*. The wide breadth of the investigations provided an up-to-date, comprehensive base of knowledge, and enabled the formation of key concepts.

The *Key Concepts of Radical Innovation for SD/SPD* comprise a literary digest of the whole, and are a means to understand the material covered; by grouping all the

information under large, umbrella headings, i.e. *concepts*. The number of concepts resulted purely as a simplification of complex material. It was the rationale of this researcher, an industrial designer, to provide *simplicity* out of the complex reality. There is widespread consensus for *radical innovation* and *interdisciplinary action*, requiring better education and better professional practice. The literature review provided a major contribution to the outcomes of this research towards these ends, as the comprehensive digest of the material led to models and connected principles.

This research covered all major design professions involved in the design and manufacture of products, seeking synthesis and recognizing connections and synergies. Therefore perspectives are covered from *both industrial design and engineering disciplines, and their education at tertiary level*. This could lead to initial steps towards the removal of the current entrenchment in silo thinking of individual professions. Therefore these investigations, as documented in the literature review, were an integral part of the success in developing a draft educational framework for industrial design and engineering. These *key concepts of radical innovation for SD/SPD* were synthesized in relation to each other (see *Synthesis of Expert Views, Appendix I*).

The literature review shows that the human factor is an essential element in SD/SPD and the evolving trend towards systems thinking and PSS (Product-Service Systems). Sustainable Design strategies are explored, to highlight major differences in approaches. Transitional strategies towards strategic design are outlined by expert views. Therefore the key concepts are:

1. Emphasis on the Social Element of SD/SPD;
2. Transition towards Systems Thinking via PSS;
3. Complementary Sustainable Design Strategies; and
4. Transition towards Strategic Design.

It is shown how the professions of industrial design and engineering complement each other. Educational perspectives and academic design research are investigated from both disciplines. The chapter closes with an examination of prior surveys of SD/SPD in design and engineering curricula.

2.2 *Concept 1: Emphasis on the Social Element of SD/SPD*

2.2.1 *'Wicked' Problems are User-Centred in Systems Design*

The notion of problems being 'wicked' originated from Rittel and Webber in 1973 (Rittel & Webber, 1973). This is based on systems design, described by Hugh Dubberly in an email interview with Dan Saffer, (<http://www.dubberly.com/articles/what-is-systems-design.html>), accessed 15.10.10, (Saffer, 2006). According to Dubberly in this interview, information theory, operations research and cybernetics from engineering were integrated into the design process by Rittel and others at the Universities of Ulm, Germany and California, U.S.A., called the Design Methods Movement:

A systems approach to design asks:

- For this situation, what is the system?
- What is the environment?
- What goal does the system have in relation to its environment?
- What is the feedback loop by which the system corrects its actions?
- How does the system measure whether it has achieved its goal?
- Who defines the system, environment, goal, etc.—and monitors it?
- What resources does the system have for maintaining the relationship it desires?
- Are its resources sufficient to meet its purpose?

A systems approach to design is entirely compatible with a user-centered approach. Indeed, the core of both approaches is understanding user goals. A systems approach looks at users in relation to a context and in terms of their interaction with devices, with each other, and with themselves (<http://www.dubberly.com/articles/what-is-systems-design.html>).

According to Rith and Dubberly, 2007, the Design Methods Movement was responsible for most design process models e.g. 'define, prototype, evaluate' (Rith & Dubberly, 2007, p. 72). Initial ideas were refined as 'second generation' design methods, with Rittel's ideas summarized as follows:

- Simple problems (problems which are already defined) are easy to solve, because defining a problem inherently defines a solution;
- The definition of a problem is subjective; it comes from a point of view. Therefore, when defining problems, all stakeholders, experts, and designers are equally knowledgeable (or unknowledgeable);

- Some problems cannot be solved, because stakeholders cannot agree on the definition. These problems are called wicked, but sometimes they can be tamed;
- Solving simple problems may lead to improvement – but not innovation. For innovation, we need to re-frame wicked problems;
- Because one person cannot possibly remember or keep track of all the variables (of both existing and desired states) in a wicked problem, taming wicked problems requires many people;
- These people have to talk to each other; they have to deliberate; they have to argue;
- To tame a wicked problem, they have to agree on goals and actions for reaching them. This requires knowledge about actions, not just facts;
- Science is concerned with factual knowledge (what-is); design is concerned with instrumental knowledge (how what-is relates to what-ought-to-be), how actions can meet goals;
- The process of argumentation is the key and perhaps the only method of taming wicked problems;
- This process is political; and
- Design is political (Rith & Dubberly, 2007, p. 73).

From the above definitions, it can be concluded that SD/SPD are essentially 'wicked' problems at their beginning. They are ill-defined, complex problems involving numerous stakeholders and requiring diverse viewpoints, and systems thinking that *include* the social element in problem definition, i.e. user-centred. Hence, different approaches and/or combination of approaches need to be considered, which *emphasize* the social element to achieve *radical innovation*.

It is namely in the *use* of products and the human behaviour / environment interface where a lot of environmental damage occurs (Fletcher & Goggin, 2001). The authors advocate a widening of horizons:

product focus – making existing products more resource efficient;

results focus – producing the same outcome in different ways; and

needs focus - questioning the need fulfilled by the object, service or system, and how it is satisfied (Fletcher & Goggin, 2001, p. 16).

The latter *needs focus* is concerned with people, therefore *SPD is people-centred* and needs to embed human and non-human need, diversity of culture and experience. The challenge is that sustainability will mean different things to different people within a 'local' context, making a 'one-size fits all' approach unsuitable. A 'responsive' approach will be required instead of one that is 'impositional', i.e. not imposing a Westernized model onto other cultures or environmental scenarios, but to be responsive to what works best in local conditions, both culturally and environmentally (Walker, 2002, pp. 3-4). The creation of transnational 'spaces' is suggested (Gough, 2002), to enable scholarly collaboration and sharing of indigenous, local knowledge traditions: 'thinking globally' using knowledge traditions outside of the dominant Western model.

Hence, different approaches and/or combination of approaches need to be considered, which *emphasize* the social element. The combination of science and design, as defined and taught by Rittel, requires multidisciplinary in practice, and in tertiary education. It requires the collaboration of industrial designers, engineers and others, to achieve multidisciplinary viewpoints and definition of 'wicked' problems to achieve *radical innovation*.

2.2.2 The Human Factor as Part of the Whole, within Systems Thinking

The integral importance of the human factor for SD is emphasized by the very first principle of the Rio Declaration, which set out the overall global framework of international cooperation towards SD at the Earth Summit in 1992.

Principle 1

Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature

(<http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=78&ArticleID=1163>), accessed 15.11.10.

Sustainable Product Design (SPD) evolved from earlier definitions such as *Green Design (single-issue focus)* and *Ecodesign (2-issue focus: environment and economy, supported mainly by life cycle management (LCM))*. The present definition is now

aligned with the three components of Sustainable Development. These are concern for the *environment, economy and social* factors, or otherwise expressed as the 3Ps of 'people, profit and planet' (Elkington, 1998). A model for design and 'well-being', illustrated below (Figure 4), shows how individual well-being is integral to linking the three components of sustainability.

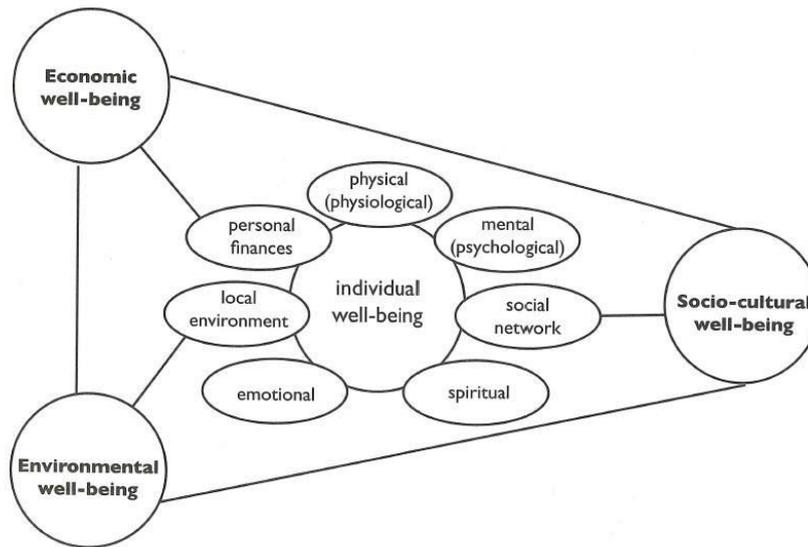


Figure 4: A model for design and 'well-being', (Fuad-Luke, 2007, p. 24),
 adapted from (Fuad-Luke, 2005, 24-25 October)

"Ecology is the science that addresses the relationship between living things and their environment" as originally defined by Haeckel, becoming a formal science by the end of the 19th century (Belovsky et al., 2004). Due to environmental awareness that grew from beginning comments (Carson, 1962), the environmental movement strengthened with every disaster caused by industry. Therefore the need for restoration and the reintegration of humans with their environment became evident. "The most important roles for ecologists in this time of transition are to quantify connections between the biosphere and society and to help define sustainable future paths as natural energy flows again assume a greater importance. We define ecology broadly as *the study of the functioning of the biosphere*, and ecologists as those who seek to understand this functioning" (Day Jr et al., 2009, pp. 321, my italics). Roy Clapham first used the term '*ecosystem*' in 1930, to describe the environment including all known biological and physical attributes.

Chiapponi described the environment as a *system which included mankind* (Chiapponi, 1998) and subdivided into anthropic: (technosphere/sociosphere) or non-anthropic: (biosphere/geosphere). He declared that design could play an active role in addressing environmental problems, yet warned of reducing environmental design simply to recycling issues and promoted *interdisciplinarity* to provide complexity of thought and different expertise. Therefore humans must be understood as part of the system; all environmental problems are those that involve humans, and that previous detrimental actions can be reversed through human design. This makes *emphasis on the social element of SD/SPD* a powerful tool for reintegration of humans with their environment, and the regeneration of healthy ecosystems.

The outright denial of damage persisted until concerns were publicized from early environmentalists, notably Rachel Carson (Carson, 1962), a leading voice of a group that encompassed growing numbers of left-wing activists and scientists against industrial and government practices, of environmental pollution through the use of toxic chemicals and radio-active testing, gathering strength from the 1950s onwards. Her attacks were mainly against the chemical industry and the manufacture of pesticides for agricultural, residential and also industrial use: the waste chemicals being directly fed into streams and rivers once discarded. In 'Silent Spring' she depicted a future scenario of no birdsong, because the birds had all been poisoned by eating insects laden with toxic chemicals.

Besides this, Carson was also against the industrial mores that had helped to further remove and alienate humankind from nature and empathy with other living species. Modern industrial manufacturing systems are driven by specialization and economic concerns, so that a wider perspective is lost or not valued. Yet this wide perspective of systems thinking, of how humans relate to the environment and other life-forms as well as the economy, is precisely what is necessary (Carson, 1962, p. 29), and indeed, underpins the whole concept of SD.

Carson likens the carcinogenic effects of chemicals as akin to radiation. The chemicals in question are largely “DDT, lindane, benzene hexachloride, the nitrophenols, the common moth crystal paradichlorobenzene, chlordane, and, of course, the solvents in which they are carried” (Carson, 1962, p. 201). She accurately depicted the bio-accumulating effect of toxic chemicals and/or other toxic substances when stored and accrued in all life-forms, as they are passed on and enlarged in the food chain. The disastrous effects of toxic chemicals can impact on animals and humans alike, interfering with the endocrine system, causing cancer and/or mutations. What is little known is that *products* can also contain thousands of synthetic chemicals, which are legal yet remain largely untested (Foster & Clark, 2008, p. 6).

This is of great concern to industrial designers and engineers, as designed artefacts will be in direct or indirect contact with the end-user not only in their use, but also become part of the landscape through landfill. This can then have enormously detrimental effects on the environment, the food chain, and humans. Yet the links between toxic chemicals, products and their negative consequences remain largely invisible, and also unaccountable.

According to Foster & Clark, 2008, Carson’s concerns were supported by members of the scientific community, including U.S. geneticist H.J. Muller, a Nobel Prize winner in 1946 in physiology/medicine (he discovered that genetic mutations in organisms could result from radiation), and “the most prestigious scientific defender of Carson’s *Silent Spring*” (Foster & Clark, 2008, p. 5). The authors report of Muller:

the real importance, he suggested, of *Silent Spring* lay in the profound understanding that it conveyed of the interconnections within nature and between nature and society: in “the enlightenment it brings the public regarding the high complexity and interrelatedness of the web of life in which we have our being” (Foster & Clark, 2008; Muller, 1962, p. 5).

Foster and Clark, 2008, see that “this larger ecological critique that challenged the whole nature of the modern production system that represented her most enduring contribution” (Foster & Clark, 2008, p. 15). The worst chemicals such as DDT have

now been banned, but the fight *to change industrial and consumer behaviour* has only just begun. The challenge for industrial designers and engineers is therefore to change *user behaviour*: with products that promote SD, are simultaneously benign in their composition and use, and also have meaning and are a delight to use.

2.2.3 Symbiotic Effects between Ecosystem Services and Human Well-being

An extensive appraisal was executed globally by the Millennium Ecosystem Assessment, which assessed the state of the world's ecosystems and related services from 2001 – 2005 (<http://millenniumassessment.org/documents/document.356.aspx.pdf> and <http://www.wri.org/>), accessed 03.12.10. The report links symbiotic effects between ecosystem services and human well-being, which can impact on each other both negatively and positively. The investigations uncovered four main findings:

1. Human demands for food, water and natural resources have expanded exponentially over the last 50 years, resulting in a loss of biodiversity, in many cases irreparable;
2. Human well-being and the economy have benefitted from the significant changes made to ecosystems, but at the cost to the environment and ecosystem services, as well as aggravating the conditions of poverty for some people. There is a danger that these factors will impact on future generations;
3. Ecosystem services could deteriorate and hinder achieving the Millennium Development Goals; and
4. The reversal of deteriorating ecosystems and their services require "significant changes in policies, institutions, and practices that are not currently under way" (Institute, 2005, p. 1).

Other investigations were executed by the United Nations Environment Program (UNEP) and the European Environment Agency, with a growing "concern about nature fragmentation and loss of biodiversity, shortages in freshwater availability, over-fishing of the seas, global warming, extreme weather events, urban air pollution, and environmental noise" (Vlek & Steg, 2007, p. 3).

The authors point out that negative environmental effects are primarily based on *social and behavioural problems*. They see that the effects will be intensified with a growing demand for food, water and material resources, with shortages carried by particularly fragile areas such as the Middle East, sub-saharan Africa and southern Asia. Vlek and Steg, 2007, present a range of European psychology research, and divert their focus from environmental effects to the *behavioural* driving forces that caused them, which they identify as *population, affluence, technology, institutions* and *culture*.

A common view is that world *population* is a main negative factor, the present 6.5 billion people expected to become approx. 9 billion by 2050, extensively in developing nations (Engelman, Halweil, & Nierenberg, 2002), cited in (Vlek & Steg, 2007, p. 6). Vlek and Steg declare the "total environmental resource use (involving wasteful emissions) is a multiplicative function of population, consumption and technology."

$$\text{Impact} = P \times A \times T$$

(P = Population, A = Affluence or consumption per person and

T = Technology used per unit of production) (Ehrlich & Holdren, 1971).

The review article refers to natural human aspiration for growth and improvement through evolution (Takacs-Santa, 2004). Takacs-Santa lists the cumulative effects as increased clearing of vegetation to enable human settlement, growing separation from nature, increased technology, intensified consumption of raw materials and (fossil) fuel energy and an expanding transport infrastructure. Vlek and Steg add: mass motorisation and the computer revolution (Vlek & Steg, 2007, p. 6). Unfortunately, human aspiration, growth and well-being have been increasingly linked to *material affluence*, with soaring consumption patterns and use of resources. Yet once fundamental human needs have been satisfied, happiness is not achieved through increased consumption of material goods, citing: (Csikszentmihalyi, 1999; Diener, Suh, Lucas, & Smith, 1999). The article indicates that well-being needs to be achieved through an extended system, of broader notions of *quality of life rather than material affluence* in the present consumption model (Oelander & Thøgersen, 1995), cited in (Vlek & Steg, 2007, p. 7).

2.2.4 Technology needs to be linked to Human Behaviour

According to the authors, psychology links many environmental problems as a 'commons dilemma' (Vlek & Steg, 2007, p. 9). This is where collectively harmful effects are caused by individual actions and behaviour (of persons and/or manufacturers). The manufacture and purchasing of products, which can contain toxic chemicals, can cause problems in their use and also at disposal to landfill.

Of the four main areas of research (problem diagnosis, policy decision making, practical intervention and effectiveness evaluation), it is the area of *practical intervention* where industrial design and engineering will have the most traction, to positively influence the technology/behaviour interface (Vlek & Steg, 2007, p. 10). Therefore *technology* and *user behaviour* will be of prime importance to activate positive change. These two areas must not be in isolation from each other, but combined. Industrial designers and engineers will then be able to reward positive user behaviour through a combination of design and technology (Midden, Kaiser, & Teddy McCalley, 2007), necessitating a dual approach.

Behavioural scientists see this dual view of technology and human behaviour as a way towards achieving more sustainable behaviour and consumption (Midden et al., 2007). Technology needs to be understood in terms of user behaviour and in what way it causes interaction. The authors give four roles of technology: *intermediary*, *amplifier*, *determinant* and *promoter*.

As *intermediary*, technology facilitates user behaviour and use of natural resources, and "environmental impact depends on the specifics of how, when, and where the technology is used" (Midden et al., 2007, p. 157). An *amplifier* technology will extend an initial goal, will use greater and greater resources and can have a 'rebound' effect (increased efficiency, less materials or cost can increase availability and/or desirability and generate much higher volumes of product consumption). A *determinant* technology will make people use a product and act in a certain way through 'realization conditions' (Midden et al., 2007, p. 161), often without their knowledge.

Used as a *promoter*, “well-designed technical environments, systems, and products have a great potential for supporting environmentally sustainable behaviour” (Midden et al., 2007, p. 155). Therefore the power of technology to previously cause harmful environmental effects can equally be reversed into areas of positive influence, when used as a *promoter* of user behaviour beneficial to the environment.

But technology and design must be seen within the *context* of *institutions* (i.e. habits and traditions, norms and values) currently in place, and create opportunities and potential for transition to a more sustainable quality of life. Vlek and Steg (Vlek & Steg, 2007), argue for an embedding of *culture* for such transition, and see some key aspirations towards this, in keeping with the Brundtland requirements of eliminating poverty, achieving equity and being mindful for future generations.

1. safeguarding the availability of basic resources;
2. protecting human health from environmentally risky conditions;
3. ensuring sufficient quality of human living environments;
4. protecting natural areas with their wildlife; and
5. promoting greater harmony between humanity and (other) nature.

The authors underpin the social changes necessary to transform the current negative environmental situation. For industrial design and engineering, it means positively influencing not just the product itself, but also *sustainable materials systems, collective effects of using a product or product-service system, and sustainable user behaviour*. “Such changes in thinking require significant psychological and sociological transformations” (Vlek & Steg, 2007, p. 9).

The authors conclude that this can be achieved through “multidisciplinary research and development, in which the role of the social and behavioural sciences must be significantly extended” (Vlek & Steg, 2007, pp. 14-15). Therefore multidisciplinary collaboration is necessary and to be promoted within tertiary education. Specialists (psychologists, social and behavioural scientists, ecologists, scientists, industrial designers, product designers, mechanical and mechatronics engineers etc.) need to

concern themselves with holistic problems, rather than addressing smaller, individual portions of a larger design problem.

2.2.5 Human Factors and Understanding Consumption

A hierarchy of human needs has been previously formulated in seminal works by Maslow (Maslow, 1971), (Maslow & Lowery, 1998), and cited in the literature. These are that 'deficiency' needs of one's own person have to be met before 'growth' needs, extending towards an outer context, can eventuate. "In an affluent (Western) society consumers can generally take basic Maslowian needs such as food, shelter and safety for granted, and will be more geared toward the realization of higher needs such as affiliation, love, esteem and self-realization" (Arnold Tukker, 2004, p. 250). From this one can conclude that the market, in developed or developing countries respectively, will ultimately determine whether high or low technology solutions are needed, combining use of local craftspeople, materials and technologies, and customized to suit diversity of culture and environment. The author further states that in general, society is moving towards an *experience economy*, citing (LaSalle & Britton, 2003; Pine & Gilmore, 1999), and notes:

...LaSalle and Britton argue that human beings do not desire goods in themselves, but the benefits goods provide at the higher levels at which human beings operate, such as physical, emotional, intellectual and spiritual (Arnold Tukker, 2004, p. 251)

Deficiency needs	Physiological Safety/security Belongingness and Love Esteem	Hunger, thirst, bodily comforts Out of danger Affiliate with others, be accepted To achieve, be competent, gain approval and recognition
Growth needs	Cognitive Aesthetic Self-actualization Self-transcendence	To know, to understand, explore Symmetry, order, beauty To find self-fulfilment and realise one's potential To connect to something beyond the ego or to help others find self-fulfilment and realize their potential

Table 1: Summary of Maslow's hierarchy of needs (T. Bhamra & Lofthouse, 2007, p. 57)

Another structure (Max-Neef, 1992) gives fundamental human needs as: *subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom*. The ways of satisfying these are through *being, having, doing and interacting*.

He gave 5 types of satisfiers:

1. *singular* - satisfying one need only;
2. *synergic* - satisfying one need, and simultaneously another, whether wholly or partially;
3. *pseudo* - falsely satisfying;
4. *inhibitor* - satisfying one need while inhibiting satisfying others; and
5. *violator* - not satisfying the given need and simultaneously preventing satisfying others.

Fundamental Human Needs	Being (qualities)	Having (things)	Doing (actions)	Interacting (settings)
Subsistence	physical & mental health	food, shelter, work	feed, clothe, rest, work	living environment, social setting
Protection	care, adaptability, autonomy	social security, health systems, work	co-operate, plan, take care of, help	social environment, dwelling
Affection	respect, sense of humour, generosity, sensuality	friendships, family, relationships with nature	share, take care of, make love, express emotions	privacy, intimate spaces of togetherness
Understanding	critical capacity, curiosity, intuition	literature, teachers, policies educational	analyse, study, meditate investigate	schools, families, universities, communities
Participation	receptiveness, dedication, sense of humour	responsibilities, duties, work, rights	co-operate, dissent, express opinions	associations, parties, churches, neighbourhoods
Leisure	imagination, tranquillity, spontaneity	games, parties, peace of mind	day-dream, remember, relax, have fun	landscapes, intimate spaces, places to be alone
Creation	imagination, boldness, inventiveness, curiosity	abilities, skills, work, techniques	invent, build, design, work, compose, interpret	spaces for expression, workshops, audiences
Identity	sense of belonging, self-esteem, consistency	language, religions, work, customs, values, norms	get to know oneself, grow, commit oneself	places one belongs to, everyday settings
Freedom	autonomy, passion, self-esteem, open-mindedness	equal rights	dissent, choose, run risks, develop awareness	anywhere

Table 2: Max-Neef's satisfiers of human needs (Max-Neef, 1992),
cited in (T. Bhamra & Lofthouse, 2007, p. 59)

Since the Industrial Revolution, well-being is now increasingly expressed through the Western model of production/consumption and was first criticized by Papanek, who advocated design for need instead of wants.

Need: Much recent design has satisfied only evanescent wants and desires, while the genuine needs of man have often been neglected. The economic, psychological, spiritual, social, technological, and intellectual needs of a human being are usually more difficult and less profitable to satisfy than the carefully engineered and manipulated "wants" inculcated by fad and fashion (Papanek, 1985, p. 15).

According to the DEEDS (Design Education & Sustainability) project, these needs are part of the human condition: "Rather obviously, many needs are best satisfied by non-commercial services, such as care in a family or amongst friends, and not by products" (J.H. Spangenberg, A. Fuad-Luke, & K. Blincoe, 2010, p. 1487). As products are now increasingly the means to satisfy human needs, design responsibilities clearly lie with industrial designer and engineers. The authors differentiate between ecodesign, dealing only with *eco-efficiency* of environment and economy, and sustainable design (which they term Design for Sustainability - DfS), which needs to concern itself with larger issues, systems, consumption and production (J.H. Spangenberg et al., 2010, p. 1486), see 2.4.

Bhamra and Lofthouse, 2007, promote dematerialization and to focus on human needs, away from a product-based well-being. They advocate using Life Cycle Management to optimize a product's life cycle. These points are also reiterated by Manzini (Manzini, 2002), and again by Vezzoli and Manzini (Vezzoli & Manzini, 2008). They advocate PSS (Product-Service Systems), see 2.3.3, as a way forward, away from purely 'product-based well-being'. Vezzoli and Manzini, 2008, extend this to include not only services, but also experiences, events and interactions or 'access-based well-being'. However, they warn that PSS/access-based well-being can still just be a multiplication of the original production-consumption structure for well-being that dominates internationally (Vezzoli & Manzini, 2008, p. 20). As they have documented, no single approach has been a cure-all for SPD:

- PSS / access-based well-being is still divisive into the haves and have-nots in society, those who can afford PSS and those who cannot; and
- 'light products' with less materials, size, weight etc. seem worthy in the first instance, but carry the danger of a 'rebound' effect, i.e. when multiplication (through manufacturing, affordability, accessibility etc.), then equates to or surpasses the original volume of materials, manufacturing processes etc. An example of this is the mobile phone, with reduced size, materials, affordability and accessibility resulting in exponential sales volumes and fashion trends, making them highly disposable and wasteful of resources.

Currently only 20% of the world population are able to afford product-based well-being, but use 80% of resources (Fuad-Luke, 2009). This unsustainable model cannot be transferred to the remaining 80% of world population. Vezzoli and Manzini do not dismiss PSS or light products, as they are desirable components of a more sustainable system. Yet Vezzoli and Manzini claim that they alone will not achieve sustainable behaviour or lifestyles.

As products can be technological solutions for problems that arise from cultural origins, we need to also address the source of problems. (e.g. security systems are necessary because of a lack of contact with neighbours to participate in 'neighbourhood watch' etc.). Also, products have evolved to increase human comfort by doing less 'work', but which results in a diminished capacity for people to solve their problems with their own initiatives and resources. This can even result in creating new problems, e.g. lack of exercise and movement, or lack of communication skills, even isolation within a community.

To reverse this, instead of *disabling goods and services*, we should design and promote *enabling solutions* (Vezzoli & Manzini, 2008). The authors make the distinction between useful products that improve living standards (such as washing machines) and '*remedial goods*' which do not, nor do these offer new possibilities and

opportunities. Instead these *remedial goods* attempt to fill a space left by the depreciation of *common goods* such as clean and healthy air, water, space, landscapes, communities, interaction with nature etc. They present the following hypotheses:

1. There is a direct connection between the diffusion of marketable goods (however efficient they are) and the crisis of common goods and everything they freely contributed (in the economic as well as the ecological sense) to the quality of life;
2. There is a direct connection between the crisis of common goods and the thriving of a new generation of remedial goods, i.e. goods and services that try to construe as acceptable living conditions that are much deteriorated; and
3. The thriving of *remedial goods* in turn causes further deterioration of common goods, and therefore ends in a vicious self-propagating circle (Vezzoli & Manzini, 2008, p. 23).

Whilst admitting that this is no easy task, they propose a '*context well-being*', which seeks to address design problems at their source, to consider new forms of well-being, a '*life-context*', "i.e. well-being that takes into account the entire scene in which human life takes place." For this they see a social learning process as necessary, and that design solutions need to be trialled and observed (Vezzoli & Manzini, 2008, p. 24). Therefore industrial designers and engineers will need to consider consumption and production backgrounds in far greater detail, and to emphasize the social context in promoting sustainable behaviour and lifestyles. This necessitates a changed nature of products and PSS: 'enabling' design solutions need to be prioritized over products that merely fill a gap. They need to be user-centred, ideally with co-creation of the user. A multidisciplinary approach involving *radical innovation*, society and technology will therefore be required to positively influence human behaviour towards sustainability and equity.

2.3 Concept 2: Transition towards Systems Thinking via PSS (Product-Service Systems)

2.3.1 Overview

Source: Konrad et al. 2005

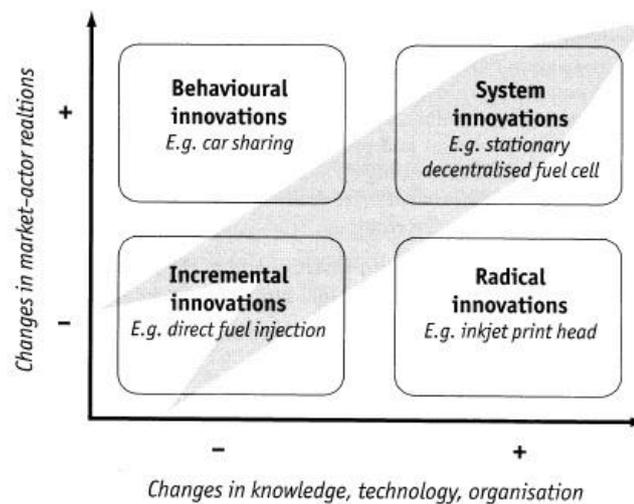


Figure 5: Differentiation of innovation types and their sustainability potential (Tischner, 2008, p. 162)

With its origins in innovation research, system innovation is considered to be a decisive factor in the sustainable transition of modern societies. Yet much is unknown about what system innovations are and how they are different from other innovation types (Tischner, 2008, p. 161).

According to Tischner, 2008, system innovations can combine both incremental and radical innovations, with integration of management. Management can be thought of as *user-oriented* changes such as PSS - Product-Service Systems (Tischner, 2008, p. 164), citing (Hirschl, Konrad, Scholl, & Zundel, 2001; A. Tukker & Tischer, 2006), see 2.3.3. The basic definitions of PSS given by (Goedkoop, van Haler, te Riele, & Rommers, 1999), cited in (Baines et al., 2007, p. 1545), are as follows:

1. Product: a tangible commodity manufactured to be sold. It is capable of 'falling on your toes' and of fulfilling a user's needs;
2. Service: an activity (work) done for others with an economic value and often done on a commercial basis; and
3. System: a collection of elements including their relations.

Therefore it is essential to emphasize the social element and user behaviour, which validates the arguments of the preceding section - *Concept 1: Emphasis on the Social Element of SD/SPD*. The greatest potential sustainable benefits are therefore achieved when connections are made along both axes (*Figure 5*): combining knowledge, technology and organization with human behaviour through *System Innovation*. The author reported on a multidisciplinary research project 'The Sustainable Office', which aimed to "develop a criteria-based classification scheme for the determination of innovation type and sustainability potential" (Tischner, 2008, p. 161). As illustrated (*Figure 5*), the following distinctions are made:

- *incremental innovations* that are made continuously with knowledge gained by doing, (from engineers etc.) or with knowledge gained by using (from the user perspective);
- *radical innovations* that are made irregularly by intentional efforts (industrial R&D, research initiatives and TEOs); and
- *behavioural innovations* where habits, values and norms of the user can be influenced and enhanced.

The following section shows a broadening of scope and the clear development towards systems thinking, from stand-alone products towards product-service systems (PSS), see 2.3.3.

2.3.2 Broadening of Scope from Products to Systems

Earlier Historical Definitions

In an overview of the various environmental strategies (T. A. Bhamra, 2004), environmental considerations prior to the 1980s were mainly concerned with 'cradle to grave' solutions, such as filters or waste management principles. Bhamra, 2004, highlights various models, such as (*Figure 6*), the earlier *eco-efficiency* model of waste management (Cooper, 1994). This is the 3 Rs system of *reduce, reuse, recycle*, an ecodesign strategy when the primary goal was of waste management, to manage

end-of-pipe solutions in an efficient way. In this hierarchy, the highest goal is a *reduction* in energy and material use.

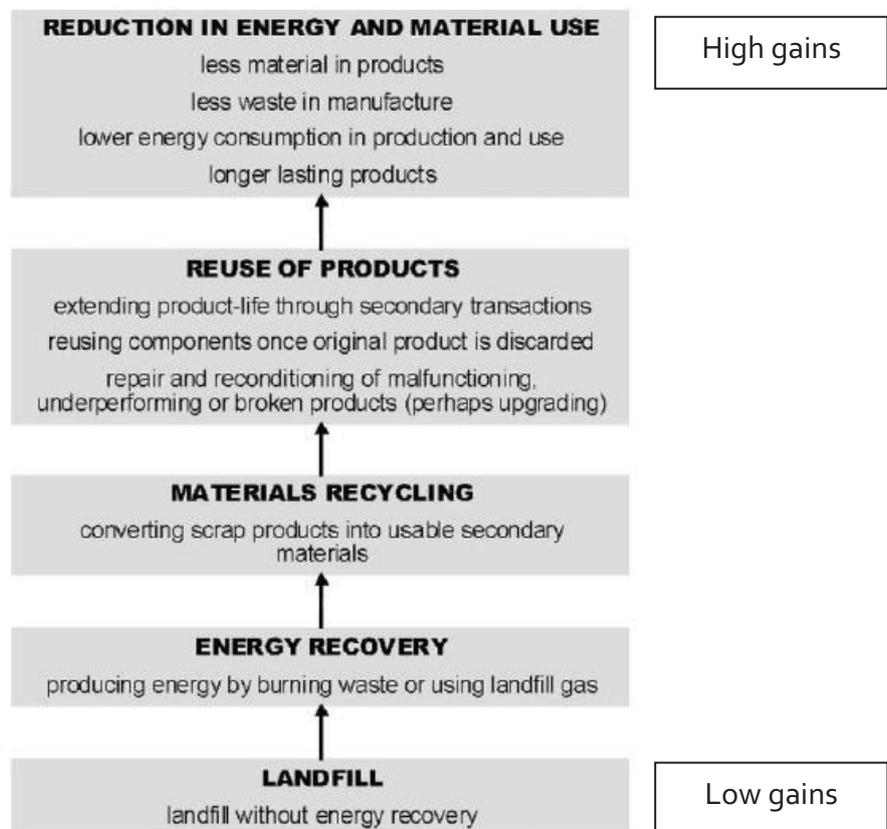


Figure 6: Hierarchy of waste management (Cooper, 1994), cited in (T. A. Bhamra, 2004, p. 560)

This evolved to consider the environment at earlier stages, with a proliferation of terms and approaches: environmentally conscious design, design for the environment (DfE), life cycle design, ecodesign, green design, ecodesign and sustainable design (T. A. Bhamra, 2004, p. 558). As cited in Bhamra, the different terminologies came from their originating disciplines (Keoleian & Menerey, 1994). Design for the Environment (DfE, DfX) originated from the engineering world of manufacture and assembly, and Life Cycle Design (LCD), equally termed Life Cycle Management (LCM) or Life Cycle Thinking (LCT) from the environmental sciences.

Bhamra uses the term *ecodesign* to describe a variety of approaches commonly in practice, as the larger term *sustainable design* denotes 'ideas about incorporating ethical and equity issues (such as wealth disparities and developing world factors) into

design' as understood by van Weenen (van Weenen, 1995), and Charter and Chick (Charter & Chick, 1997).

In an overview article of sustainable design education (Humphries-Smith, 2008), *sustainable design* is broadened to include psychological needs, and quotes (Madge, 1997, p. 49), after (E. Dewberry & Goggin, 1994), "The concept of sustainable design, however, is much more complex and moves the interface of design outwards toward societal conditions, development and ethics... and involves a general shift from physiological to psychological needs". This is in keeping with Papanek's 'design for need' and the definitive works of Maslow and Max-Neef, see 2.2.5, (Table 1, Table 2). Others (Beard & Hartmann, 1997; Simon, 1994), view *sustainable design* as using ecological and biological design principles for creating benign or restorative products, with an emphasis on environmental resource usage (T. A. Bhamra, 2004, p. 559).

Moving from Incremental to Radical Innovation

Supported by previous literature (Bakker, 1995; van Hemel, 1998), Bhamra, 2004, formulates two design approaches: *incremental* or *innovative* design (italicized approaches by Bhamra, additional italics by this author):

- *Incremental (improvement or evolutionary) approach* is where environmental issues are incorporated into design in an evolutionary approach. ...This tends to deal with the following factors: optimization; *efficiency; technology; new materials; existing product redesign*. *It has a single product or environmental issue focus.*
- *Innovative (radical or revolutionary) approach* is where environmental considerations are used as the driver for new and more radical concept development. This uses a more revolutionary approach arguing that existing products and patterns of production and consumption can and would never lead to sustainability. ... It tends to deal with the following factors: *effectiveness; innovation and creativity; mimicking natural principles and ecological models; engaging cultural and lifestyle factors*. *It is multi-disciplinary, extending beyond a single or traditional product and company boundaries* (T. A. Bhamra, 2004, p. 559).

Different strategies of design are required at different levels of innovation, as defined by Brezet (Brezet, 1997). Levels 1-2 below, (see *Figure 7*), equate to *incremental innovation*, whereas levels 3-4 equate to *radical innovation*, (T. A. Bhamra, 2004, p. 560):

1. *Product improvement.*

This entails the improvement of existing products with regards to pollution prevention and environmental care. Products are made compliant;

2. *Product redesign.*

The product concept stays the same, but parts of the product are developed further or replaced by others. Typical aims are increased, reuse of spare parts and raw materials, or minimizing the energy use at several stages in the product life cycle;

3. *Function innovation.*

This involves changing the way that the function is fulfilled. Examples include a move from paper-based information exchange to email, or private cars to 'call-a-car' systems; and

4. *System innovation.*

New products and services arise requiring changes in the related infrastructure and organizations: a changeover in agriculture to industry-based food production, or changes in organization, transportation and labour based on information technology (T. A. Bhamra, 2004, p. 560).

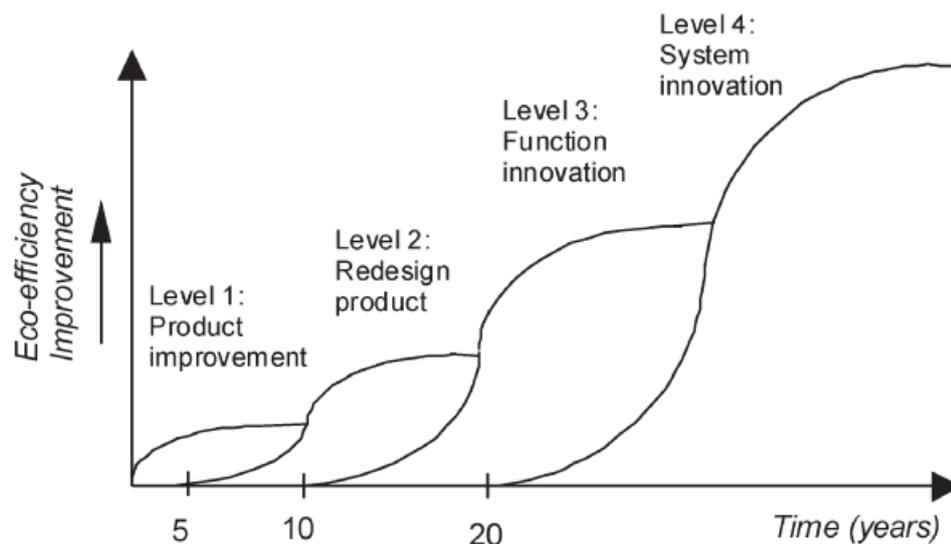


Figure 7: Brezet's four stages of product improvement to innovation (Brezet, 1997), cited in (T. A. Bhamra, 2004, p. 560)

Conceptual Design Phase linked to Radical Innovation

In Jackson's structure of environmental strategies (Jackson, 1996), cited in (T. A. Bhamra, 2004, p. 561), the conceptual design phase is placed as the area for the greatest preventative measures, and also where the greatest beneficial impacts can be achieved, known as 'frontloading'. Certain decisions are also much harder to input further down the track, so the conceptual design phase carries enormous potential for *radical innovation*.

According to a recent paper (Humphries-Smith, 2008), the proponents of this idea were originally Brezet et al (Brezet & van Hemel, 1997): their Ecodesign Checklist contained within the seminal Ecodesign Manual declared the importance of a 'needs analysis', "of how a product might fulfil social needs effectively and efficiently which of course leads immediately to the question of whether the product should be designed at all, or replaced by a system or service design" (Humphries-Smith, 2008, p. 261). The author gives further advocates of 'frontloading': (Sherwin & Bhamra, 2001; Verhulst & Baelus, 2006). Bhamra and Evans, 2001, also think that a 'needs analysis' is important, which can result in dematerialization, of products principally becoming unnecessary or evolving into product-service systems (PSS). The scope of the market is also broadened from manufactured products to a 'service provision' (see *Figure 8*).

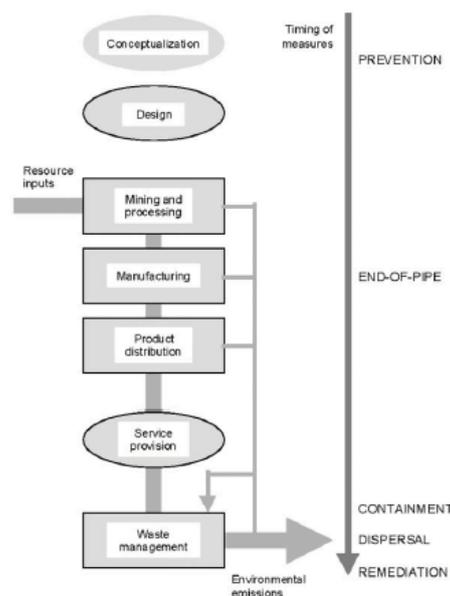


Figure 8: Structure of service system and environmental strategies (Jackson, 1996), cited in (T. A. Bhamra, 2004, p. 561)

An overview of various environmental strategies is given by the following model (Bras, 1997), with X and Y axes. Here the X axis is time and the Y axis represents broadening environmental strategies, spanning the life cycle of a single product, multiple products, single to multiple manufacturers and lastly, society as a whole.

According to this model, (see *Figure 9*), SPD would overlap and extend from phase 7: Sustainable Development. As outlined in a recent conference (Manzini, 2009), see 2.5, the incremental improvements of a company's products to achieve eco-efficiency are insufficient. It will be the role of design and engineering to take the 'quantum leap' for the *radical innovation* necessary to achieve Factors 10 - 20 in SPD (E. L. Dewberry & Monteiro de Barros, 2009). This extension is necessary to achieve levels of radical system innovation as in Brezet's Level 4 (see *Figure 7*).

The model below shows the ever-broadening scope that is required for sustainability; this thesis is concerned with promoting the widening of the next sector (see *Figure 9*), from incremental to *radical innovation* and from singular products to *PSS* – the second key concept of this thesis.

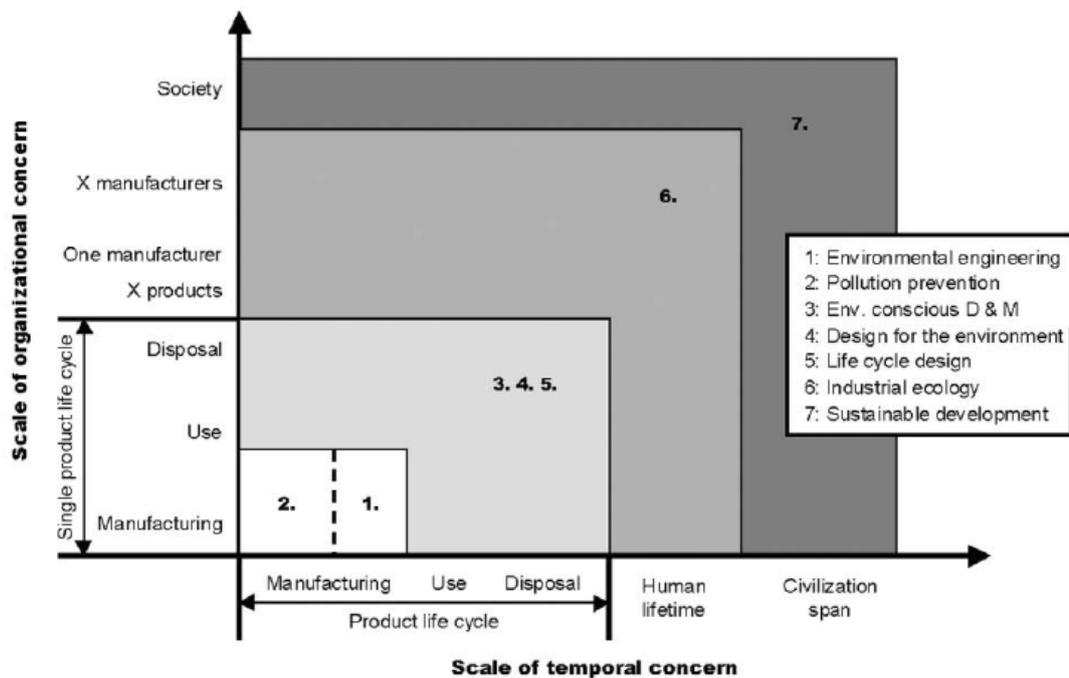


Figure 9: Environmental strategies and temporal scales (Bras, 1997),
 cited in (T. A. Bhamra, 2004, p. 561)

Van Hemel and Brezet, 1998, developed ecodesign principles and strategies, earlier (Brezet, 1997). This also informed the LiDs wheel, a visual tool for designers. In van Hemel's list below, there is a broadening of optimization at various levels, beginning with the simplest such as materials selection, and culminating at the conceptual design phase with completely new concepts.

Ecodesign strategies	Ecodesign principles
1. Selection of low-impact materials	Clean materials Renewable content materials Recycled materials
2. Reduction of materials usage	Reduction in weight Reduction in volume
3. Optimization of production techniques	Clean production techniques Fewer production steps Low/clean energy consumption Less production waste Few/clean production consumables
4. Optimization of distribution system	Less/clean/reusable packaging Energy-efficient transport mode Energy-efficient logistics
5. Reduction of impact during use	Low energy consumption Clean energy source Few consumables needed Clean consumables No waste of energy/consumables
6. Optimization of initial lifetime	High reliability and durability Easy maintenance and repair Modular/adaptable product structure Classic design Strong product–user relation
7. Optimization of end of life	Reuse of product Remanufacture/refurbishment Recycling of materials Safe incineration (with energy recovery) Safe disposal of product remains
8. New concept development	Shift to service provision Shared product use Integration of functions Functional optimization

Table 3: Ecodesign principles & strategies (van Hemel, 1998), cited in (T. A. Bhamra, 2004, p. 562)

It is important to note that both the earlier model of Jackson (*Figure 8*), and also van Hemel's model (*Table 3*), include 'service provision' as part of new concept development. This validates *Concept 2: Transition towards Systems Thinking via PSS*,

i.e. that industrial design and engineering need to consider macro issues within systems thinking, and that the design of singular products should expand to services and systems (PSS). Tertiary education for industrial designers and engineers must therefore equally grow to reflect extension of areas of expertise.

Another idea they both illustrate is that the conceptual design phase is where the greatest influence on SPD can be affected. It is at this 'fuzzy front end' that one is dealing with *problem definitions* rather than *problem solutions*, and these are more likely to be 'cultural' than technical (Hirschhorn, Jackson, & Bass, 1993). The scope of the design problem is likely to be larger, more diffuse but also with more freedom and opportunities, with potential for 'system innovation'. In (Figure 10), this 'design space' and scope of design opportunities will become more limited, the further one travels through the design process (Hodgson et al., 1997), cited in (T. A. Bhamra, 2004, p. 563).

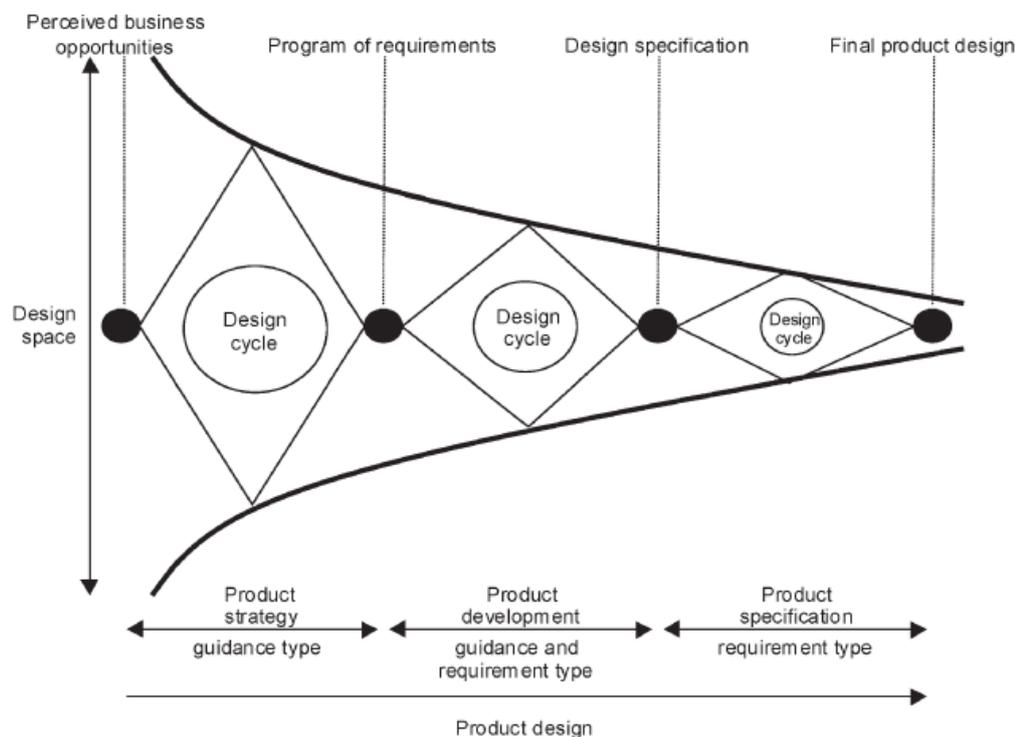


Figure 10: Conceptual model of ecodesign process
(Hodgson et al., 1997), cited in (T. A. Bhamra, 2004, p. 563)

It is therefore extremely important that environmental considerations be part of the conceptual design process from the very early stages onwards, to achieve more *radical and innovative* SPD. This was also a key finding from a more recent project DEEDS, (**D**esign **E**ducation & **S**ustainability), an EU research project conducted from 2006 - 2008, which “aimed to assess and describe the ways in which industry was integrating ecodesign” (T. A. Bhamra, 2004, p. 562).

2.3.3 PSS (Product-Service Systems)

Defining PSS

Baines et al (Baines et al., 2007) conducted a state-of-the art overview of PSS, with a number of findings:

1. PSS is a combination of product and service, emphasizing use and breaking the link of material consumption to supply value to the user, therefore reducing environmental impact;
2. PSS originated from Northern Europe in the late 1990s, notably from Scandinavia and The Netherlands;
3. PSS means servitization, a combination of products and services with emphasis on performance or use, not on ownership;
4. PSS examples in the literature emphasize environmental and social gains, yet they are also economically successful;
5. The benefits of PSS are higher value to manufacturers through differentiation, ownerless use of products for the user and a more sustainable way of living at less cost to the environment;
6. Barriers to PSS “consumers may not be enthusiastic about ownerless consumption, and the manufacturers may be concerned with pricing, absorbing risks, and shifts in the organization, which require time and money to facilitate” (Baines et al., 2007, p. 1549);
7. Successful PSS requires systems thinking from the client, early interaction with the user and organizational restructuring of the provider;

8. PSS tools and methodologies have been developed from more conventional tools, their evaluation in the field is lacking;
9. Further research is required "to develop models, methods, and theories. More widespread adoption of the PSS concept needs better understanding of PSS practices, of methods to assess value, and of organizational transitions" (Baines et al., 2007, p. 1550).

Therefore, products are fully defined within systems of use and services to various stakeholders. PSS was already recognized as a future sustainable design strategy, as:

The concept goes beyond the environmental optimisation of products and processes and requires radical and creative thinking to reduce environmental impacts by a factor of between four and 20 times while maintaining an acceptable quality of service (Roy, 2000, p. 289).

In their review article (Baines et al., 2007), PSS can be attained through a 'servitization of products' or a 'productization of services' (Morelli, 2003), (Wong, 2004), and merge where the two overlap to form a single 'offering'.

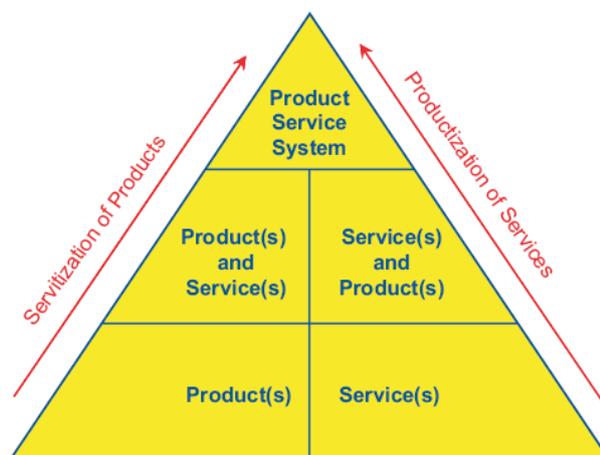


Figure 11: Evolution of the Product-Service System concept (Baines et al., 2007, p. 1546)

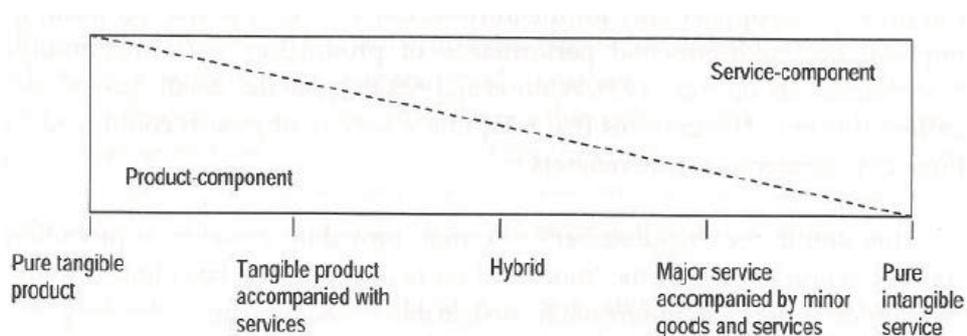


Figure 12: Product-Service continuum (Kotler, 1994), cited in (T. Bhamra & Lofthouse, 2007, p. 126)

In PSS the focus is on the *use* of a product, rather than ownership. Therefore a manufacturer leases instead of sells manufactured goods, or a combination of both. This means an expanded system whereby the product plays an integral part within the system. Other components involve communication between the user and manufacturer and/or other stakeholders for servicing and maintenance, and a take-back system for recycling and reuse of materials. The former system of manufacture for profit and release of the product to the user, who is then ultimately responsible for end-of-life disposal, becomes more complex. Whilst manufactured goods are still made for profit, there arises a symbiosis of responsibility between stakeholders, including the user, with an expectation of less environmental 'impact' than a more traditional approach. The review article reports on popular advice to manufacturers to 'move up the value chain' (Besch, 2005), and to improve competitiveness through differentiated, complex, knowledge-integrated products and services.

The article claims that the concept has been discussed in the literature for over a decade (Goedkoop et al., 1999; Manzini & Jegou, 2003; Manzini & Vezzoli, 2003; Meijkamp, 2000; Mont, 2000), but that little to date has transformed into practice. In spite of obvious benefits, "some major inhibitors are reported to arise across the design and management of engineering, manufacturing, and supply chain operations" (Baines et al., 2007, p. 1544). The authors seek to address this with further research to describe state-of-the-art of PSS to clarify understanding of existing work, and call for an extensive research programme to address the barriers that arise across design, manufacture and supply chain stages.

PSS are seen as competitive and a way to achieve sustainability, offering dematerialization, with lessened consumption and environmental impact. Most authors since 1999 (Mont, Meijkamp, Manzini and Vezzoli et al) have originated from Scandinavia, notably Sweden, and also from the Netherlands and Italy. They are mainly academics of the environmental and social sciences, with "very few contributions from Engineering, Industrial Design, or Manufacturing" (Baines et al., 2007, p. 1546). This is clearly an approach that warrants future attention from

industrial and product designers, mechanical and mechatronics engineers; in research, practice, and most importantly, *tertiary education*. The article promotes “a geographical widening of the research community and an increased contribution from authors in Manufacturing, Engineering, Design and Management” (Baines et al., 2007, p. 1550). Therefore *designing PSS, rather than stand-alone products*, needs to be promoted within the classroom for industrial design and engineering. From the investigated authors, the article states there are 3 types of PSS:

1. Product-oriented PSS: a traditional product with an extension of services (maintenance, repair etc.);
2. Use-oriented PSS: non-ownership of a product with maximum use; and
3. Result-oriented PSS: selling a result or capability via an integration of product/services.

Result-oriented PSS – the most valuable type of PSS

According to Tukker, 2004, the 3 main categories can be differentiated into 8 subcategories (*Figure 13*). Findings from SusProNet (Sustainable Product Development Network, part of the EU Fifth Framework Programme), (www.suspronet.org), were that ultimate environmental benefits are due to the *type* of PSS used.

- *product-oriented* PSS will only mean incremental environmental improvements, as the closest to the present production system;
- *use-oriented* PSS, product lease is more beneficial than product ownership, but may lead to harmful user behaviour to the environment due to lack of user responsibility. Product renting, sharing and pooling can have great environmental benefits, but with a “considerably lower market value than the competing product, due to both tangible and intangible user sacrifices” (Arnold Tukker, 2004, p. 259)
- *result-oriented* PSS, and specifically that of the function-oriented PSS, has the most potential for environmental benefits. This is where a functional result i.e. an outcome, is agreed between manufacturer and user, but is not directly defined by the product and/or technology itself (i.e. pleasant interior climate rather than gas/cooling equipment). The importance of the product as the core component of PSS diminishes and the overall need becomes increasingly abstract and experiential, the further one progresses through the PSS sub-categories 1-8 (Arnold Tukker, 2004, p. 249) .

Therefore, it is essential that the PSS types with the greatest potential to achieve radical innovation for sustainability should be developed. Firstly, *result-oriented*, functional PSS, (specifically *function-oriented*) and thereafter, *use-oriented* product renting, pooling and sharing. For this, three barriers need to be overcome, namely:

1. Design of product renting, sharing and pooling systems that have a high *intangible* value for the user, while sacrifices with regard to tangible value are minimized;
2. Development of concrete performance indicators for functional PSSs; and
3. Development of approaches which can reduce the liability risks and enhance control over 'production' uncertainties related to functional PSSs (Arnold Tukker, 2004, p. 259).

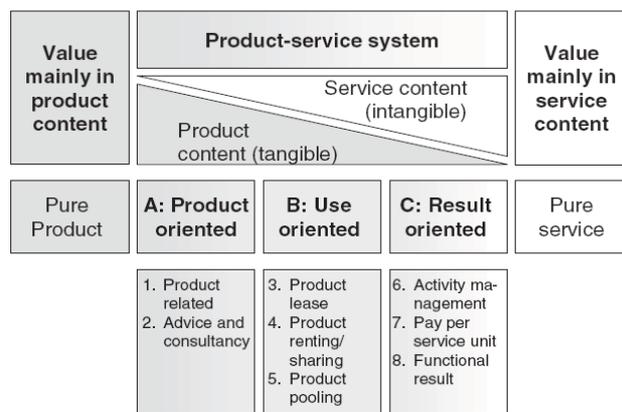


Figure 13: Differentiation of PSS categories and sub-categories (Arnold Tukker, 2004, p. 248)

Design of a PSS should be systemic, with early consultation with the user, resulting in systems thinking rather than design of a one-off product (Manzini, Vezzoli, & Clark, 2001). This can result in quite different solutions to that of traditional products, giving manufacturers a competitive edge with differentiated offerings. This requires a shift in focus and to deal with life-cycle phases normally not accounted for, such as maintenance, recovery and recycling of materials and reuse/remanufacture. The benefits will be ultimately long-term and still provide profits, albeit in an extended framework. Some restructuring of product and manufacturing systems can be necessary, such as user rewards and locations for take-back systems, e.g. early examples of glass bottles, aluminium cans etc. PSS Tools and methodologies are given in the MEPSS Handbook (Baines et al., 2007, p. 1549). PSS screening tools developed in SusProNet (Tischner, 2008), can be found in *Appendix A*.

2.4 Concept 3: Complementary Sustainable Design Strategies

In order to achieve PSS, current sustainable design strategies can broadly be divided into two approaches; *eco-efficiency* and *eco-effectiveness*. Each strategy comprises a number of tools, listed under *Appendices B and C* respectively.

- ***eco-efficiency* / *cradle-to-grave***
 - tangible design task, optimizing product and processes
- ***eco-effectiveness* / *cradle-to-cradle***
 - systems thinking with broader, holistic viewpoint (PSS), beneficial materials selection, as 'nutrients' that can be 'upcycled' within closed loop cycles

2.4.1 Eco-efficiency / Cradle-to-Grave

Life-Cycle Management

Life Cycle Management (LCM), also known as Life Cycle Design (LCD) or Life Cycle Thinking (LCT), is a linear model that contributes to levels of sustainability with incremental improvements through optimization of the various stages of a product's lifecycle. This is achieved through *eco-efficiency*, of ensuring that each stage of a product's lifecycle is implemented efficiently, using less materials, resources and cleaner manufacturing processes, with the goal of reducing or minimizing environmental impacts (Seuring, 2004).

As in (*Figure 14*), the eco-efficient LCM model is integrated with *Industrial Ecology* and the *Disposal Phase* (waste management/minimization and recycling), and therefore remains linear with a cradle-to-grave philosophy, i.e. products and manufacturing processes which result in waste.

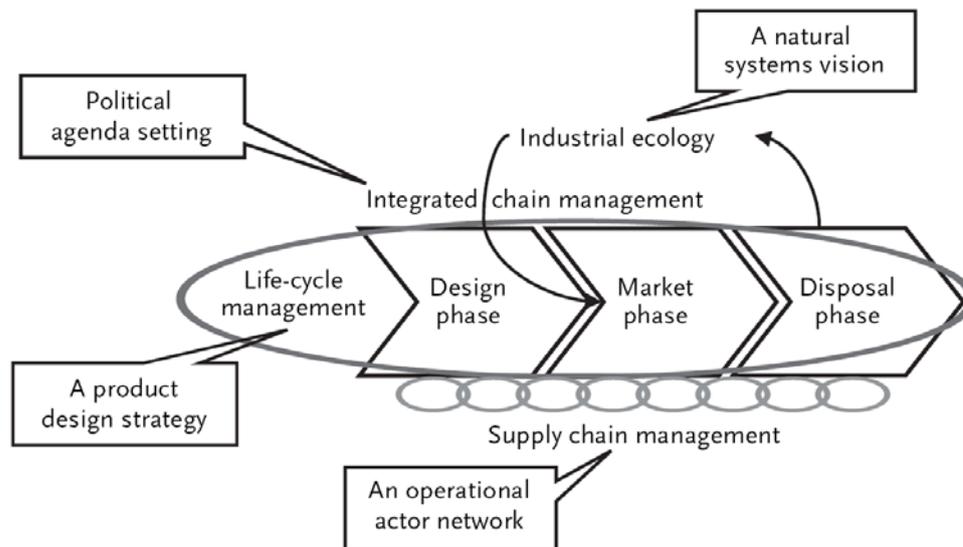


Figure 14: An integrative framework for Industrial Ecology, LCM and Supply Chain Management
(S. Seuring, 2004, p. 4)

Life Cycle Assessment (LCA) is the most commonly known component. The LCA tools assess the environmental impact of all procedures and materials of a product, from the extraction of raw materials, through to disposal and recycling. It takes a thorough assessment of all stages in a product's life cycle. This can be very time consuming and results can be unclear, especially when trying to make comparisons across products and countries. A comprehensive list of *eco-efficient tools* (LCA etc.) can be found under *Appendix B*.

Industrial Ecology takes a metaphorical view of ecology, applying closed loop systems thinking found in nature, and applied to manufacturing and industrial processes. It is mainly *eco-efficient*, and doesn't fully provide the flexibility and adaptability found in living systems. This might be improved by developing clusters of companies with synergies rather than just grouping companies in a given location (McManus & Gibbs, 2008). Their main criticism is that

...the dominant focus within industrial ecology upon inter-firm exchanges and increased efficiency within the production process neglects the broader question of consumption issues and the links between geographies of production (of retail services or housing, for example) and their consumption. Further, Ehrenfeld (2004) has suggested that there could be a 'rebound effect' at work whereby greater efficiency simply produces more consumer surplus and consumption, therefore negating any eco-efficiency gains (McManus & Gibbs, 2008, p. 534).

2.4.2 Eco-effectiveness / Cradle-to-Cradle

Cradle-to-Cradle (C2C)

In contrast to *eco-efficiency*, which seeks to *reduce, reuse, recycle* and is supported by LCM and its better-known LCA component, a cradle-to-cradle approach (William McDonough & Braungart, 2002) seeks not to be just efficient in the way things are managed, controlled and optimized (doing things right), but to address problems at their source through *eco-effectiveness* (doing the right things). Below (Figure 15), shows how *eco-efficiency* operates through reduction and minimization of harm to ecological systems, whereas *eco-effectiveness* operates through expansion of beneficial ecological systems, see Appendix C.

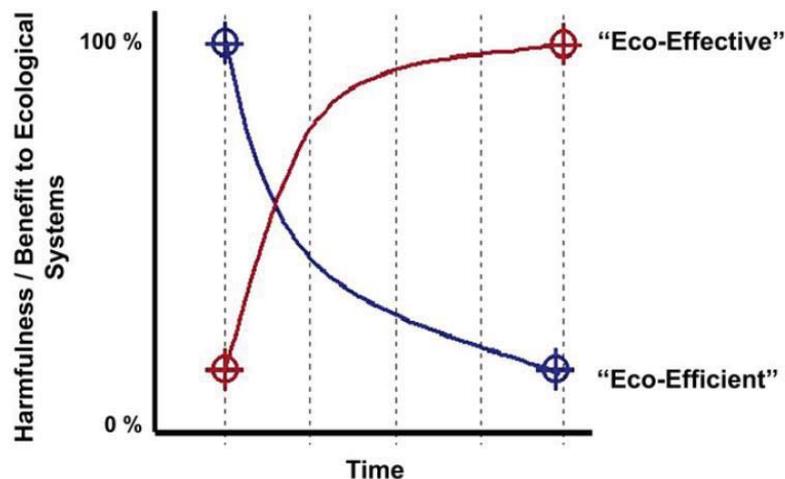


Figure 15: *Eco-effectiveness strives to generate an entirely (100%) beneficial impact*
(Braungart, McDonough, & Bollinger, 2007, p. 1343)

Contrary to the common views that developed from the 1970s onwards (WCED, 1987), that growth was harmful and that the human footprint had to be reduced to be sustainable, C2C has at its core that growth is good. Products, services, systems and their materials can be beneficial to the environment in excess when they are treated as valuable nutrients within cycles, with no concept of waste. Biological nutrients can be composted and returned to the *biosphere*, whereas technical nutrients remain in closed-loop cycles, to be reused within the *technosphere*.

To eliminate the concept of waste means to design things – products, packaging and systems – from the very beginning on the understanding that waste does not exist. It means that the valuable nutrients contained in the materials shape and determine the design: form follows evolution, not just function...Products can be composed either of materials that biodegrade and become food for *biological cycles*, or of technical materials that stay in closed-loop *technical cycles*, in which they continually circulate as valuable nutrients for industry. In order for these two metabolisms to remain healthy, valuable and successful, great care must be taken to avoid contaminating one with the other (William McDonough & Braungart, 2002, p. 104).

The authors criticize that the 'triple bottom line' components of economy, ecology and equity are still projected by the majority of companies with the priority of economy. The authors claim that the results can be so much more if all three components are considered *equally* at the very beginning, in the conceptual design phase. They call this the 'triple top line', and use their fractal tool to ask appropriate questions about the products, services or systems in the individual and overlapping sectors and to create value for each. It can be concluded that environmental and societal issues need to be identified as 'stakeholders' towards problem definition in a design brief, and recognized as equal in importance to economic interests. This must also be reflected in the design projects completed in industrial design and engineering degrees, to fulfil the triple components of SD/SPD.

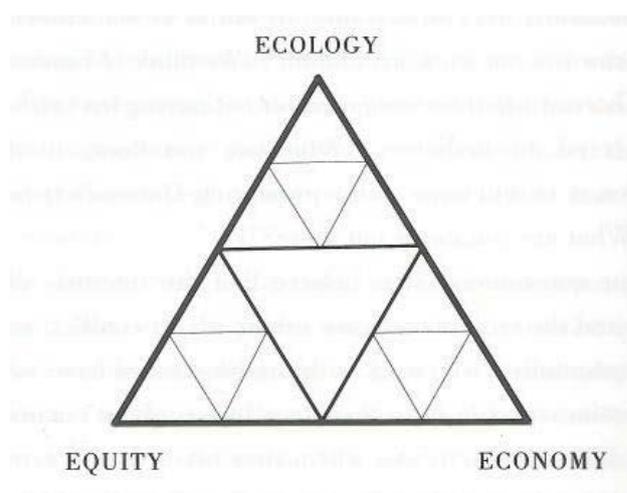


Figure 16: Fractal tile, used to visualise C2C concerns
(W. McDonough & Braungart, 2002, p. 150)

Eco-efficiency is cited as “to get more from less: more product or service value with less waste, less resource use or less toxicity” and achieved through:

- Dematerialization;
- Increased resource productivity;
- Reduced toxicity;
- Increased recyclability (downcycling); and
- Extended product lifespan

(Braungart, McDonough, & Bollinger, 2007, p. 1338).

Reduction in all senses means using less: but using less of what? The authors point to the fact that recycling will be “downcycling” in many cases, as valuable materials are downgraded when mixed with other types of plastics, metals etc., and can only be used for secondary, often inferior purposes and not in their original context. Instead of targeting “zero waste, zero resources and zero impact” they promote an “upcycling” of materials, using a system of intelligent materials pooling, where materials can be returned and/or improved after a “defined use period” (Braungart et al., 2007, pp. 1341, 1346), (see Figure 17).

Upcycling of 'Nutrients' within a Materials Bank

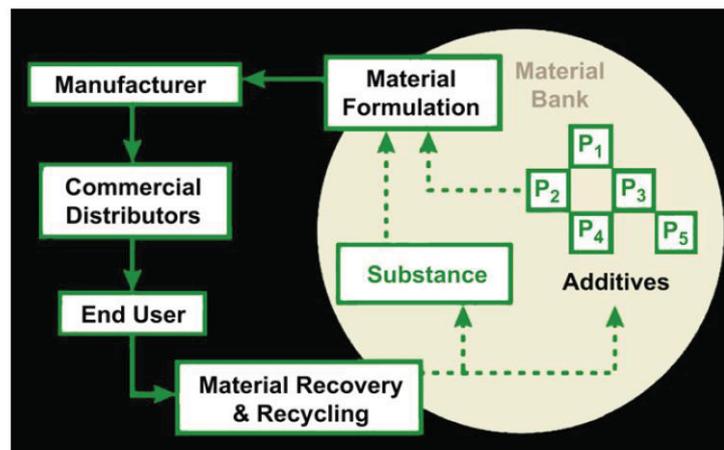


Figure 17: Material flows in the context of an Intelligent Materials Pooling community

(Braungart et al., 2007, p. 1347)

Therefore durability, to withhold (harmful) substances from the disposal period for as long as possible in the *eco-efficient model*, is not as desirable anymore within the *eco-effective* model. Instead, materials become valuable nutrients waiting to be reintegrated into the biological or technical cycle after use, whilst still needing to uphold their integrity for their intended purpose and PSS life. PSS then become part of larger systems as *upcycling* of materials for the biosphere or technosphere.

This means that, rather than striving for incremental improvements in eco-efficiency towards reduction of (harmful) products, manufacturing processes and materials, it is necessary to educate to achieve the *radical innovation* using the C2C eco-effective model. Knowledge of beneficial, sustainable materials, extraction and manufacturing processes is then required at an in-depth level. Products need to be designed as valuable components of product-service systems (PSS), with disassembly of parts, materials etc. integrated into the design, and reflected within tertiary education.

In contrast to this approach of *minimization* and *dematerialization*, the concept of *eco-effectiveness* proposes the transformation of products and their associated material flows such that they form a supportive relationship with ecological systems and future economic growth. The goal is not to minimize the cradle-to-grave flow of materials, but to generate cyclical, *cradle-to-cradle* "metabolisms" that enable materials to maintain their status as resources and accumulate intelligence over time (*upcycling*). This inherently generates a *synergistic relationship* between ecological and economic systems – a positive *recoupling* of the relationship between economy and ecology (Braungart et al., 2007, p. 1338).

The authors claim that the LCA approach is unsuitable for achieving eco-effectiveness, as it is linear and promotes cradle-to-grave activities. Eco-effectiveness demands a more cyclical approach for C2C design. For this purpose, Braungart and McDonough devised a framework of steps (W. McDonough & Braungart, 2001):

- Step 1: Free of the most dangerous substances;
- Step 2: Personal preferences..... substances to include, based on the best available info;
- Step 3: The passive positive list..... toxicity assessment according to ratings;
- Step 4: The active positive list..... optimization of substances up to the stage of 'nutrient'; and
- Step 5: Reinvention..... radical new concepts, PSS.

Yet, "Efficiency and effectiveness can be complementary strategies....Once effectiveness has been achieved, efficiency improvements are not an environmental necessity, but a matter of equity. They are necessary to ensure the fair distribution of goods and services" (Braungart et al., 2007, p. 1342). First the 'right things' i.e. 'wicked' problems have to be identified within design problem definition (1), and design problem solution (2), at the conceptual design phase (eco-effectiveness). It is here that the largest steps can be made towards *radical innovation through creativity*. After that, all other stages need to be executed efficiently, by 'doing things right' (eco-efficiency), and through *incremental innovation*. But rather than to minimize harmful effects, eco-efficiency then becomes a way to optimize and maximize positive effects achieved through the initial C2C / PSS concepts, and distributed throughout all NPD stages. Besides this, resources still have to be managed efficiently.

Main Themes of Cradle-to-Cradle

The 3 main tenets of cradle-to-cradle emulate nature and have been described as:

1. *Waste equals food*: imitating natural ecosystems, all materials are nutrients: there is no waste as everything can be regenerated at the end of one product, process, or system to form another;

Understanding these regenerative systems allows engineers and designers to recognize that all materials can be designed as nutrients that flow through natural or designed metabolisms. Although nature's nutrient cycles comprise the *biological metabolism*, the *technical metabolism* is designed to mirror them; it's a closed-loop system in which benign, valuable, high-tech synthetics and mineral resources circulate in cycles of production, use, recovery, and remanufacture.

(William McDonough, Braungart, Anastas, & Zimmerman, 2003, p. 436A)

2. *Use current solar income*: using renewable rather than depleting energy sources, such as solar heat and light; and
3. *Celebrate diversity*: different environments each have a unique set of circumstances and the best-adapted inhabitants (human and non-human) will

thrive. Designs that are best adapted to local conditions and material flows will also thrive.

...optimal sustainable design solutions draw information from and ultimately “fit” within local natural systems. These solutions express an understanding of ecological relationships and, where possible, enhance the local landscape”

(William McDonough et al., 2003, p. 437A).

To assist designers and engineers to achieve these goals, the main themes were expanded to 12 Principles, formulated for optimizing products, processes and systems (Anastas & Zimmermann, 2003; William McDonough et al., 2003), shown in (Table 4):

Principle 1:	Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
Principle 2:	It is better to prevent waste than to treat or clean up waste after it is formed.
Principle 3:	Separation and purification operations should be designed to minimize energy consumption and materials use.
Principle 4:	Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
Principle 5:	Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.
Principle 6:	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
Principle 7:	Targeted durability, not immortality, should be a design goal.
Principle 8:	Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.
Principle 9:	Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
Principle 10:	Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
Principle 11:	Products, processes, and systems should be designed for performance in a commercial “afterlife”.
Principle 12:	Material and energy inputs should be renewable rather than depleting.

Table 4: The 12 Principles of Green Engineering

(Anastas & Zimmermann, 2003; William McDonough et al., 2003)

The C2C principles are described in detail (Anastas & Zimmermann, 2003), and listed under *Appendix C*, see also (<http://pubs.acs.org/est>).

The *C2C 12 Principles* can be applied from the conceptual design phase onwards, with the first principle as a baseline: that all material and energy inputs and outputs should be as inherently nonhazardous as possible. For this, MBDC (McDonough Braungart Design Chemistry) have devised a set of materials assessment criteria and steps, as shown in (*Table 5*):

<i>Human health criteria</i>	<i>Ecological health criteria</i>
Carcinogenicity	Algae toxicity
Teratogenicity	Bioaccumulation
Reproductive toxicity	Climatic relevance
Mutagenicity	Content of halogenated organic compounds
Endocrine disruption	Daphnia toxicity
Acute toxicity	Fish toxicity
Chronic toxicity	Heavy metal content
Irritation of skin/mucous membranes	Persistence/biodegradation
Sensitization	Other
Other relevant data (skin penetration potential, flammability, etc.)	(water danger list, toxicity to soil organisms, etc.)

*Table 5: Parameters for MBDC's materials assessment protocol
(William McDonough et al., 2003, p. 438A)*

Industrial examples are diverse, with award-winning products: manufacturers include companies such as Rohner and DesignTex (textiles), Shaw Industries (carpeting), Hermann Miller (furniture) and Nike (footwear and apparel) (William McDonough et al., 2003; Segars, Bradfield, Wright, & Realff, 2003). Below is an example of the environment assessment criteria for Herman Miller, based on MBDC criteria (*Table 6*):

Human health and eco-toxicological assessment	Ecological criteria	Recycled/renewable content
No problems identified or expected, or extremely low risk. Low to moderate risk. Lacking sufficient data to make a determination. Severe problems or high risks identified or expected.	Fish toxicity Daphnia toxicity Algae toxicity Toxicity to soil organisms Persistence/biodegradation	Percentage of total product weight Post-industrial recycled content Post-consumer recycled content Renewable content
Human criteria	Bioaccumulation	Disassembly
Carcinogenicity Disruption of endocrine system Mutagenicity Reproductive toxicity Teratogenicity Acute toxicity Irritation of skin/mucous membranes Chronic toxicity Sensitization Others (e.g., carrier function, skin penetration potential)	Content of halogenated organic compounds Heavy metal content Climatic relevance/ozone depletion potential	Can the component be separated with no dissimilar materials attached? Can common disassembly tools be used (pry-bar, hammer, drivers, utility knife, pliers)? Can one person disassemble the component in 30 seconds or less? Can the material type be identified through markings, magnets, and so on?
	Recyclability	
	Material is a technical or biological nutrient, and a commercial infrastructure exists. Material can be down-cycled, and a commercial infrastructure exists. Material can be incinerated for energy recovery. Material is normally landfilled.	

Table 6: Herman Miller Design for Environment assessment criteria
(William McDonough et al., 2003, p. 440A)

A highly successful example of using C2C in SPD is the Herman Miller 'Mirra' chair, introduced in 2003. Using the MBDC protocol, materials are 96% recyclable, aided by fast and efficient disassembly. According to William McDonough of MBDC, co-author: 'Cradle to cradle: remaking the way we make things' (William McDonough & Braungart, 2002):

Herman Miller's Mirra chair represents the most advanced and complete application of the Cradle-to-Cradle design protocols among any product manufactured to date. The chair, and the company, confirms that great design and ecological and economic success are possible today, cited in (Berry, 2005, pp. 222-224).



Figure 18: Back view of 'Mirra' chair (Berry, 2005, p. 229)

Other eco-effective systems are those of 'biomimicry' (Benyus, J. M. 1997), where products and PSS mimic and emulate nature in form, function and use of materials etc. (<http://www.biomimicryguild.com/>, <http://biomimicryinstitute.org/>, <http://www.asknature.org/>).

2.5 Concept 4: Transition towards Strategic Design

This section concerns itself with aspects of *problem definition* in the conceptual design phase towards *SPD context*, known to be 'wicked' problems. This is to direct attention to widening the search space, to potential ways of new thinking and creativity that will be necessary for both disciplines for *radical innovation*. Walker, 2002, suggests reframing our views of sustainable design, to create possibilities of how things could be:

Instead of thinking about design within this conventional frame, we can approach the subject in fresh ways and think about how to create a material culture that is consistent with and beneficial to personal and social well-being, environmental stewardship and economic stability. To do this we must start with fewer pre-conceptions and we must improvise as we go (Walker, 2002, pp. 7-8).

reframing our perspectives for sustainable design	
industrial design	design of functional objects
product design	creation of material culture
specialization	improvisation
conventional	uncertain, uncomfortable
professional	amateur, dilettante
specific	holistic, integrative
instrumental	intrinsic
problem solving	experimenting
solutions	possibilities
<i>a priori</i> design	contingent design

Table 7: Reframing our perspectives on sustainable design (Walker, 2002, p. 9)

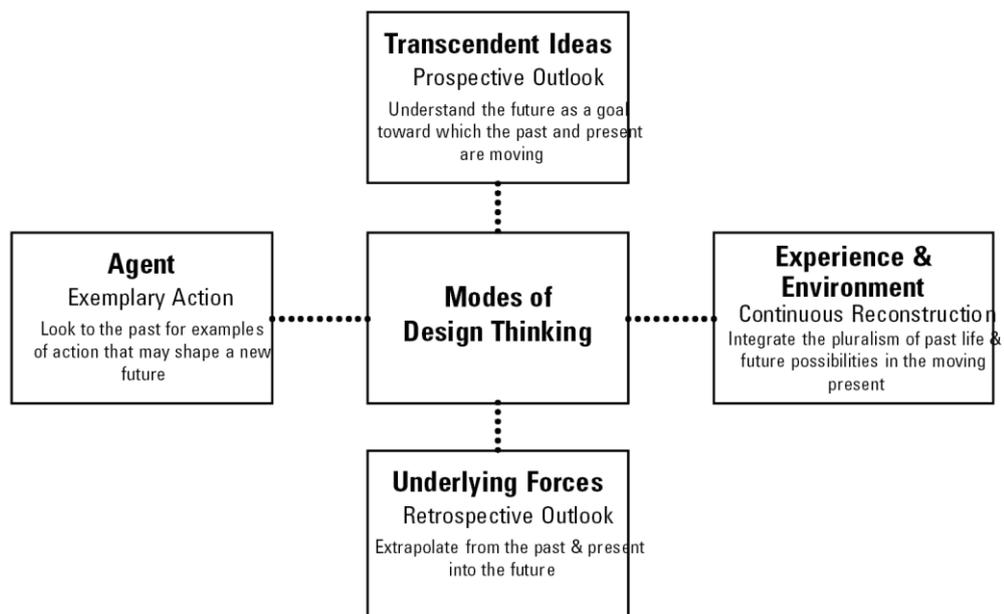


Figure 19: Generative principles in design thinking (Buchanan, 2001, p. 76)

Figure 19 illustrates the generative principles in the ecology of design culture (Buchanan, 2001, p. 76), as products and PSS contain *experience and expression* as part of material culture. Therefore transitional PSS towards sustainable design equally need to embody *meaning* from the past and present to be successful, or set a future scenario of a more sustainable quality of life, towards which one moves in the 'moving present', see *Appendix D* on backcasting / foresighting. *Meaning* can be construed as the purpose of a product or PSS (Walker, 2006, p. 22), in keeping with Maslow's Hierarchy of Human Needs, (see *Table 1*).

- *Functional*, to fulfil biological and physical needs
- *Social/Positional*, giving social status and identity to the user
- *Inspirational/Spiritual*, reflecting spiritual needs and personal growth

According to Walker, it is when a product combines more than one purpose beyond that of basic functionality, that there is potential growth for consumerism. *Functional + Social/Positional* products combine functionality with display of identity and social status. This results in fashion trends which become obsolete fairly quickly, subject to new materials and technology. *Social/Positional + Inspirational/Spiritual* can include ornaments, genuine artistic endeavours, right through to tourist souvenirs. They can be used as status symbols and do not necessarily threaten sustainability, although mass produced souvenirs can undermine the culture they are meant to promote. *Functional + Social/Positional + Inspiration/Spiritual* can be religious and cultural artefacts and will be valued because of their meaning and association with higher emotions. It is this last category that contains the most value and meaning, and to aspire towards.

Knowing that a product can lead to (detrimental) consumerism can be converted to positive growth, see 2.4.2 for eco-effectiveness, to *promote* sustainable behaviour, also known as 'intentional design' (Stegall, 2006). Stegall, 2006, conceives this as a hierarchy based on interconnected components in ascending order: *philosophies of resources, form and function, purpose and spirit*. Therefore it can be concluded that

designers and engineers need to target the highest component of *purpose and spirit* in all of their conceptual designs, which will then automatically include the preceding components of *philosophies of resources* and *form and function*. This means that the focus of a product / PSS must be on user behaviour, on its *use and intention*. The aim is then to promote sustainable behaviour through positive ways that engage and have meaning for the user, that delight and give enjoyment with *purpose and spirit* within the diverse context of local environment and culture. (Stegall, 2006, p. 58).

Dogan and Walker, 2003, see a danger that users are presently too far removed from the creation of products, so that responsibility for the environment is perceived as far away and not in the scope of the ordinary citizen. To rectify this, the authors advocate “Integrated scales of design and production for sustainability” (ISDPS), where international and local processes are combined, (see Figure 20), integrating:

- *Direct encounter* in the creation of material goods;
- *Transience* of products to be recognizable; and
- *Localisation* input into design, production and post-use (Walker, 2003, p. 189).

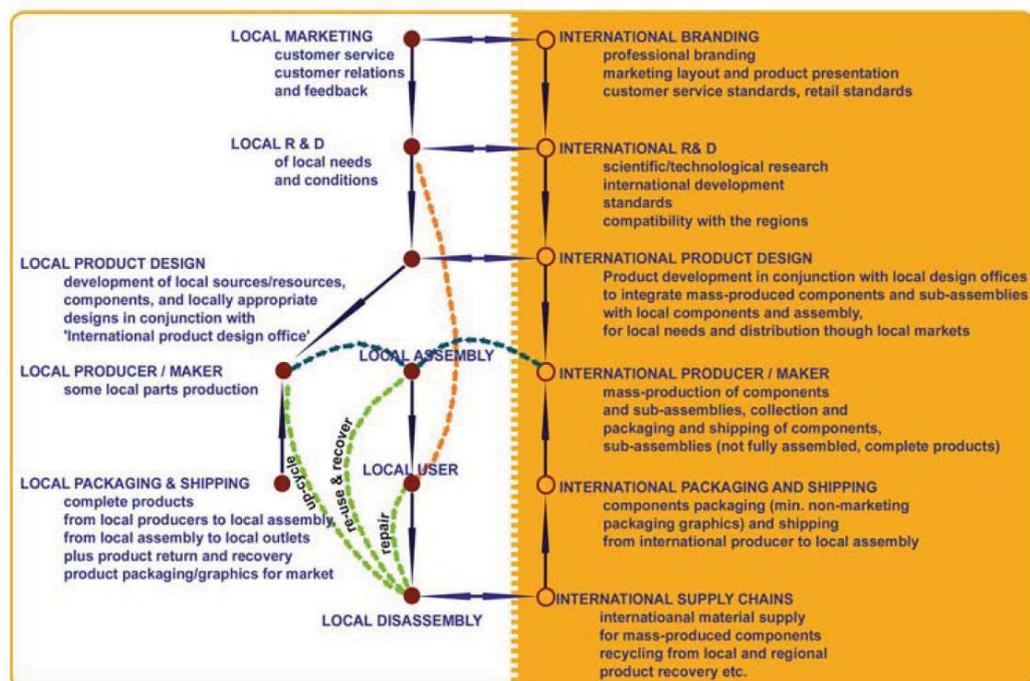


Figure 20: The relationships within the product design process for ISDPS concept (Dogan & Walker, 2003, p. 138)

There is a vast scope of possible product attributes for the material culture of SPD. It is important to realize that a 'one size fits all' approach is not appropriate when considering the human context, as *the 'social' element of SPD needs to embody meaning, experience, culture and habitat, which are all diverse and essentially local.*

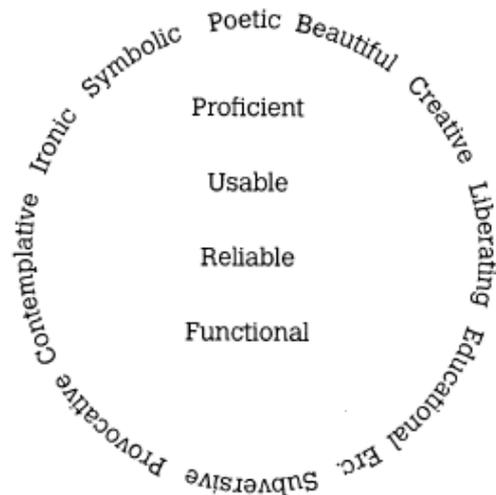


Figure 21: Wheel of options for product enhancement, (Parsons, 2009, p. 83)

Ways to integrate strategic design were recently presented in the 'Changing the Change' conference for designers, held in Turin, Italy, 10th – 12th July 2008, as "the designer community can play a positive role in this necessary re-orientation and that this can be done by building new *design knowledge*" (Manzini, 2009, p. 4), (www.changingthechange.org).

The main messages were that *radical* changes in lifestyle were called for, and that sustainability be totally integrated and the "meta-objective" of all design activities. For designers this meant "to rethink themselves, to rethink how they operate and reshape their position in society" (Manzini, 2009, p. 6). Manzini is a notable design researcher, who gave three important points gained from over a twenty-year period of design discussions that he considered important for future direction:

- a) *Research on eco-efficiency has been successful, but it has not improved the overall picture;*

Using less of everything, being efficient in our use of energy and materials, lightening of products etc. is not enough. Instead we have to do things in completely new ways, and consider new ways of living and how we interact with products, services and systems.

b) *Recognizing the environment problem is not synonymous with more sustainable choices and behaviour;*

There is a danger that the over-exposure of environmental threats in the media can lead to new problems. In the absence of *positive alternatives*, people and communities can feel threatened, which can lead to fear-based, negative and even dangerous behaviour. Therefore, it is imperative to *provide positive, sustainable solutions as visions of sustainability*.

c) *The feasible alternatives found so far indicate new qualities.*

The enabling capacities and qualities of self, private and public spaces, physical 'commons' such as air, water, landscape, social 'commons' such as neighbourhoods and communities, the use of time and the integration of 'local' and culture are all points to consider as emerging issues. The emphasis is to build on assets at all levels: personal and communal know-how and capabilities, local materials and cultural meaning.

The conference (2008, Italy) generated a *Design Research Agenda for Sustainability*. The 1st Draft, dated 12.07.08, is for design researchers to collaborate in a design research programme, to accumulate knowledge, ideas and tools for the future:

1. Background statements

- sustainability calls for systemic changes, locally and globally;
- social learning processes are necessary for transition; and
- activation through design research, enabling collaboration and a more sustainable knowledge society (Manzini, 2009, p. 10).

2. *Emerging Issues*

- *Ways of living*

Designing for *context-based well-being* that includes:

- physical 'commons' such as air, water and landscape;
- social 'commons' such as public spaces, communities, neighbourhoods;
- developing 'commons' such as open knowledge, internet;
- sustainable well-being through behaviour;
- sense of personal balance;
- sense of community "as communication, protection, participation, recreation, identity, freedom and generosity" (Manzini, 2009, p. 11); and
- new sense of time i.e. *slowness* is welcomed.

- *Ways of producing*

Understanding and designing for:

- distributed systems that connect people, places and things; and
- integration of local (identities, culture, materials, craftsmanship).

- *Ways of designing*

New role for designers:

- as connectors, facilitators and enablers, "visualisers and visionaries", change agents.

New design knowledge and education:

- changed nature of design with culture; PSS;
- New designing and learning networks;
- Changes in design education;
- Address barriers to sustainability in design schools;
- Inter-project transfer of knowledge; and
- Local and global knowledge integration (Manzini, 2009).

2.6 Complementary Professions of Industrial Design/Engineering

It is of the utmost importance that the disciplines of industrial design and engineering are able to communicate with each other, ideally within multidisciplinary SPD projects, for a *complementary* contribution towards *radical innovation*. This thesis provides a way forward with *Chapter 5, Educational Framework and Guidelines*, for implementing structures that need to be considered towards this.

While engineers are mostly concerned with technology and technical solutions, the industrial design profession grew from a combination and overlapping of different areas. The Industrial Revolution of the 19th century meant increasing standardization of manufacturing techniques and competition amongst products. Products needed to be functional and affordable, but also to appeal visually and emotionally to the consumer, who was now aggressively targeted with advertising to boost sales campaigns (Heskett, 1980, p. 105). The division of labour in industry caused a new way of working and labelling of certain tasks that had previously been fully integrated into the manufacture of hand-crafted products.

In response to the social transformations that industrialisation brought with it, and the ensuing need for material culture to carry new socio-cultural meanings, designing combined a new set of activities which crossed the production/consumption divide. Consequently, it was uniquely placed to represent the notion of 'modernity' as it related to both arenas (Sparke, 2004, p. 35).

Chiapponi and Margolin (Chiapponi, 1998; Margolin, 1998) saw the need for the industrial design profession to change in view of the many environmental issues that were already recognized by earlier critics. These were Victor Papanek, who promoted '*design for need*', low-tech designs for the developing world (Papanek, 1985), and R. Buckminster Fuller, who promoted high-tech designs, products and *systems thinking*. Papanek and Buckminster-Fuller were the first to use fairly harsh criticism of the design profession for designing only what was required by the client, and emulated by Margolin (Margolin, 1998). Margolin claimed that "Design must disengage itself from

consumer culture as the primary shaper of its identity, and find a terrain where it can begin to rethink its role in the world" (Margolin, 1998, p. 89).

Margolin, 1998, called for designers to reinvent themselves "to find ways of engaging the massive problems that confront mankind" (Margolin, 1998, p. 91), and to identify worthwhile projects. He was highly critical of the fact that designers were absent at the Earth Summit in Rio de Janeiro, 1992, and so could not contribute to implementation of the Agenda's aims, claiming that "Once again, design remains invisible because the design professions have not done an adequate job of explaining to themselves and others the powerful contribution they could make to the process of creating a sustainable world" (Margolin, 1998, p. 92). Even though the tide is turning, with many notable examples of SPD now in the literature (Fuad-Luke, 2002, 2004; Pilloton, 2009), his quotes are unfortunately as relevant today as they were then.

Spangenberg et al declare that satisfiers, i.e. products and PSS, will depend on culture and local conditions, with complementary roles for design and engineering in achieving '*true satisfiers*' of sustainable consumption, whilst also addressing needs:

Design for Sustainability, addressing all dimensions of sustainability and asking more fundamental questions, plays its most important role in combining the effects of satisfier efficiency with the supply and product 'efficiencies'. For engineering, the focus is rather opposite and therefore both disciplines seem to be complementary – a fact most often overlooked by the stakeholders involved, as due to different mentalities their mutual dependency is often not recognised.

(Joachim H. Spangenberg, Alastair Fuad-Luke, & Karen Blincoe, 2010, pp. 1488 (Naturwissenschaftlerinneninitiative Verantwortung fuer Frieden und Zukunftsfahigkeit e.V. and DEEDS (Design, Education and Sustainability) Project, 2008),

A reason for the statement "Industrial design is an under-utilised resource for ecodesign" (Lofthouse & Bhamra, 1999), cited in (Sherwin & Evans, 2000, p. 115), is that the differences and therefore differing strengths of industrial design and engineering are still not fully realized (Sherwin & Evans, 2000). The authors cite prior distinctions made "...industrial design is commonly seen as 'people-centred' and engineering design is commonly seen as 'technology-centred' (Bates & Pedgley,

1998), and that industrial designers would be 'familiar or proficient' with a wide range of topics, and design engineers specialising in only a few topics (Lofthouse, 1999). Sherwin and Evans concluded:

This means that industrial designers deal more in the realms of the consumer and behavioural orientated design issues using incomplete information and knowledge, while design engineers focus more on technological and product focused design issues using more prescriptive design methods and precise information (Sherwin & Evans, 2000, p. 115).

The authors refer to previous models of design activity (Chick & Charter, 1997), where innovation moves through steps of Re-pair, Re-Fine, Re-Design, Re-Think; the latter requiring the most time and effort, but with the most benefits for the environment.

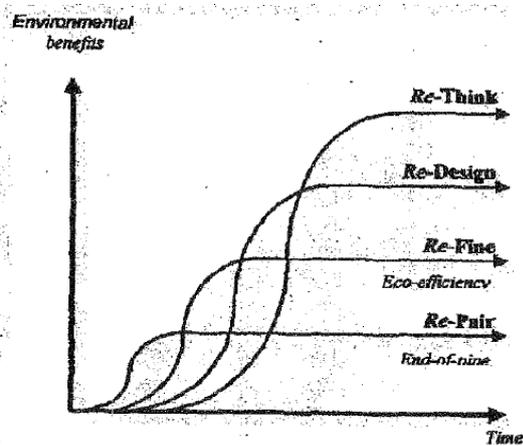


Figure 22: Model of ecodesign innovation, (Charter, 1997), cited in (Sherwin & Evans, 2000, p. 113)

They also distinguish 3 types of design activities within the product development process (PDP):

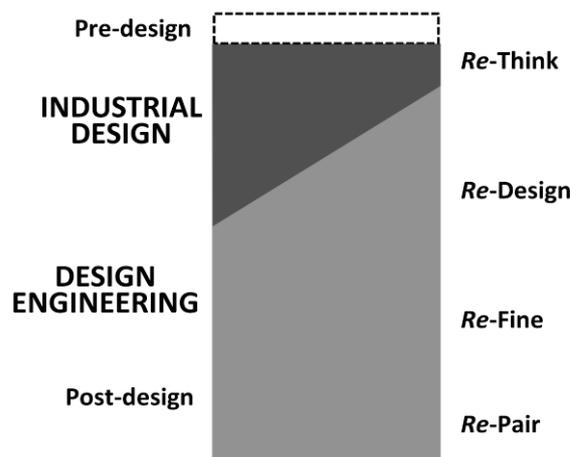
Primary Design	Innovation driven – concept based, looking towards the future
Core Design	Present day projects – continuation of families of products
Continuous Improvement	Improving parts of existing products

Table 8: Design activities (Sherwin & Evans, 2000, p. 114)

According to their research, industrial designers are currently utilized in industry within core design and continuous improvement for 90% of their time, yet their strengths lie in creative thinking and *radical new concepts*. Sherwin and Evans

therefore suggest “early stage ecodesign is very much dependent of the type of design project and PDP undertaken and the type of ecodesign considerations in question” (Sherwin & Evans, 2000, p. 116).

In their model shown below (*Figure 23*), they suggest that industrial design is best utilized at the primary or conceptual design phase, to achieve the radical levels of innovation for Factors 4 – 20, with entirely new concepts of PSS. Where the PDP is already more advanced, where *eco-efficiency*, materials selection, fixtures and technical solutions are required, this is an area for design engineering. They point to the dominance of the latter ‘technocentric’ view towards SPD. Their viewpoint is that this will have to change: the full potential of industrial designers will be required within Strategic Design to achieve the more radical levels of innovation at the conceptual design phase, as indicated (Sherwin & Evans, 2000, pp. 116-117).



*Figure 23: Model of integrating Ind. Design and Design Engineering
(redrawn from: Sherwin & Evans, 2000, p. 116)*

Based on personal experience and observations (Sherwin, 2004), the above themes were confirmed. Sherwin wrote of the potential of “design as a stimulus for strategic sustainable innovation” (Sherwin, 2004, p. 26), to achieve “designed sustainability”, written as part of the Forum Challenge for Forum for the Future (<http://www.forumforthefuture.org>).

Using industrial experience (Electrolux, Philips), Sherwin reported on the separation between industrial designers and engineers, and that designers were largely absent from large, commercial projects, where design input came mostly from engineers, with a technical background.

This situation contributed to mostly technical solutions, which sought to achieve *incremental* improvements, and supported by the life cycle approach *towards eco-efficiency first*. As reported by the author, the focus of the life cycle approach on the 'technicalities' of design was previously documented (Sherwin, 2001; Sherwin & Bhamra, 1st - 3rd February 1999). Sherwin warned of seeing the life cycle approach, and life cycle derivative methods, as being the one and only measure of best practice: yet from his experience, this is predominantly the case within industry.

He claimed that "In contrast, practice in sustainable design – going 'beyond eco-design' and being more innovative in nature – is rather scarcer" (Sherwin, 2004, p. 23). Sherwin reported that such projects are usually experimental and that very little actually reaches the market, citing examples: (E. Dewberry & Sherwin, 2003; Manzini & Jegou, 2003; Walker, 1998).

Sherwin emphasized that SPD, or 'designed sustainability', is *people-centred with a socio-cultural focus* (as in *Concept 1: Emphasis on the Social Element of SD/SPD*) that calls for a strategic role of design. Such Strategic Design is better equipped to attain levels of *radical innovation* rather than *incremental improvements*. The latter is due to the 'business as usual' modes of operating within industry, and therefore "unsurprising that few designers are involved in the little sustainable design that may take place" (Sherwin, 2004, p. 29).

Humphries-Smith cited Manzini and Jegou (Manzini & Jegou, 2003), who investigated social behaviour and made the socio-centric elements of everyday living strategies the main focus, using systems thinking, away from an initial technology and product focus. "Therefore, there is a clear link with these notions regarding the socio-centric

dimension and the definition of sustainable design, which requires the fulfilment of peoples' needs but in an eco-efficient way which considers ethical supply chains as well as 'cradle to cradle' considerations" (Humphries-Smith, 2008, p. 264), see also 2.4.2.

Whilst acknowledging that creativity is not exclusive to designers, due to their "inherent skills and training", designers have:

...the potential to conceive of and propose more sustainable solutions that might be attractive and desirable to people as alternatives to current unsustainable lifestyles and behavioural practices. Similarly, the sheer scale and nature of sustainability requires radical, new thinking and solutions. The strategic orientation of designed sustainability (above) suggests designers may have some key skills – such as creative and imaginative minds – to conceive new sustainable solutions (Sherwin, 2004, p. 29).

Sherwin calls for a greater utilization of designers "to further tap into and engage this latent potential" (Sherwin, 2004, p. 29). From the documented literature, it can be concluded that *designers need to proactively step-up their involvement in SPD at the primary, conceptual level, and for the barriers to multidisciplinary to be challenged.*

For this to happen at a professional level, *there is a need for collaboration across disciplines to be promoted at tertiary education level.* Ways to achieve this can be multidisciplinary projects, systems thinking (C2C and PSS) and problem-based learning (PBL), so that each gains knowledge and understanding, and thereby appreciation, of other disciplines, and the strengths that each can offer (Marxt & Hacklin, 2005, p. 419).

2.7 Educational Perspectives

2.7.1 Differences between Design and Engineering Courses in SPD Education

While it is true that many design areas can be arts/humanities based, it is too simplistic to define modern industrial design as being only interested in aesthetics. Rather, one should understand that an industrial designer / product designer is *visually and emotionally aware, with a training and background which is a crossover of fine and applied arts combined with technology, and adopts a more ethnographic approach to design problems* (Morris, Childs, & Hamilton, 2007). This can affect the definition of problems and their resulting solutions.

A review of the major differences in SPD tertiary education between design and engineering courses was made by educators in the UK (Morris et al., 2007). The authors are jointly from the Universities of Brighton and Sussex, which have joined together to become the UK Centre of Excellence in Teaching and Learning in Creativity (CETL in C). They found that *creativity* plays an integral part in contributing to sustainability, notably at the 'innovative' end of the spectrum, where leaps of imagination are required to achieve Brezet's Level 4 of System Innovation, (previously in *Figure 7*). As the Universities of Brighton and Sussex offer courses in both design and engineering, as do many other UK universities, they were in an ideal situation to compare pedagogies of the two disciplines, as given below (*Table 9*):

Pedagogy	Engineering	Design
Subject matter	Itemised, modular	Integrative, holistic
Subject range	Narrow, deep	Broad, shallow
Delivery	Lecture-based	Problem-based
Career	Professional, employed	Vocational, self-employed
Creativity	Problem-solving	Problem-defining
Interface	Technology	Human
Projects	Theoretical	Applied

Table 9: Pedagogic comparators in engineering and design (Morris et al., 2007, p. 138)

The 'analytical and logical route' (Morris et al., 2007, p. 135) of mechanical engineering evolved with a scientific approach. By contrast, the industrial design profession was created to bring artistic and cultural meaning to the proliferation of products with the onset of the Industrial Revolution, as in 2.6. The divergence and separation of the artistic from the scientific has long been recognized: the authors cite the Fielden Report (Fielden, 1963), the Conway Report (Conway, 1969) and the Finniston Report (Finniston, 1980). This has been well documented in the UK. For the Universities of Brighton and Sussex "there appears a polarisation in the courses of staff, students and pedagogy that mirrors the traditional artistic/analytical divide" (Morris et al., 2007, p. 136).

The main differences in pedagogic approaches, as found by Morris et al, 2007, are summarized (*Table 9*). They found that design students received a shallow and broad education, which might include arts and humanities, architecture, as well as scientific elements from mechanical and electrical engineering, business, law, accounting and IT. This whole range of subjects can be taught from the onset, but the level of knowledge is progressively deepened. Morris et al, 2007, found that "sustainable design lends itself particularly to a phased approach as it has its own clearly recognisable phases; green design; eco design; sustainable design" (Morris et al., 2007, p. 136), see 1.2. Students can be taught to approach a design problem from an ever widening level, from the single issue of *green design*, considering all aspects of a product's life cycle (LCM and LCA) of *eco-design*, through to including social considerations of *sustainable design*. This approach has been adopted for design-based degrees in the European Union (Socrates, 2005), cited in (Morris et al., 2007).

This holistic approach is often supported by problem-based learning (PBL) such as design projects, providing a "motivational and deep learning platform" which allow the students to integrate and practice their knowledge at an increasingly deeper level (Morris et al., 2007, p. 137). The authors claim that it can be effective to involve the students first with design knowledge and then to introduce environmental issues. As the design process is circular, it can be concluded that environmental knowledge will

result in a review of the initial problem definition, and should hone problem finding skills.

Student self-reflection as well as group critique sessions are a regular design practice in PBL, where design students are able to gain knowledge from peer review. However, SD/SPD knowledge has to be significantly embedded in student consciousness for critiquing of SPD to happen spontaneously. Group critique offers the opportunity to make students aware of environmental issues if previously not the case (Morris et al., 2007, p. 137).

By nature of the wide array of topics for design students, Morris et al, 2007, conclude that design students will have a greater exposure to:

.. a wider variety of specialists and this facilitates a cross-linking of cultures and perspectives. The conjoining of previously unrelated ideas, thoughts and concepts is well recognised as a feature of creative thinking and this is a major factor in the creative outputs arising from design students (Morris et al., 2007, p. 138).

For engineering students, the teaching approach is more likely to be theoretical, with a science base. Topics are taught with a narrow focus, in a logical, linear and in-depth manner. A final-year project usually offers the main opportunity of practical application, with any further practice reserved for industrial experience after graduation. As reported by the authors, the limitations of this approach have been recognized by the engineering profession, with various moves for improvement. These include consideration of learning spaces and PBL (Molina & al, 2003), team working, multidisciplinary and ICT (information and communications technologies) (Dutson, Todd, Magleby, & Sorenson, 1997; Kulacki & Krueger, 1998), as cited by (Morris et al., 2007, p. 139).

The authors claim that according to a Forum on Creativity ("Forum on Creativity in Engineering Education," 2006), the integration of creativity for engineers is marginal and met with scepticism in many cases. Morris et al, 2007, note that:

As a result, engineers are less likely than designers to be “fashioned” as creative thinkers, outside of being taught basic creativity tools. In comparative studies, postgraduate engineering students and undergraduate design students are set the task of redefining the purpose of a product. The purpose of a product is obviously known so the exercise involves an abandoning of norms and undertaking leaps of imagination. Students must also present their findings to the cohort which magnifies the desire to conform among logical thinkers, rather than to express openly among creative thinkers. Whilst almost all of the design students are usually successful at this exercise, it is rare that the majority of engineering students are successful (Morris, 2001-2004; Morris et al., 2007, p. 139).

Within the context of sustainable design, *creativity is essential for achieving levels of radical innovation*, rather than the lesser levels of green or eco design, see 1.2. Therefore achieving Factors 10 - 20 improvements (E. L. Dewberry & Monteiro de Barros, 2009), see also 1.1, demand that innovative problem solving be the norm, rather than the exception: radical changes are necessary and can be facilitated through creativity. Morris et al, 2007, see this as the strength of design courses where students must redefine problems using creativity, and not analytical thought.

The authors conclude that currently this is an area “where design students excel” whereas “the move to take up creativity has been apparently slow in engineering courses” (Morris et al., 2007, p. 140). However, the authors warn of mutual disdain of the other profession, as global sustainability issues require both professions, which:

makes irrelevant the petty groupings and divides of designers, some of whom by practice, ignorance, snobbery or a lack of ability ignore the power of analysis, and engineers, some of whom by practice, ignorance, snobbery or a lack of ability ignore the principles of form and industrial design (Morris et al., 2007, p. 141).

They conclude optimistically that the creation of the Centre of Excellence in Teaching and Learning (CETL) in Creativity project at the Universities of Brighton and Sussex, in 2005, will promote and support future collaboration and improvement. It is based on design pedagogy, promotes strategic creativity and the improvement of teaching creativity for engineering. This is enabled through a laboratory for using and “playing with” new technologies, amongst other practices (www.sussex.ac.uk).

2.7.2 SD/SPD and Industrial Design Curricula / International

EMUDE – Emerging Demand for Sustainable Solutions

“EMUDE is a programme of activities funded by the European Commission. The aim is to explore the potential of social innovation as a driver for technological and production innovation in view of sustainability” (Jegou, 2008).

This programme involved the following European design schools:

- Academy of Fine Arts, Krakow, Poland;
- ENSCI Les Ateliers, Paris, France;
- Estonian Academy of Fine Arts, Tallinn, Estonia;
- Politecnico di Milan, Italy;
- School of Design, The Glasgow School of Art, Glasgow, Scotland;
- School of Design, University of Applied Science, Cologne, Germany;
- Technische Universitat Eindhoven, Eindhoven, The Netherlands; and
- University of Art and Design, Helsinki, Finland.

The EMUDE programme incorporated design students to investigate social signals towards sustainability, and to promote and reinforce these using *strategic design integrated with PSS*, so that 'social innovation' was achieved. Design students from the above TEOs were supported with a toolkit for their investigations into ways of living, which included photos, interviews and documentation. Over 140 European scenarios were assessed as potential design projects, reviewed by the EMUDE research panel. According to (Figure 24), below, "Society is reoriented" at the end of this cycle, and further iterative cycles are possible. Therefore, initial first steps can be made at the local level, which are 'enabling' solutions in sustainable everyday living (Manzini & Jegou, 2003).

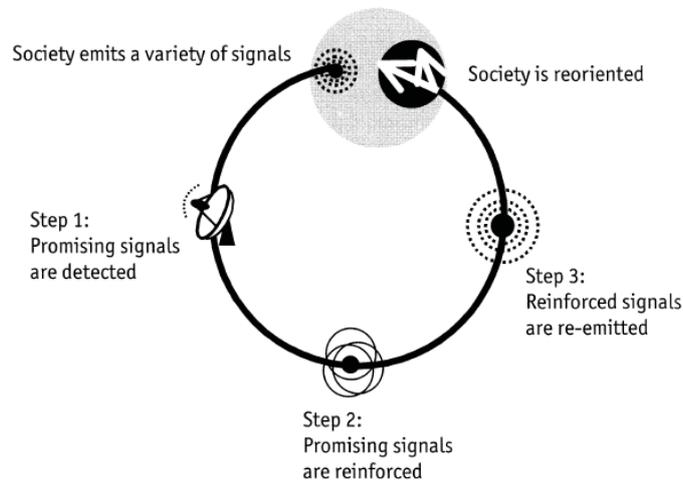


Figure 24: EMUDE research process (Jegou, 2008, p. 180)

Selected projects were grouped into *macro-issues with a wide perspective* (Jegou, 2008, p. 181). One PSS example is that of eStop, a communication device that enables pedestrians to connect with car drivers for carpooling via the internet, so that they fulfil desirable criteria prior to travel (age, gender etc.), and ultimately build a network with shared interests.

These projects facilitated direct user involvement in sustainability, at a local level. Products were integrated into PSS, so that existing or new and/or adapted social structures are *supported* by technology. Direct user involvement also means shared responsibility towards sustainability. This enables empowerment, enthusiasm and a feeling of kinship in a wider community, and reflects the *Inspirational/Spiritual* in the purpose of a product. Individual products become “collective solutions” as PSS in different scales of use. From the above can be concluded that *technology must be integrated and coordinated with strategic design, to promote ‘enabling’ design solutions*. The social component is integral to sustainable ways of living and sustainable PSS, as demonstrated by the EMUDE programme.

2.7.3 Academic Design Research Projects – Case Studies

Other examples of strategic design were developed between academic staff at Cranfield University, UK, and industrial partners (E. Dewberry & Sherwin, 2003).

'Foresighting' into the future is how the projects were developed, using known methods such as brainstorming, backcasting etc, but importantly, concern "design-oriented solutions that respond to the need for sustainable change at a variety of levels: product, process and behavioural" (E. Dewberry & Sherwin, 2003, p. 128). The projects all involved 'stand-alone' products, but were systemic and designed to influence more sustainable *behaviour* of the user(s). Examples given were of a 'Smart Sink' for water management and a 'Data Wall' for communicating use of resources and energy to the user: individual kitchen products become part of systems thinking.

The authors also cite the Living Memory (LiMe) EU-funded research project, 1997 – 2000, between Philips Design, Queen Margaret University College, Edinburgh, Domus Academy, Milan and the Imperial College of Science and Technology, London. Community living is *supported* by products such as a café table, a bus stop, a public information point within a street setting, a workplace desktop and a 'puck' within the foyers of buildings. These artefacts allowed users to digitally input and access public community information, also to create new community information and networks, and requiring participation of the user. They created a *technology/behavioural interface*.

Finally the SusHouse project (Strategies for the Sustainable Household) looks at 'systems innovation', to promote more sustainable ways of living, and investigated shopping, cooking/eating, clothes care management, heating and lighting options in 2050 (www.sushouse.tudelft.nl). It was conducted as an EU research project between Delft University of Technology, Manchester School of Management, University of Hannover, Politecnico di Milano, Avanzi College of Food Industry, Budapest University, Attila Jozsef University, Hungary, College of Agriculture in Hodmezovarhely, Hungary, University of Soporon, Hungary.

The projects focussed on sustainable consumption and lifestyles, away from a product-focus, and *integrated and supported* human factors at a local level. They used systems-thinking and PSS. They combined discipline-based, formal knowledge, with

informal, intuitive knowledge from different stakeholders such as community, and early, strategic design input at the start and throughout the projects. Methods used were brainstorming, workshops, backcasting, feedback analysis, 2D and 3D exploration. They saw a new role for designers within strategic design, and that “future-based design thinking can act as a subtle form of demand creation (in terms of technology, markets or behaviour) for companies and society alike” (E. Dewberry & Sherwin, 2003, p. 136).

2.7.4 DEEDS (Design Education & Sustainability)

The DEEDS project (Design Education and Sustainability), funded by the EU Leonardo programme 2006-2008, recognized that a radical step-change in design practice and education was necessary. It expanded the 3 components of SD to 4: environmental, economic, human/social and societal/institutional (the social element is expanded into 2 levels: those of individual/personal and collective/societal), and formulated a set of design principles (SCALES), which can be used by both design practitioners and educationalists.

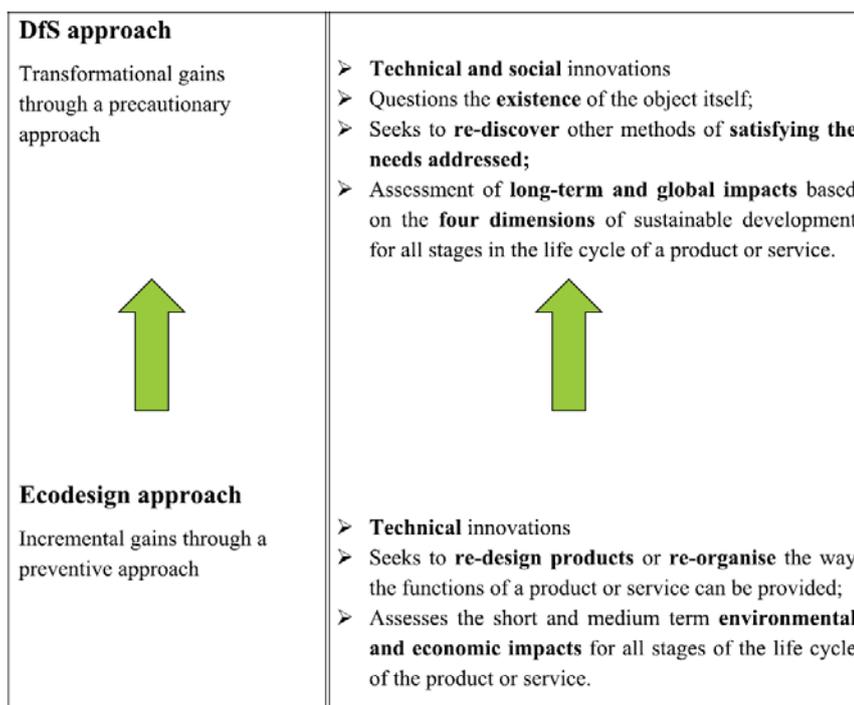


Figure 25: From ecodesign to Design for Sustainability (Spangenberg et al., 2010, p. 1490)

<p><i>Special skills – holistic approach</i></p> <p>S 1 Develop new skills for recognising, framing (looking for systemic connections) and solving problems</p> <p>S 2 Define problems holistically by systems & Life Cycle Thinking (LCT), combined with appropriate technical and social innovation</p> <p>S 3 Analyse problems from multiple perspectives, including the four sustainability dimensions – economic, human/social, societal/institutional and environmental – including the full richness of the human dimensions (mental, physical, emotional and spiritual)</p> <p><i>Special skills – eco-efficient production & resource usage</i></p> <p>S 4 Develop LCT, LCA and ‘cradle to cradle’ skills, be familiar with technology know-how and appropriate application of lightweighting (materials reduction), renewables/new materials, extended product lives, reusability and recyclability (designing ‘quality waste’), waste avoidance, energy issues, and dematerialisation (moving from products to dematerialised services)</p> <p>S 5 Integrate efficient service provision in design solutions, by designing product – service – systems PSS, products suitable for sharing and pooling, pay-per-use or -per-experience</p> <p>S 6 Maximise consumer satisfaction per service enjoyed by addressing human needs; consider different material and immaterial options to do so and choose the most sustainable one; design fertile products offering users experience, emotion, relation, pride, self-esteem and awareness</p> <p><i>Special skills – communication & leadership</i></p> <p>S 7 Lead the agenda – develop leadership skills</p> <p>S 8 Tell engaging stories – develop presentation, narrative and scenario setting skills</p> <p>S 9 Forge new visions of enterprise – understand economic thinking without adopting it (know the language, but don’t have the mindset of business)</p> <p><i>Creating change agents</i></p> <p>C 1 Expand your context – be aware that the sustainability context expands the design context in thinking and practice</p> <p>C 2 Change perceptions – by making use of the diversity of ‘value-added’ outcomes of DfS</p> <p>C 3 Set new aspirations – practice DfS approaches that provide significant, immediate and visible benefits to encourage consumers to aspire to a new, sustainable cultural representation of the “good life”</p> <p><i>Awareness – systemic & context</i></p> <p>A 1 Be aware of context and connections (people, planet, prosperity; key drivers and timeframes)</p> <p>A 2 Be aware of positive and negative impacts, feedback loops and side effects in this context</p> <p>A 3 Be aware of choice and responsibility under these circumstances</p> <p><i>Learning together</i></p> <p>L 1 Seek to work with other disciplines – practice inter- and trans-disciplinary thinking and practice</p> <p>L 2 Be a teacher–learner – practice mutual learning, creativity and team working, understand sharing ideas as a way to stimulate creativity</p> <p>L 3 Participate with your peers – practice teaching and learning through participation, involving an extended peer community of relevant stakeholders</p> <p><i>Ethical responsibilities</i></p> <p>E 1 Develop design that does no harm (responsible design, with integrity), but contributes to a sustainable way of a “good life”, long term and globally, also if applied in mass production</p> <p>E 2 Create genuine consumer empowerment – offer design that enhances personal standing and acceptance, and thus social sustainability and encourages user involvement (consumer empowerment)</p> <p>E 3 Focus on experiences not objects – develop practical, functional and fun design that deepens life experiences and strengthens personal and social cohesion</p> <p><i>Synergy & co-creating</i></p> <p>S 1 Activate through participation – promote the development of teams, communities and networks</p> <p>S 2 Engage in synergistic clusters of competence</p> <p>S 3 Practice collaboration, sharing and partnering, and the involvement of stakeholders in the problem definition and the solution design process.</p>
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Table 10: SCALES core principles (Spangenberg et al., 2010, p. 1492), source (Blincoe et al., 2009)

2.7.5 SD/SPD and Engineering Curricula / International

Overview

An institutional obstacle of incorporating SD into engineering education is cited as “a reluctance to tamper with teaching programmes” (Szymkowiak, 2003, p. 183). According to the author, the definition of SD as being solely of an environmental nature is detrimental, as it excludes the social aspect.

International efforts towards SD in engineering education included US, Latvia, the University of Eindhoven and the Delft University of Technology, The Netherlands, Brazil, Finland and Brunel University, UK. Lucena and Schneider point out “Several of these programs were all the more cutting-edge because they included STS-related themes such as social aspects of risk (at Delft) and ethical dimensions of sustainability (at Brunel) before it was considered fashionable to do so” (Lucena & Schneider, 2008, p. 252). STS is the academic field of science, technology and society – it was part of new curricula proposed in engineering which also included ethics and economics.

Other effects have been various humanitarian agencies involving engineers. According to the authors, all of these programmes have historically omitted to include the local, indigenous communities in their efforts towards SD, preferring to imprint a Westernized version of modernity without sufficient inclusion and consultation of local practices. This resulted in development agencies such as Participatory Action Research (PAR) and Participatory Learning and Action (PLA) to rectify this.

In this article (Lucena & Schneider, 2008), a major criticism is that the participation of engineering students in such humanitarian projects serve mostly the students themselves and their curricula needs, rather than the people they intend to help. Another criticism is that of the problem-solving skills of engineering students, who learn Engineering Problem Solving (EPS) within their curricula (Downey & Lucena, 2006), cited in (Lucena & Schneider, 2008, p. 254). The authors conclude:

As SD projects in engineering education evolve into SCD projects, faculty and students should incorporate communities' histories, voices, concerns, conflicts, knowledges and desires by learning how to listen and recognise value in the perspectives of others, including non-experts. This may require rethinking the preparation students receive to participate in such projects, to include courses in development studies, fieldwork methods, regional history, or others (Lucena & Schneider, 2008).

Schneider et al, 2008, (Schneider, Leydens, & Lucena, 2008) report that this is also documented in the Barcelona Declaration of 2004, requiring engineers to "Listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures" (Schneider et al., 2008, p. 310). Various efforts have been made to incorporate this, such as engineering projects in Belgium and Ecuador that were transformed by the input of social scientists (Dewulf, Craps, Bouwen, Abril, & Zhingri, 2005). According to Schneider et al, 2008, organizations committed themselves to integrate SD into educational programmes. The authors cite a 2005 report from the 'Visiting Professors' Scheme', which listed two of the guiding principles as to "seek engagement from all stakeholders' and to "make sure you know the needs and wants" (Dodds & Venables, 2005), cited in (Schneider et al., 2008).

SD/SPD and Engineering Curricula / International / Community

The authors comment that the integration of community is not clear from the above report. They also comment on the findings of a global survey of engineering students (Azapagic et al., 2005), which highlighted that student knowledge re stakeholder participation is greatly lacking. The survey uncovered that "overall, the level of knowledge and understanding of environmental and sustainability issues by engineering students is not satisfactory and that relatively large knowledge gaps exist" (Azapagic et al., 2005, p. 13), and detailed in 2.7.7.

A number of recommendations were offered (Schneider et al., 2008, pp. 313-314) for the inclusion of community, based on their experiences in teaching 'Humanitarian Engineering Ethics' (HEE) within engineering or applied science at the Colorado

School of Mines. Here, a special interest can be combined with minors 'Humanitarian Engineering' and 'Humanitarian Studies and Technology', with courses in ethics, economics and area studies.

One course, 'Engineering and Sustainable Community Development' (ESCD) is combined for both senior undergraduate and graduate students, with the goal "to fill what we see as a significant gap in SD engineering education: an awareness of the strengths and limitations of engineering education to engage community perspectives" (Schneider et al., 2008, p. 313). They emphasize the following:

- Technology Transfer vs. Technology Porting – a technology cannot be simply transferred in an identical version to another location, but should include socio-economic and political factors;
- *Community Deficiencies v. Capacities* – it is better to focus on the positives, the capacities, strengths and available situational context (materials etc.) rather than on what is missing;
- *Single v. Multisector Approaches* - an holistic approach is beneficial to take advantage of the interrelatedness of community offerings;
- *Community Charity v. Ownership* – with ownership and involvement comes community buy-in, enthusiasm, pride and success; and
- *Planners v. Searchers* – a top-down, planning role of engineering can be detrimental, and it is better to involve the community in searching for solutions.

The authors recommend that *engineering education be opened up to include non-technical subjects from the social sciences and humanities, and to have meaningful interaction with community within mid- to long-term projects* (Schneider et al., 2008, p. 314).

SD/SPD Engineering Curricula / International / DUT

Interdisciplinary problem-based learning (PBL) is increasingly seen as a way to integrate SD into engineering education, "as environmental problems are intimately connected to social and political issues. Major problems are often of a hybrid character; they cannot be solved by a single discipline" (K. Mulder, 2004). This is to counteract the effects of traditional, rational, technology-based engineering education, which has up to now resulted in technology-driven concepts.

A 3-tier approach for SD was agreed for Delft University of Technology (DUT):

3-Tier SD Framework at DUT			
1	Elementary course	<u>all students of DUT</u>	'Technology in sustainable development'
	40 study hours	general / theoretical	most relevant concepts, models and practical exercises
	40 study hours	department specific component Objectives:	connecting SD to the specific discipline <ul style="list-style-type: none"> • to develop consciousness among students of SD challenges • to develop students' understanding of the role technology plays within society, specifically in the process of SD • to develop knowledge of most relevant concepts, models and tools regarding SD and basic skills for application in professional life
2	Integration of SD	<u>all regular disciplinary courses</u>	- in a way appropriate to the nature of each specific course - pilot projects to gain experience and document best practices
3	Graduation: SD specialization SD specialization appendix next to graduation degree SD graduation project	<u>within faculty / dept. framework</u> 2-week colloquium comprising: 1 week <u>Highly successful</u> - tangible examples - direct appreciation 1 week 8 weeks 23-42 weeks	- to enable 'specialists to support line management' - on technological innovation through SD - intensive course, sailing on a boat whilst receiving intensive tuition and visiting appropriate SD sites - tuition of STD principles (Sustainable Technological Development), potentially offering graduate projects for consideration (Weaver et al, 2000), cited in (K. F. Mulder, 2006, p. 141) SD courses with topics chosen from <i>Table 12</i> advice from faculty specialists on SD content

Table 11: 3-tier SD framework at DUT, (K. Mulder, 2004, p. 281; K. F. Mulder, 2006, pp. 138,141)

Design analysis and tools, <i>in general</i>	Life cycle assessment, recycling, sustainable energy
Design analysis and tools, <i>specialised</i>	Environment and chemistry, photo-voltaic energy, eco-toxicology, sustainable building
Management	Environmental management, environmental law, chain management, risk analysis
Policy and society	Technology assessment, sustainability in global perspective, environmental philosophy, environmental economy

Table 12: Clusters of various topics on SD courses (K. F. Mulder, 2006, p. 141)

DUT transformed itself from an institution of 'hard core technologists' in the 1970s (K. Mulder, 2004, p. 278), with environmental issues introduced across faculties (see Table 11, Table 12). With a 5-year engineering curricula, priority was given to the introduction of ethics courses, (see Table 14). For SD, the author states *the colloquium as being very well received by students: one week on the boat provides an intense learning situation with tangible SD examples and direct appreciation of SD issues*. It can be concluded, that this is an excellent way to inspire and motivate students, to positively influence their values towards SD/SPD. This is also confirmed by the alumni SD student organization that was established by the students themselves for communication between SD graduates, see (www.osiris.tudelft.nl).

Hence, the above illustrates how learning about SD issues can be *made enjoyable*, which generates enthusiasm, motivation and inspiration for the topic content. Such a learning environment can be a positive experience for both students and academic teaching staff. It can be concluded that *elements of fun* should be integrated into SD curricula, which will help engender the values and qualities necessary for future sustainable entrepreneurs, by providing deep learning in an enjoyable way.

SD/SPD Engineering Curricula / International / Context via Ethics

The importance of societal context is clear for integrating SD/SPD issues into tertiary education for industrial design and engineering, as part of the social component of SD. Ethics and societal concerns are listed within the engineering graduate profiles of both the International Engineering Alliance (IEA) and IPENZ, see 1.4.2. In a recent overview article (Zandvoort, 2008, pp. 133-134), Zandvoort reports on the integration

of ethics into engineering curricula from the viewpoint of Bucciarelli, Conlon, Heikkerö, Didier and Huet, Börsen and Zandvoort et al. The aforementioned participated in a Special Interest Group D6: Ethical Issues in Engineering, (www.unifi.it/tree/index.php?1=d&s=6, www.eiee.tudelft.nl), accessed on 09.07.10.

	Ethical Viewpoint / Criticism	Suggestions
Bucciarelli Conlon	<ul style="list-style-type: none"> - critical of teaching ethics to engineers as individuals, as professional work is collective, i.e. within an organization - insufficient attention paid to social element - same views as Bucciarelli 	<ul style="list-style-type: none"> - called for "substantial reform of undergraduate engineering education ... enabling a more expansive and critical study of engineering, including its social and political dimensions" (Zandvoort, 2008, p. 135) - support from sociology - employability + social responsibility, undue focus on the former would negate capabilities in the latter.
Heikkerö	<ul style="list-style-type: none"> - deemed an engineer's motivational attitude to be of ultimate importance - virtue ethics, which focuses on personal virtuous character traits, still uncomfortable for eng. educators - what are appropriate, virtuous attitudes for engineers, and how can they best be taught? 	<ul style="list-style-type: none"> - should be directed by consensus of all stakeholders in engineering education - advocates using existing processes (research, design, learning, negotiating and decision making) to be used as a teaching platform, to highlight positive and negative attitudes within these processes.
Didier and Huet (Didier & Huet, 2008)	French survey on Corporate Social Responsibility (CSR) in engineering education- interviewed deans of engineering schools + faculty members	<ul style="list-style-type: none"> - conclude greater clarification of CSR and implication for engineering education necessary.

Table 13: Overview of ethical viewpoints (Zandvoort, 2008)

According to the overview paper of Zandvoort (Zandvoort, 2008), Börsen reported on the 7.5 ects course 'Philosophy of Science and Ethics' taught at the University of Copenhagen since 2005, (for biochemistry, chemistry and nanotechnology students, but can equally be adopted for engineering students). Ects = European Credit Transfer Accumulation system, where 60 credits equal the workload of a full-time student for the whole year. The course prepares students for post-normal research, defined as:

"scientific work that is embedded in a societal context characterised by uncertainty and conflicting values-systems" (Zandvoort, 2008, p. 137). According to Zandvoort, Börsen concedes that one of the goals to "synthesise/accept a compromise among the different views involved" is not met in the course (Zandvoort, 2008, p. 137). Zandvoort observed the difficulty of an individual researcher being able to resolve collective issues.

A final review is given by Zandvoort of joint venture teaching of a 6 ects compulsory course for engineering students, titled 'Ethics and Engineering' and taught at Delft University of Technology (DUT). More details will be provided below of this successful example of teaching ethics, as Zandvoort concludes that "The goals and contents of this course appear to be very much in agreement with the plea of Bucciarelli and Conlon for a broad approach in engineering education that includes consideration and critical analysis of 'context'" (Zandvoort, 2008, p. 138).

Zandvoort (Zandvoort, 2008, pp. 138-139), lists the following issues:

- a 'macro-ethical' scope of social, organizational, legal and political issues should provide the context to engineering solutions, i.e. collective societal issues at a systems level rather than personal ethics at an individual level: "What is needed, says Bucciarelli, is not just a more expansive reading of the codes of ethics re what it might mean to be responsible, but a substantial reform of undergraduate engineering education across the board, enabling a more expansive and critical study of engineering, including its social and political dimensions, than is currently the case." Bucciarelli, supported by Conlon, cited in (Zandvoort, 2008, p. 135).
- service-learning and/or global service-learning, whilst providing a way to measure student learning and fulfil accreditation criteria, does not necessarily provide insight into the source of a problem e.g. the cause of poverty etc., Shuman et al (Schuman, Besterfeld-Sacre, & McGourty, 2005), cited in (Zandvoort, 2008, pp. 138-139)
- teaching principles of ethics on an individual basis, i.e. personal professional integrity, does not address how engineers work collectively within their profession. This allows macro, collective issues of social responsibility to be largely ignored within the teaching of research ethics (Pimple, 2002) et al, cited in (Zandvoort, 2008, p. 139).

In conclusion, the above viewpoints emphasize the importance of systems thinking and problem definition to address macro-ethical, societal issues. Consequently, *decision making needs to be able to achieve a compromise between different stakeholders*. As above, an applied example of teaching ethics is given at DUT (Zandvoort, Van Hasselt, & Bonnet, 2008) - compulsory ethics courses in the end part of curricula for the applied sciences and engineering. A *very successful course* is a Joint Venture teaching model (JV), and a component of the MSc programmes of (Bio)chemical Engineering, Life Science and Technology (LST) and Applied Physics, under the Faculty of Applied Sciences, with LST shared with Leyden University. It is run twice a year with more than 150 students annually, with good student ratings.

In an appraisal of the MSc Joint Venture teaching model (JV) in ethics and engineering (Zandvoort et al., 2008), a significant point of departure is the widening of the ethical context to enable *collective* decision-making. This is in contrast to an individual ethical focus that can still be a part of ABET criteria (Accreditation Board for Engineering and Technology – US), (Zandvoort et al., 2008, p. 189). Course topics reflect this:

- The responsibility of individuals within hierarchical organizations;
- The responsibility of business organizations;
- The actual and possible role of the legal system in channelling the development and use of technology; and
- The actual and possible procedures for collective decision-making regarding technology.

The course runs twice a year, and is composed of two stages.

- **Stage 1** comprises 5 weeks of 9 lectures (1-2 hours), and 9 tutorials (2 hours), with groups of 15-20 students and an exam written in week 7; and
- **Stage 2** comprises 8 weeks, an essay, jointly written by teams of 5 students, and presented orally to teaching staff and a student audience.

Ethics Framework at DUT			
BSc	1 st year course		'Technology, Society and Sustainability'
	2 nd year course		'Sustainable/socially responsible design of manufacturing processes'
	3 rd year course		'Sustainable entrepreneurship' (Bonnet, Quist, Hoogwater, Spaans, & Wehrmann, 2006)
MSc	<p><i>MSc Joint Venture teaching model (JV) in Ethics</i></p> <p><i>Highly successful</i></p>	<p>Goals:</p> <p>Learning Objectives:</p>	<p>"- to teach engineering students (how) to recognise and analyse the ethical aspects and problems of their future professional practice and (how) to conduct a solution-oriented debate about such problems</p> <p>- to enhance the students' insight into the complex processes of collective decision-making that scientists, technologists and engineers may become involved in, and to increase their insight into the ethical aspects that may be interwoven into these processes" (Zandvoort et al., 2008, p. 189)</p> <p>"- the recognising and analysing of the ethical aspects and problems related to technology and the professional practices of engineers</p> <p>- providing insight into the relevant backgrounds relating to those ethical aspects and problems</p> <p>- imparting the knowledge and skills required to enable one to reason on these issues in a consistent and reliable manner and to enter into solution-oriented debate with others on these same issues</p> <p>In this way the reader aims to:</p> <p>- contribute to preparing scientists, technologists and engineers to practice their professions in an ethically responsible manner" (Zandvoort et al., 2008, p. 189)</p>

Table 14: Ethics framework at DUT, including the MSc Joint Venture teaching model (JV)
(Zandvoort et al., 2008)

'The BP Texas city oil refinery isomerisation unit explosion on March 23, 2005: Responsibility within organisations.'
 'The Case of Lapindo Mudflow – Sidoarjo'
 'Marketing drugs to the developing World. An ethical and practical exploration of global responsibilities'
 'AIDS in South Africa. An ethical reflection on the patent system for AIDS inhibitors.'
 'Bio-ethanol in Brazil'
 'The European Common Agricultural Policy, African agriculture & biotechnology: an ethical review.'
 'The need of legislation in the development of human-animal chimeras'
 'Embryonic stem cells. Should it still be in ethical debate?'
 'Should it be allowed for a country to transport its waste to another country?'
 'With power comes responsibility. Was Greenpeace responsible and liable for the aftermath of the Brent Spar case?'
 'What are the social implications of autonomous life enhancement?'

Table 15: Essay topics of the MSc Joint Venture teaching model (JV) (Zandvoort et al., 2008)

The teaching team comprises 4-6 teaching staff from *Philosophy* and *Applied Sciences*, with PhD students from both faculties, and the inclusion of an overseas guest professor was attained for 2007-2008. The teaching material comprises a theory reader, referred to in the lectures, and a workbook with practical case studies and work assignments. The tutorials assist with the practical application of the learnt theory to the workbook examples. The workbook and the majority of the reader material were written by the Department of Philosophy. The Stage 1 exam consists of yes/no questions, closed book, and the rest being open questions, open book.

Collaboration and equal teaching input is achieved through this course for the two faculties, making the importance of ethics visible to students, and staff became acquainted with each other's discipline. A drawback is that the course is dependent on the availability of appropriate staff, and therefore requires a sustained level of interfaculty commitment for its success.

The team nature of the essay writing proved to be very rewarding from the student appraisals, and gave them much insight and deep learning of their chosen topics. An important feature to note of the essay writing is that topics deal with *macro issues giving a wide perspective* of the context into which products and PSS must fit.

Potential improvements for the course were defined as stronger input from an industrial viewpoint and an extension of cultural values other than the dominant

Western model. Finally, one of the authors believed one course could not deliver all the social knowledge necessary for engineers (Zandvoort et al., 2008).

2.7.6 SD/SPD in Curricula / Interdisciplinary

Overview

There have already been a number of interdisciplinary projects within tertiary education. Students are able to experience viewpoints from other disciplines, which can not only positively affect their attitudes and values by exposure to diverse perspectives, but also their approach to problem definition. A clarification is first given of the terms multidisciplinary, interdisciplinarity and transdisciplinarity (Uiterkamp & Vlek, 2007, p. 176).

"*Multidisciplinary* means that a particular (policy) problem or an (other) observable phenomenon is considered from different disciplinary viewpoints....." *(different viewpoints)*

"an *interdisciplinary* endeavour, in which relevant parts (concepts, models, methods, findings) of different scientific disciplines are merged together and neatly integrated" *(merged result)*

"In contrast to multi- and interdisciplinarity, *transdisciplinarity* signifies the crossing of boundaries between scientific and non-scientific communities." *(across boundaries)*

The authors state "Sustainability is a multidimensional concept involving economic security, social well-being, and environmental quality" (Uiterkamp & Vlek, 2007, p. 177). Yet they concede that practicing multidisciplinary is "challenging" and that "Researchers from different backgrounds have to find each other and get acquainted. They must learn to understand and appreciate each other's perspectives. They must derive a common motivation from the idea that the whole may become more than the sum of its parts" (Uiterkamp & Vlek, 2007, p. 177).

SD/SPD Curricula / Interdisciplinary

Uiterkamp and Vlek, 2007, provide practical examples of interdisciplinary curricula at the University of Groningen, The Netherlands. This resulted from inter-departmental collaboration between environmental science, psychology, economics and sociology, with joint research projects. One of these projects is presented in brief - see (Uiterkamp & Vlek, 2007): *Scenario Analysis for Low Energy Consumption and Low CO₂ Emissions - SCAN – SCenarioANalysis*, (see Table 16).

Important to note is that *various scales of use* are discussed towards improving low-energy/low CO₂ scenarios for the Netherlands. This uses *systems thinking*, from large-scale to small, namely Greenhouse Horticulture, Industry, Freight Transport and Households. The project asked the following research questions:

1. *What would be subjects' expected quality of life within several domain-oriented variants of long-term low-energy/low CO₂ scenario?*
2. *What is the social acceptability of the proposed scenario variants?*
3. *What is the feasibility of the different elements of the scenario variants?*

Greenhouse Horticulture	Industry	Freight Transport	Households
- Introduction of a 100% energy tax in the European Union, compensated by lower taxes on labor			
- Voluntary agreements on energy-saving measures, information, and subsidies			
<ul style="list-style-type: none"> - Application of co-generation of heat and energy - Introduction of Environmental Management Plans for Business Companies - Improved access to the energy market, e.g., for decentrally generated electricity - Regulation of energy-savings via environmental permits 		<ul style="list-style-type: none"> - Various technical measures regarding fuels, engine design, vehicle mass reduction, rolling and drag resistance - Infrastructure favoring transport by rail and water - Allowance of larger transport quantities and return-loads 	<ul style="list-style-type: none"> - Energy standards for new and renovated houses - Restrictions on car parking - Road pricing - Non-motorised infrastructure - Car-pooling - Stimulating public transport - Introducing company transport management
<ul style="list-style-type: none"> - Setting quota on natural gas consumption 	<ul style="list-style-type: none"> - Realizing production energy cascades 		<ul style="list-style-type: none"> - Limiting maximum speed via car speed limiters - Raising fuel excise tax

Table 16: *Scenarios for general and specific energy-saving measures (Uiterkamp & Vlek, 2007, p. 182)*

The authors reported an “improvement of the quality and realism of such scenarios”, further that “The results of natural science-based climate modelling and scenario building were subjected to social science-based evaluation and assessment procedures” (Uiterkamp & Vlek, 2007, p. 190).

DUT provided an example of an interdisciplinary SD project in 1999, where teams of 4-6 students collaborated from different TEOs (see *Table 17*). The project was based on water used for drinking, industry, agriculture and river water management. After a 2-week introductory phase on board a boat on the IJssel River (*elements of fun*), students worked for another 12 weeks within their own individual TEO, with a virtual platform for communication. The learning environment on the boat was ‘very helpful’ and aided bonding amongst the students; separation after this time was rather more difficult and time consuming to arrange travel to weekly meetings (K. F. Mulder, 2006, p. 141).

DUT	Civil Engineering
Fontys University Eindhoven (polytechnic)	Mechanical Engineering, Micro Biology and Chemistry
University of Amsterdam	Philosophy, Social Geography, Political Science and Physics
Van Hall Institute Leeuwarden (polytechnic)	Environmental studies

Table 17: The TEOs of the interdisciplinary IJssel project (K. F. Mulder, 2006, p. 140)

Backcasting (see *Table 18*) was used to describe a future vision of a sustainable lifestyle: the necessary creative steps are then planned to achieve this goal. Communication between the students became easier, with the use of non-technical jargon and a growing awareness of their contribution from their own individual discipline. SD/SPD will require diverse perspectives (multidisciplinarity) for problem definition, as they are largely ‘wicked problems, and (interdisciplinary) design projects are necessary to enable collective problem-definition and problem-solving.

A simple calculation has shown that fulfilling the material needs of present and future generations on the basis of equity requires a jump in the environmental efficiency of technology by a *factor of between 10 and 50, say 20*, over the next years (Weterings and Opschoor 1992). These jumps in environmental efficiency of technology cannot be brought about by technical innovations alone. The social conditions for these leap-frog technologies still have to be determined but will invariably involve significant *structural and cultural change* (De Meere and Berting 1994, Schwarz 1997).

The Interdepartmental Research Programme Sustainable Technological Development was undertaken in the Netherlands to explore and illustrate, together with policy-makers in government and industry, how technological development could be shaped, by back casting from visions of sustainable futures and to develop instruments for this. The programme was established by five ministries and took place between 1993 and 1997 (Programme STD 1997).

Table 18: Programme on backcasting in the Netherlands (K. F. Mulder, 2006, p. 141)

A successful way of doing this was established at Delft University of Technology (DUT) from 1996, where sustainable entrepreneurship is taught in the 3rd year of undergraduate study in Chemical Engineering and Materials Sciences Engineering. Subject matter is taught early in the year as a 6 ects course equal to 160 hours of study, with one day a week allocated from September to December. This integrated business, entrepreneurship and sustainability, involving writing a *business plan*, and a clear focus on entrepreneurship. Ideas and a plan of action are set by the entrepreneur (student), who must find ways of integrating sustainability into the business plan. This will engage a wide range of topics, requiring teamwork and presentation skills, and "should include economics, organisational aspects, product design, production and strategy" (Bonnet et al., 2006, p. 158). It involved contributions of lecturers from engineering, social sciences, management sciences, sustainability studies and communication. The *business plan* was written in groups of five students, and had to integrate the following sustainable elements:

- *Sustainable mission and strategy;*
- *Stakeholder involvement;*
- *Sustainable product idea and marketing;*
- *Sustainable production and innovation;*
- *Sustainable organization and management; and*
- *Financial accounting, reporting and sustainability.*

The business plans are evaluated by at least two academic staff from different disciplines (e.g. engineering and management) using the following criteria: originality of the business idea, sustainability, context analysis, marketing plan, production and management plan and financial evaluation (Bonnet et al., 2006, p. 162). The course aimed to instil aspirations of entrepreneurship within a technology and business context, adhering to social responsibilities and market restraints, whilst learning oral and written presentation skills, see (www.odo.tudelft.nl).

2.7.7 Prior SD/SPD Frameworks/Surveys in Design & Engineering Curricula

Prior SD/SPD Frameworks

A review of the literature revealed that *individual* SD/SPD courses are taught at both undergraduate and postgraduate level in industrial design and engineering. Supporting principles and individual examples have been listed within this chapter: C2C, PSS, biomimicry, academic design research projects (EMUDE, DEEDS, LiMe and SusHouse), as well as interdisciplinary courses at DUT (SD and ethics frameworks, including MSc Joint Venture teaching model (JV) in Ethics), and at the University of Groningen. See also (www.delft.nl, www.twente.nl, www.erauni.nl, www.sussex.ac.uk).

However, a *comprehensive and detailed* framework that integrates the best progression of sustainability issues at all levels (years 1-4), and for both disciplines, is lacking. This emphasizes the need for such an educational framework, and the aim of this research. This research has therefore targeted SD/SPD for mainstream undergraduate tertiary education in industrial design and engineering.

Prior SD/SPD Surveys

Sustainability within curricula has increasingly been investigated, cited by Ramirez (Ramirez, 2006) for the following disciplines: architecture (Fowles et al., 2003), engineering (Nguyen & Pudlowski, 1997), interior design, (Elliott, 2004; Metropolis, 2003), and mixed design disciplines (Metropolis, 2002). These surveys and studies have generally shown “that sustainability issues are hardly penetrating into core

design programs" (Ramirez, 2006). *Ramirez's 2006 survey of industrial design academic staff in Australia* concluded: "...aspects of environmentally sensitive design are currently being incorporated in most Australian industrial design degree programs, albeit to a minor extent. The higher challenge is to go beyond "ecodesign" into the greater sphere of "sustainable design", of which eco design is a subset, as suggested by Tischner et al (2000)" (Ramirez, 2006, p. 199). Ramirez's adaptation of the original (Figure 2), is shown below (Figure 26).



Figure 26: Adapted from Charter, Tischner et al, 2000, see Figure 2 (Ramirez, 2006, p. 199)

Ramirez's 2007 worldwide online survey of industrial design academic staff was conducted the following year (Ramirez, 2007). Both investigations were directed at *academic staff* in industrial design, not students.

Key outcomes (Ramirez, 2007):

- "Most participants seemed to interpret sustainable design as being identical with ecological design or green design, which focuses mostly on minimization of environmental impacts and usually not covering the aspects of promoting an equitable society" (Ramirez, 2007, p. 3);
- The majority of topics were about the inter-connected subjects of design for disassembly, using recyclable and recycled materials that have less impact on the environment;
- Less coverage was taught on LCA, product durability and using water, energy and fuel efficiently;
- Less than half of the participants taught topics covering dematerialization, PSS (Product-service systems), cleaner manufacturing and distribution efficiency; and
- Whilst SD/SPD issues are covered as topics, only half the participants included sustainability issues within *assessment criteria*: therefore sustainable design remained unrewarded.

Ramirez concluded that there has been a positive development, with sustainability issues *gradually* being integrated into Industrial Design education either as compulsory or elective courses (Ramirez, 2007, pp. 3-5). A more recent survey conducted in 2008 concluded: "As Ramirez in both studies has only sought the views of academics it is impossible to triangulate the data and ascertain a rich picture of what learning is actually taking place and what learning needs to take place for a graduate designer entering the design profession" (Humphries-Smith, 2008, p. 266).

An international survey of engineering students (Azapagic et al., 2005), was conducted from October 2000 to June 2002, covering 21 universities worldwide, with 3134 students from the areas of general, chemical, mechanical, civil and environmental engineering, and also engineering design and manufacture. The universities that responded were from Australia, Brazil, France, Germany, Italy, Sweden, Thailand, USA, UK and Vietnam. The survey uncovered that "overall, the level of knowledge and understanding of environmental and sustainability issues by engineering students is not satisfactory and that relatively large knowledge gaps exist" (Azapagic et al., 2005, p. 13). These knowledge gaps were identified as:

Environmental Issues

- *biodiversity loss;*
- *salinity; and*
- *photochemical smog.*

Environmental Tools, Technologies and Approaches

- *industrial ecology;*
- *product stewardship; and*
- *tradable permits.*

Environmental Legislation, Policy and Standards

- *the largest knowledge gap overall.*

Sustainable Development

- *components of Sustainable Development (economy, environment and society);*

- *approaches to Sustainable Development;*
- *precautionary principle;*
- *inter-and-intra-generational equity; and*
- *stakeholder's participation (Azapagic et al., 2005, p. 13).*

Surveys of sustainable design in the curricula have targeted *either* design (Ramirez, 2006, 2007) *or* engineering (Nguyen & Pudlowski, 1997), (Azapagic et al., 2005). An *initial pilot study was undertaken for both disciplines* (Humphries-Smith, 2008). It investigated general understanding of 'sustainable design', the extent of integration in the design curriculum in the UK and whether to incorporate sustainable design for the whole curriculum or to educate sustainable specialists. Firstly, undergraduate design and engineering course content of UK TEOs was investigated. Secondly, survey questions were posed to UK academics in design and engineering faculties, as well as design and engineering students at Bournemouth University and companies from the Bournemouth area employing graduates from their courses (Humphries-Smith, 2008). The following questions were modified for each respective target sector:

1. To what extent are your design/engineering students aware of sustainable design issues?
2. To what extent do your design/engineering students apply sustainable design tools/techniques?
3. To what extent do you think all designers/engineers should be aware of sustainable issues?
4. To what extent do you think all designers/engineers should be able to apply sustainable design techniques?
5. Would you consider providing a course that produces a graduate who is a specialist sustainable designer? Please give reasons for your answer.
6. What do you consider sustainable design to be?

This last question was similarly posed in the final year New Zealand student survey of the present research, to determine students' understanding of sustainable design.

Key findings (Humphries-Smith, 2008):

- Academics considered sustainable issues to be adequately covered with various course content, providing knowledge of tools and techniques, concurring with the findings from Ramirez;
- Curricula examination showed that concentration was still on the techno and eco-centric ecodesign, using tools such as LCA, mostly excluding the social dimension which is the 3rd element of sustainable design;
- Students and employers considered they had insufficient knowledge of tools and techniques;
- Overall consensus in the importance of acquiring such knowledge;
- All participants had various definitions of sustainable design, but that most referred to ecodesign rather than including the social element of sustainable design;
- All participants saw sustainable design as important for the future rather than the present; and
- Various employers perceived aesthetics as valuable for sustainable design.

Humphries-Smith accepted the limitations of this initial study, but saw it as a means “to gain rich data that could be triangulated to obtain a fuller picture of the state of sustainable design education in the UK, both in terms of extent and need” (Humphries-Smith, 2008, p. 268).

Following on from surveys and/or studies conducted by Ramirez (Ramirez, 2006, 2007), Nguyen & Pudlowski (Nguyen & Pudlowski, 1997), Azapagic (Azapagic et al., 2005) and Humphries-Smith (Humphries-Smith, 2008), further research was necessary. Ramirez researched only design academic staff in Australia (Ramirez, 2006) and then worldwide (Ramirez, 2007), excluding New Zealand. Azapagic researched only engineering students worldwide (Azapagic et al., 2005), also excluding New Zealand. Humphries-Smith executed a limited survey to design *and* engineering academics, students and employers in the UK (Humphries-Smith, 2008), intended as an initial pilot study, and indicated that further research was necessary. Therefore there was a need to ‘triangulate’ previous research with further data and an extended student survey for the disciplines of industrial design and engineering, the location to be New Zealand.

A survey concluded by 2005 (Chapman, Flaws, & Le Heron, 2006), found SD in New Zealand tertiary education, *in general*, to be seriously lacking. It investigated how often 'sustainability' appeared in the titles of undergraduate and postgraduate courses. Only 46 such courses were found (based on University Calendars from 1993 – 2004): Auckland (16), AUT (0), Waikato (5), Massey (9), Victoria (3), Canterbury (5), Lincoln (8) and Otago (0). Another measure was to list the number of theses with sustainability in the title from 1993 – 2004 (excluding research reports, honours or postgraduate diploma dissertations), with meagre results. A further test was an email survey of 12 academics across the universities, actively seeking appropriate personnel responsible for UNDES and/or relevant projects and publicity. The report concluded the results to be 'almost zero', even with FoRST science funding (Chapman et al., 2006, p. 289).

Such results were disappointing and the report concluded that the context of UNDES delivery must be fully understood, as "New Zealand has struggled to embed educational pathways involving environmental or sustainability" (Chapman et al., 2006, p. 290). They saw obstacles to be the *disciplinary boundaries* within the university system and that alignment of initiatives is hard to achieve, with little coordination between schools and universities. Finally, they saw that a realistic *assessment of the existing situation to be crucial for a way forward towards improvement*.

This report was finalized by 2005: therefore it would be interesting to investigate the present status and to provide another perspective, with a focus on industrial design *and* engineering. This thesis therefore not only has importance as a current measure of New Zealand SD/SPD tertiary education for industrial design and engineering, but also *enables valuable comparisons between the New Zealand and international studies*.

Prior Research into Sustainable Design Education at Tertiary Level in NZ

PhD candidate Nicola Bould's research, University of Otago, New Zealand, is still under completion at the time of this writing. Bould's research (Bould, 2009), investigated international and New Zealand TEOs mainly from the design discipline,

whereas this author's research focussed on both design *and* engineering, specifically industrial and product design, mechanical and mechatronics engineering. The present research was conducted both internationally, highlighting successful examples of sustainability in industrial design *and* engineering curricula, and also gained a New Zealand overview through the final year student survey of participating design and engineering TEOs. The New Zealand survey results of this research were then compared to the international survey of engineering students (Azapagic et al., 2005).

Bould, 2009, conducted her preliminary research using 16 international interviews from design, engineering and architecture academic programs from March – July 2007. They were from nine universities, in six countries, "specifically chosen due to their involvement in sustainability and design" (Bould, 2009, p. 4520). From Bould's paper, it is not known whether these were also practising professionals. New Zealand investigations were completed thereafter as the principal research, from February 2008 to March 2009, comprising tertiary course data from TEOs offering industrial or product design, and personal interviews with 15 design staff and 23 second-year design students. Therefore Bould's research was mainly qualitative.

Bould, 2009, depicted findings of New Zealand design TEOs graphically; preliminary results showed international activity to be approx. twice that of New Zealand. Bould further investigated levels of awareness when sustainable design was taught in an integrated way or in separate course(s). Bould, 2009, found that almost 50% of students had a 'high level' of awareness when taught specific course(s) in sustainable design, and a 'medium level' achieved by slightly more than 50% of students when integrated throughout. Students from taught courses were more motivated to link with like-minded associates interested in sustainability: an important factor for linking students with similar sustainability values via a web-based portal e.g. DUT – see 2.7.5, (www.osiris.tudelft.nl). Bould concluded that an integrated approach had the most success; however, specific, taught courses still had their merit; accommodating both approaches. Bould determined, similar to this author, that design problems are 'wicked', requiring new approaches (Bould, 2009, p. 4527).

2.8 Key Conclusions of Literature Review

SPD is people-centred. Therefore socio-cultural knowledge (identifying human need, human/technology interfaces, behaviour and consumption patterns etc.) is *essential*, especially if the goal is *radical innovation*, necessary to achieve improvements of factors 10 -20. The user can become part of the process with co-creation, for result-oriented, functional PSS with *enabling* design solutions, and the combination of international with local craftsmanship, materials and habitat. Student designers and engineers must engage with the *societal component of SPD* to a far greater depth, requiring *Emphasis on the Social Element of SD/SPD* in future tertiary education. They need to consider social behaviour and how to influence this positively through a design/technology interface, for more sustainable ways of living, and quality of life.

Holistic perspective and systems thinking need to be at every level of human intervention for a true emulation of nature. For SPD within tertiary education, this means teaching the *interrelatedness of all things*: of environmental, economic and social issues, human spirit and body, human and non-human life forms, humans living within nature and being part of nature, humans at the end of the food-chain and simultaneously part of the earth's biodiversity. Materials and artefacts provide a way to express human values, meaning and diversity of culture, requiring a *Transition towards Systems Thinking via PSS (Product-Service Systems)*.

The contribution of Ethics courses can widen a student's perspective, to initiate a mindset of designing enabling, result-oriented, functional PSS that benefit and give support to humankind as well as the biodiversity of the environment. It is time to distance ourselves from the previous hierarchical viewpoint of mankind dominating all other life forms, and of creatures, natural resources and the environment being only there to be used and to 'serve' us. We must now embrace ideas of 'what is our positive contribution to this earth?' For this, a more cyclical worldview is necessary; one that is circular instead of hierarchical, supportive of other life forms and reflected in the

products, services and systems we design and manufacture. For this, macro-issues need to be at the heart of design briefs, to design with a wide perspective, that give benefits to the environment, economy and society through diverse stakeholders.

Complementary Sustainable Design Strategies highlighted the need to go beyond ecodesign, eco-efficiency and incremental *technological* improvements of reducing harmful effects of products and manufacturing processes. Industrial designers and engineers must now advance to *radical innovation* and the positive, beneficial growth of eco-effectiveness, C2C and PSS. This is dependent on *creativity, systems thinking and insight into human behaviour*.

For *Transition towards Strategic Design*, Sherwin (Sherwin, 2004; Sherwin & Evans, 2000), and the author of this research advocate that industrial/product designers should be greater utilized towards *radical innovation* at the conceptual design phase of NPD, where their training and natural aptitude can have the most effect towards SPD. The arts and humanities focus of industrial design is well-suited to strategic design, involving people and behavioural aspects of SPD. Yet they can be complemented with the technology focus of engineering, as most recently documented (Joachim H. Spangenberg et al., 2010).

A dual approach of design and technology is therefore necessary to *promote* sustainable behaviour, supported by C2C / PSS. This requires mutual understanding, respect and collaboration between industrial design and engineering. Therefore the two complementary disciplines of industrial design and engineering must learn how to communicate and collaborate with each other. There also needs to be greater involvement of other disciplines such as social sciences and ecology, facilitated through multidisciplinary student projects. The *Synthesis of Expert Views* (see *Appendix I*) provides a graphical summary of the complete literature review. It was one of the initial research outcomes and enabled further refinement and definition of the *Conceptual Educational Framework and Guidelines*, by using the design process described in *Chapter 3*.

3. RESEARCH METHODOLOGY

3.1 *Research Methodology and Design Process of this Thesis*

The nature of the problem determines methodology: here 'fuzzy', complex, humanistic problems are at the core of this thesis, as opposed to problems of a mechanistic, algorithmic nature. Therefore a systems overview can be helpful, as seen by the literature review. Our understanding of the design process has matured, for example, a recent version of this process was formulated by The Design Council, UK, as the 'double diamond' and illustrated below (see *Figure 27*). Here, four stages are involved, *discover, define, develop and deliver*, and 'places emphasis on the Discover phase as one of the most critical, and the one which makes best use of the designer's knowledge and skills" (Design Council, 2007, p. 10), see also (www.designcouncil.org.uk).

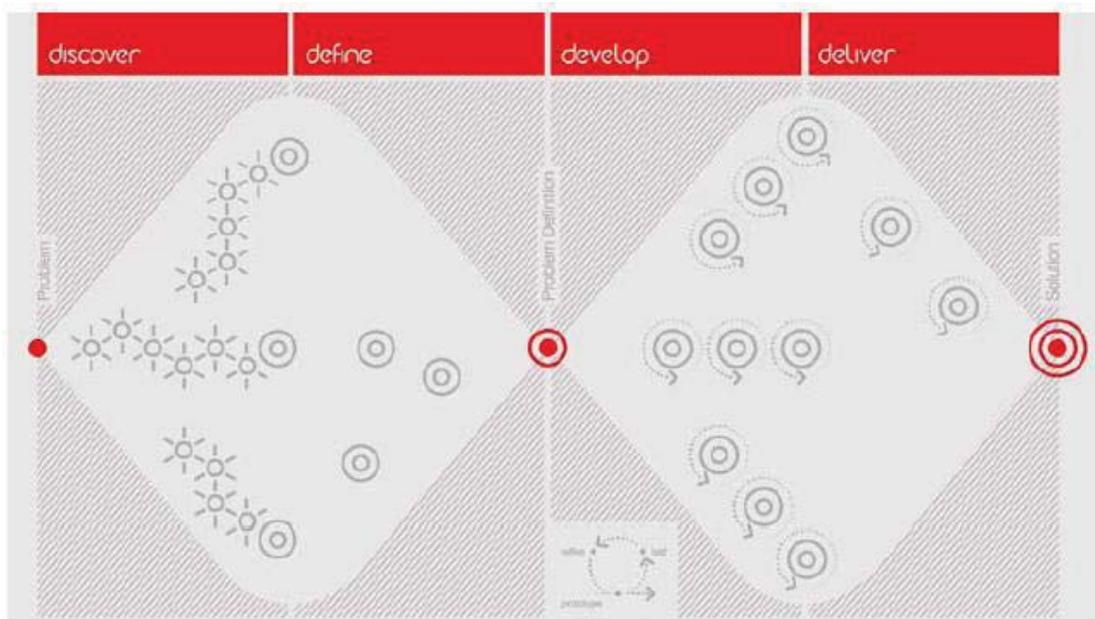


Figure 27: Double diamond design process (Design Council, 2007)

This diagram of the design process, by a UK government body, is a valid design methodology for the design professions, with a complete listing of methodology systems beyond the scope of this thesis. The 'double diamond design process' best

illustrates the structure of this thesis. This was approached from the point of view of a design brief, and from the perspective of the researcher's background, namely *industrial design*. This will also go some way to explain the wide perspective (and therefore length) taken by the research within the literature review, within the *discovery* phase. Features of the double diamond design process have also been used in the diagrammatic structures within *Chapter 5*. These are based on common principles of diverging (problem finding /analysis) and converging (problem solving/synthesis). Processes therefore expand, and contract, arriving at a point, or outcome, and are iterative by nature.

As detailed under 1.1, *radical innovation* is now necessary to achieve improvements of Factors 10-20, with design and engineering seen as essential contributors (E. L. Dewberry & Monteiro de Barros, 2009). A generic educational framework was therefore necessary towards achieving this, which would be useful to *both* disciplines. The aim of this research, the *Conceptual Educational Framework and Guidelines*, would be a common structure for both industrial design and engineering. This thesis not only brings together the key concepts of *radical innovation for sustainability*, but gives them a coherent structure, showing:

- how the elements fit together (*Strategic Design Cycle Model*); and
- further development into a prototype undergraduate degree structure for design/engineering (*Conceptual Educational Framework and Guidelines*).

The key recommendations are documented within four concepts, inherent to the organization of this thesis. This *Conceptual Educational Framework* would therefore be a common structure for both industrial design and engineering, and can be used to combine with discipline-specific core content from both disciplines. The *Synthesis of Expert Views* (see *Appendix I*), was the conclusion of the literature review. Using *design methodology*, this concluding synthesis was simultaneously the end, and also the basis and starting point for the next phase in the diverging/converging design process (see *Figure 3, Figure 27*).

3.2 Rationale for Key Concepts of Radical Innovation

The *key concepts of radical innovation* are a direct outcome of this research, and have been formed solely by this author. As mentioned briefly in 2.1 of the literature review, a digest of the material was organized and structured as concepts, used as a means to simplify the important points of the research. It was the rationale of this researcher, an *industrial designer*, to use a wide perspective, across the boundaries of individual disciplines, as represented in much of the literature. The concepts provide clarity and simplicity in a territory that is large and complex, and include some conflicting viewpoints. The *transdisciplinary nature of the discovery phase* therefore made an integral contribution to the outcomes of this research, and fulfilled the rationale of this researcher of *applying design process, from complex to simple*.

An outcome of the *discovery* phase was achieved with the *Synthesis of Expert Views, Appendix I*. This is a diagrammatic scheme of the whole, a comprehensive gathering of all the information contained within the literature review. The design process was that of working backwards: from the whole mass of information, the next phase of *define* achieved moving from the complex to simple and involved several iterations.

The first iteration in this process involved the ordering and grouping under major umbrella headings. Therefore the information was first grouped under major themes: context; a review of what was meant by Sustainable Design; what design strategies are currently used; and also expert views on *how to* move towards Sustainable Design. Further perspectives were gained, separating the holistic description of *design* into the disciplines *industrial design, engineering, and their education*.

The second iteration and further simplification involved clearer definition, enabling the formation of *key concepts*:

- *context* evolved into the recognition of the importance of *social context*;
- *an historical overview of the meaning of Sustainable Design* evolved into the recognition of a *broadening of scope from products to systems*, culminating in PSS (Product-Service Systems);
- *a review of Sustainable Design strategies* evolved into the recognition of currently opposing design strategies of *eco-efficiency* and *eco-effectiveness*, and that these could be *complementary*; and
- *an investigation of expert views* evolved into the recognition of the need for *strategic design*, where *sustainable behaviour* is targeted and rewarded through a design/technology interface.

The areas of investigation and their definition, as above, therefore determined the nature and number of *key concepts of radical innovation*:

1. *Emphasis on the Social Element of SD/SPD*;
2. *Transition towards Systems Thinking via PSS (Product-Service Systems)*;
3. *Complementary Sustainable Design Strategies*; and
4. *Transition towards Strategic Design*.

The *Conceptual Educational Framework* would be based on these *key concepts of radical innovation for sustainability*, as above, which are sourced entirely from the complete literature review and supported by expert views therein. These *key concepts* are then combined with successful examples of SD/SPD international tertiary education for design *and* engineering, as well as pertinent information gained from the final year New Zealand student survey for *both* disciplines. The latter highlighted the current gaps in student knowledge, as well as motivating and inspiring factors towards SD/SPD. This research, and the ultimate outcomes of the *Conceptual Educational Framework and Guidelines*, therefore gained knowledge from three sources:

- LITERATURE REVIEW;
- TEACHING; and
- LEARNING.

3.3 Rationale for using a Survey

Research methodologies are known to be either quantitative or qualitative, and used for different purposes:

- a) *quantitative research*
 - *applying measurement to data of all kinds (Hall, 2008, p. 221); and*

- b) *qualitative research*
 - *applying interpretation to data of all kinds (Hall, 2008, p. 254).*

The various research methods (Hall, 2008) use different forms of data collection instruments and procedures. *Surveys* can be cross-sectional, to collect data at a single point in time from a target sample, or longitudinal, repeatedly collecting data at intervals within a timeframe. *Experimental methods* use two groups for comparison: a treatment group, operating under certain criteria, and a control group, which do not. *Case studies and field research methods* are related, by making observations within a true-life context; the latter include observational methods of ethnography.

According to Yin (Yin, 2002, 2004) cited in (Hall, 2008, p.107-110), *case studies* are more extensive than field research methods, as they involve multiple data collection sources, both quantitative and qualitative (interviews, observation, record analysis etc.), within the natural context of present or recent true-life events. *Field research* also involves observation of people in their natural setting, foremost in anthropology, yet case studies produce multiple outcomes through their design (Hall, 2008, p.110-113).

The rationale for choosing a survey over other research methods (Bould, 2009), is the following: it was considered important by the researcher to both *compare* quantitative data with an international survey (Azapagic et al., 2005), as well as to *interpret* qualitative data within the survey, the latter being to ascertain sustainable values and motivation towards sustainable entrepreneurship. As a replication of the survey

questionnaire by Azapagic et al, 2005, was necessary for comparison, *a cross-sectional survey* was the most appropriate research methodology, with a questionnaire as the data collection procedure.

According to Hall, 2008, the advantages of using a survey rather than experimental methods, are that a far greater range of topics can be dealt with, which have a closer connection to reality. Hall discussed survey limitations as lacking the richness of context, not being able to show cause and effect relationships, and the self-reporting nature of information from the participants. It was the intention of this research to extend the range of topics covered in the questionnaire (*quantitative data*), as a reflection of the extensive nature of the literature review, and to include open-ended questions (*qualitative data*).

The previous survey conducted by Azapagic et al in 2005, has since been numerously cited in the literature in peer reviewed academic papers, and therefore was a successful and credible source for comparison. Also, the Azapagic survey was executed within a period of October 2000 to June 2002, and showed that there were substantial gaps of knowledge in SD/SPD of engineering students at that time. It was important to extend the survey to New Zealand industrial design and engineering students, as not previously included within international surveys.

Also, it was important to investigate the levels of *current* SD/SPD knowledge and awareness of students from these disciplines in New Zealand, to measure whether any progress had been made since the timing of the Azapagic survey. The target audience was therefore final year students in industrial design and engineering in New Zealand.

Quantitative Data within the Survey – to measure against previous Data

Within the survey, there was a majority of *quantitative* data gathered, see *Appendix F*. The data provided a current insight into the levels of awareness and knowledge of sustainability issues of New Zealand final year industrial design and engineering students. The results can be *directly measured* against knowledge levels of international students, and identified areas where survey results are significantly different to each other in a statistical sense, see 4.3. This was enabled through a replication of survey questions from an earlier survey (Azapagic et al., 2005), with extended questions by this author on topics not previously covered in prior research.

Qualitative Data within the Survey – to interpret the Data

Qualitative data was gained within the survey via a number of open-ended questions. Industrial design and engineering students were asked to give their *own understanding* of sustainable design. This linked to previous research conducted by Ramirez of design academic staff, first in Australia and then worldwide (Ramirez, 2006, 2007), and Humphries-Smith of design and engineering academic staff and students at Bournemouth University, UK (Humphries-Smith, 2008). The survey of this research equally investigated student ratings of the importance of SD, as per Azapagic et al (Azapagic et al., 2005). Finally, it examined whether any sources had especially inspired and motivated students towards SD/SPD. The information gained was open to *interpretation* by the author of this research. This would give an indication of students' internal values, motives and holistic comprehension of sustainable design that could not be achieved through topical questioning.

Purpose of the Survey

The purpose of the survey was therefore to both *compare quantitative data* (against an international study) *and interpret qualitative data* (of open-ended questions). The survey was voluntary and anonymous, with participating final year industrial design, product design, mechanical and mechatronics students as a group. Individual results (from disciplines, majors and/or TEOs) would NOT be compared against each other, as that was not in the interest of the holistic and multidisciplinary nature of this thesis.

3.4 Design of Survey Questionnaire

3.4.1 Questionnaire Composition and Design

The present survey questionnaire was based on the earlier survey by Azapagic et al for engineering students (Azapagic et al., 2005). This was due to the fact that not only were survey results given, but also the actual survey questionnaire was reproduced in full, with fairly extensive questioning. Other surveys of a similar nature, i.e. investigating sustainability in tertiary education of design and/or engineering, presented only the results and outcomes (Ramirez, 2006, 2007), or presented only limited questions (Humphries-Smith, 2008).

It was therefore decided to reproduce all previous questions of the earlier survey (Azapagic et al., 2005), as a comparative measure between New Zealand and international results. Further questions were added, as well as a number of open questions. All topics were considered relevant to industrial design, product design, mechanical and mechatronics engineering, and reflective of current knowledge gained from the literature review.

Of interest to this research would be any student gaps in knowledge of sustainability issues, i.e. topics that received less than 2.5, as per the rating system of Azapagic et al (Azapagic et al., 2005). Both surveys used the following ratings:

- | | | |
|---|---|------------------------------|
| 1 | = | 'Not heard of' |
| 2 | = | 'Heard of but can't explain' |
| 3 | = | 'Have some knowledge' |
| 4 | = | 'Know a lot' |

It would also be important to note any topics graded significantly *worse* than international values (see 4.3.1). These topics are then of special interest to New Zealand educators and to receive future focus, as well as any other low survey results.

3.4.2 Drafting the Survey Questionnaire

A draft survey questionnaire was prepared - see *Appendix E*, described below. The questionnaire pre-testing process included a pilot survey, to test the validity, formatting and time taken to participate in the survey. Steps that ensured content validity of the questionnaire included verification and contribution by experts, such as academic staff in industrial design and engineering. The provision of a glossary for definition of terms used in the survey was omitted after the pilot study, as all abbreviations used were also given in full within the questionnaire text: the glossary was deemed superfluous. The draft survey questionnaire was divided into three parts:

1. *Awareness/Understanding/Knowledge*: to find out what the students understand by the terms *Sustainable Development* and *Sustainable Product Design (SPD)*, and contributing factors;
2. *Study courses*: to find out where and how the students gained their understanding and knowledge; and
3. *Ratings of the importance*: to find out their knowledge and ratings of:
 - Sustainable Development (SD)
 - Sustainable Product Design (SPD)

In *Section 1: Awareness / Understanding / Knowledge*, definitions were given:

Sustainable Development (SD): "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (WCED, 1987).

Sustainable Product Design (SPD): "Incorporating sustainability issues of 'people, planet and profit' (3Ps), (Elkington, 1998), into the design of products and part of Sustainable Development"

After the pilot study, the definition for SPD was replaced with an open question:

Give your own understanding of Sustainable Design (which contains Sustainable Product Design – SPD).

It was deemed important to find out students' own definitions of Sustainable Design, which contains SPD, to assess their true understanding and in keeping with prior surveys as above (Humphries-Smith, 2008; Ramirez, 2007)

Section 1:

Sustainable Development (SD)

- I Sustainable Development Concepts
- II Environmental Issues

Sustainable Product Design (SPD)

- III Environmental Product Policy (EPP) – Legislation, Policy & Standards
- IV Environmental Management Systems (EMS) / Standards
 - a) International
 - b) New Zealand
- V Tools / Technologies / Approaches
- Eco-efficiency / Eco-Effectiveness / Conceptual
- VI Design Discussions / other (omitted after pilot study)

Section 2:

Study Courses, additional questions (omitted after pilot study).

3.5 Pilot Study of Survey Questionnaire

A pilot study of the survey questionnaire was conducted, (see Table 19). It was submitted to TEO academic staff from industrial design, product design, mechanical and mechatronics engineering, and approx. 2 final year students from each area.

TEO	Location	Degree	Department
Massey University	Wellington	BDes	College of Creative Arts Institute of Design for Industry and Environment <i>Industrial Design</i>
	Auckland (Albany)	BE	College of Sciences School of Engineering and Advanced Technology <i>Mechatronics</i> <i>Product Development</i>
	Palmerston North	BE	College of Sciences School of Engineering and Advanced Technology <i>Engineering & Industrial Management</i> <i>Industrial Automation</i>
UNITEC	Auckland	BDVA	School of Design Department of Design and Visual Arts <i>Product Design</i>
The University of Auckland	Auckland	BE	Faculty of Engineering Department of Mechanical Engineering <i>Mechatronics Engineering</i> <i>Mechanical Engineering</i>

Added for Final survey:

University of Otago	Dunedin	BDes	Department of Design Studies Industrial Design
Otago Polytechnic	Dunedin	BDes	School of Design Product Design
Massey University	Auckland (Albany)	BDes	Auckland School of Design <i>Industrial Design</i>

Table 19: Pilot study and Final survey participants

After the pilot study, which included written and verbal feedback from both academic staff and students, the initial draft survey questionnaire was edited and reformatted for visual clarity. The final survey questionnaire was reduced from 6 to 4 pages, see

Appendix F. The time to complete the questionnaire was estimated as approx. 5-10 minutes. The essential changes to the questionnaire are as follows:

- Boxes were given for the range of undergraduate degrees: *industrial design, product design, mechanical and mechatronics engineering*. Therefore the results would be presented from these main areas, with 'other' degree specifications also provided for;
- The definition of *Sustainable Development* was retained;
- *Open Question*: students were asked to give their own definition of Sustainable Design (which contains SPD). As various definitions can be found within the literature, it was deemed important to see whether the students understand the meaning rather than to give an exact repetition of somebody else's quote;
- Some topics were considered superfluous and deleted;
- New Zealand Environmental Management Systems (EMS) were deleted;
- *Tools/Technologies/Approaches* were previously divided into eco-efficiency, eco-effectiveness and conceptual. This was changed to 'eco-efficiency vs eco-effectiveness'. Topics listed under 'conceptual' were deleted, as conceptual design strategies are too numerous to list in their entirety, and certain conceptual design strategies may be known only to either designers or engineers;
- *Study Courses*: questioning towards advancement of further integration of sustainability into courses was deleted, as it was deemed in the future and outside the scope of this survey. Although it was agreed valuable to gain student requirements for the future, such questioning should take place within a separate mechanism;
- *Open Question / Study Courses* acquired an additional question 'Is there any topic you would like to know more about and why?'
- *Ratings* section was reduced to Sustainable Development only, which was in line with Azapagic's survey. The importance of SD for "You as an engineer" was extended to "You as a future professional", to reflect the broadening of the survey questionnaire to different disciplines;
- *Open Question*: "Describe any sources that especially inspire and motivate you towards SD and SPD (study courses/papers, academic staff and/or other influences such as personal values, family, culture, religion etc.)" This question was discussed in detail with an academic staff member. It was considered of value, to gain an insight into what are the drivers for championing SD/SPD. From another academic source, it was deemed important to have a few open questions for qualitative responses;
- *Glossary* was deleted, as all abbreviations used were also given in full within the questionnaire text, and therefore deemed superfluous; and
- *Formatting*: The survey questionnaire was reformatted, so that the boxes were visually aligned to facilitate improved and easier answering of questions.

3.6 Final Survey – Nature of Survey Sample

The main priority was to have sufficient numbers from each of the two main disciplines of design and engineering, identified as being “core catalysts of change” (E. L. Dewberry & Monteiro de Barros, 2009, p. 29) towards *radical innovation for sustainability*, see 1.1. As this is the main subject of this thesis, within the context of industrial design and engineering tertiary education, the target sample consisted of final year students from industrial design, product design, mechanical and mechatronics engineering. These majors were identified by the author of this research to be most directly involved in the design and creation of *products*, and therefore most appropriate for the target sample. This involved five tertiary education organizations (TEOs) located in Auckland, Palmerston North, Wellington and Dunedin, New Zealand.

The questionnaire aimed to find out New Zealand students’ levels of knowledge in the areas of SD/SPD in their final year of study, as opposed to questioning all study years (Azapagic et al., 2005). The reasoning behind this is that a survey of final year students would give the clearest and most definite indication of gaps in knowledge, as students would have received almost all of their tertiary education by that time. These knowledge gaps by the final year most clearly indicate if topics were not covered in the curricula, or not covered adequately, and would identify the level of SD/SPD knowledge that graduates take directly into industry. This is extremely important for New Zealand SMEs and creating potential sustainable entrepreneurs. This survey contained both quantitative and qualitative questions, as previously described.

3.7 Ethics Considerations

3.7.1 The Human Ethics Committee at Massey University

The outgoing TEO of Massey University (The Massey University Human Ethics Committee) was responsible for all ethics procedures and appropriately consulted.

3.7.2 Ethics Procedures – Low Risk Notification

It was determined that the student survey was deemed to be of low risk (not involving any physical activities, no risk of physical or emotional harm and/or embarrassment and not involving students under the age of 16). Therefore ethics approval was unnecessary; a 'low risk' was recorded via:

- Screening Questionnaire
- 'Notification of Low Risk Research/Evaluation involving Human Participants', see *Appendix G*. (An Information Sheet and Consent Form were distributed with the survey).
(<http://www.massey.ac.nz/massey/research/research-ethics/human-ethics/approval.cfm>).

3.8 Distribution of Survey Questionnaire

3.8.1 Schedule of Distribution

TEO	Location	Degree	Major	Distribution
Massey University	Wellington Auckland (Albany) Auckland(Albany) Palmerston North	BDes BDes BE BE	Industrial Design Industrial Design Mechatronics Mechatronics	22.07.10 11.10.10 30.07.10 + 02.08.10 19.08.10
UNITEC	Auckland	BDVA	Product Design	26.07.10
The University of Auckland	Auckland	BE BE	Mechatronics Engineering Mechanical Engineering	24.08.10 24.08.10
University of Otago	Dunedin	BDes	Industrial Design	06.09.10
Otago Polytechnic	Dunedin	BDes	Product Design	27.09.10

Table 20: Distribution schedule of final year student survey in New Zealand, 2010

The survey documents consisted of the survey questionnaire, as well as a detailed information sheet concerning the research and individual consent forms for participants, as mentioned above. These accompanying documents were

requirements of the Massey University ethics procedures. Anonymity was upheld; names and signatures of consenting participants were separate to the actual questionnaires. All documents were securely held by the researcher, to be destroyed within a timeframe agreed by the main supervisor. For the purpose of distribution, the researcher personally distributed the survey documents within TEOs located in Auckland. The appropriate academic staff distributed survey documents for all TEOs located outside of Auckland, with the documents sent and returned to the researcher by mail. The appropriate academic staff had been consulted for this purpose with prior correspondence, to attain their approval and participation.

3.8.2 Summary of Survey Characteristics

In total, 175 final year students were available for the survey, i.e. contributed with voluntary participation, from 5 TEOs across New Zealand, and located in Auckland, Palmerston North, Wellington and Dunedin. The numbers comprised 80% male and 20% female students, of which 34.3% came from Design, and 65.7% from Engineering, see 4.2.

As previously mentioned as to the purpose of the survey, see 3.3, the survey would NOT compare between disciplines, majors and/or TEOs. Instead, the New Zealand survey results would be compared to the earlier international survey of engineering students (Azapagic et al., 2005).

The means values were already available within the international survey, and the international variance values were obtained directly from Azapagic. This enabled the performance of a statistical t-test, to examine whether the two sets of survey results were significantly different to each other, see 4.3.1.

Analysis and evaluation of the survey results are detailed in *Chapter 4, Survey Results and Evaluation*, and satisfy the third and last research objective outlined in 1.6.1, towards the *development of an educational framework with supporting guidelines*.

The first two objectives were fulfilled within the literature review, with the research aim and objectives recapitulated here, for clarity:

Research Aim

Develop an educational framework with supporting guidelines, combining knowledge gained from Objectives 1, 2 and 3 below. This is intended as an aid and underlying structure for curricula builders towards embedding radical innovation for sustainability in Industrial Design and Engineering curricula.

Research Objectives

1. Show the *key concepts of radical innovation for sustainability* through a review of the literature;
2. Highlight *international examples of successful practices within industrial design and engineering tertiary education*; and
3. Investigate *NZ final year students in Industrial Design and Engineering*:
to measure current awareness, understanding and knowledge of SD/SPD and compare New Zealand and international studies, as sustainability is important for accreditation of Bachelor undergraduate programs in NZ.

4. SURVEY RESULTS AND EVALUATION

4.1 Overview

The United Nations Decade of Education for Sustainable Development (UNDES) is in progress from 2005 – 2014, and currently at the half-way mark in 2010. A survey concluded by 2005 (Chapman et al., 2006), found SD in New Zealand general tertiary education to be seriously lacking, see 2.7.7. It was therefore important to measure whether any progress had been made, specifically for the disciplines of industrial design and engineering, the two professions most directly influencing the design and manufacture of products. The importance of sustainability has also been recognized by the professional bodies for these disciplines, IPENZ and DINZ respectively, and part of accreditation criteria for TEOs in New Zealand. SD/SPD issues are therefore of great interest to New Zealand tertiary educators in design and engineering.

This chapter presents the New Zealand survey results, and includes analysis and discussion, i.e. evaluation. It will provide an up-to-date status of the level of awareness and knowledge of SD/SPD issues of industrial design and engineering students in their final year of study in New Zealand. The results are also compared to an international survey (Azapagic et al., 2005), as previously discussed. An evaluation of the results will contribute towards developing a draft educational framework for industrial design *and* engineering curricula. This is achieved by indicating gaps in student knowledge and *other valuable information*. The latter is gained through open questioning within the survey, and includes: students' understanding of Sustainable Design; SD/SPD topics they would like to know more about; how they rate the importance of SD; and motivational and inspirational influences towards SD/SPD. The NZ survey results and international comparison were presented at a peer reviewed conference held in Auckland, 2011 (Haemmerle & Dr. Shekar, 2011)

4.2 New Zealand Survey Results

Selection Criteria:

Final study year, Industrial Design, Product Design, Mechanical and Mechatronics Engineering in NZ

Percentages:

Overall: 80 % male, 20 % female, of 175 students in total, from 5 TEOs

Comprising: 34.3 % Design

65.7 % Engineering

Survey Ratings:

A scale of 1 – 4, representing least to most knowledge, as per Azapagic et al (Azapagic et al., 2005):

1 = 'Not heard of'

2 = 'Heard of but can't explain'

3 = 'Have some knowledge'

4 = 'Know a lot'

Azapagic et al defined knowledge gaps to be less than 2.5, and replicated in this survey.

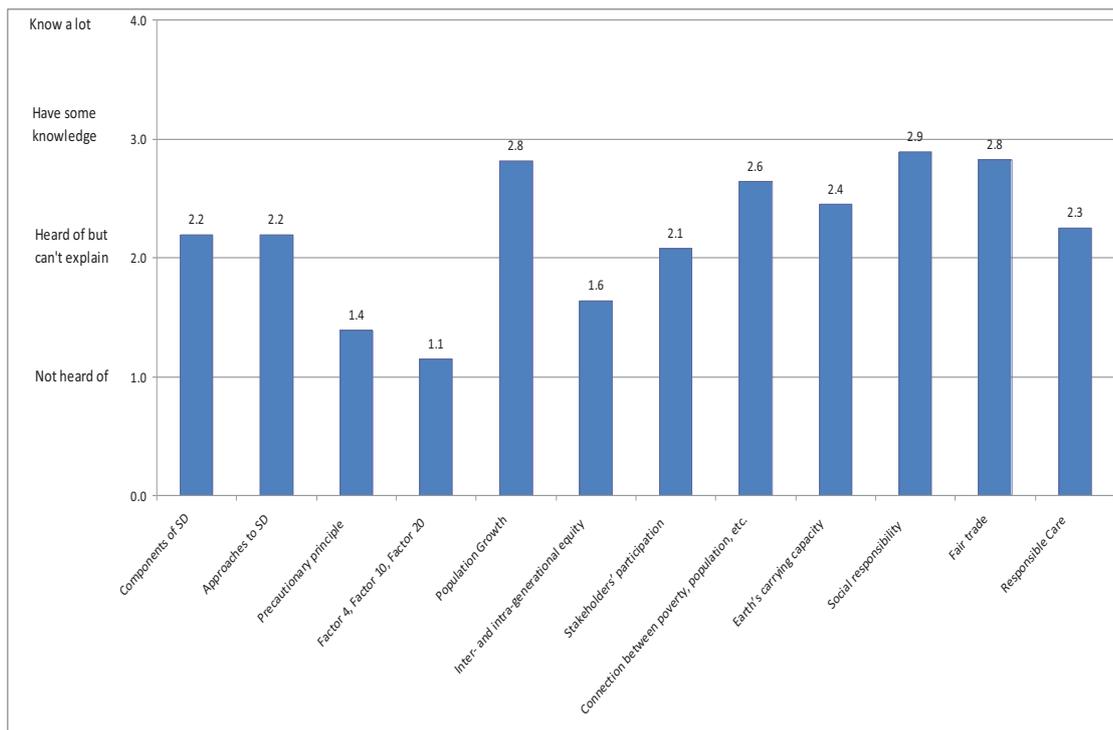


Figure 28: Sustainable Development Concepts, NZ Survey 2010

Comment: Especially low values for Precautionary Principle, Inter- and intra-generational equity, and the additional topic of Factors 4, 10-20. Combined, the poor results for these topics indicate no knowledge of the need to reduce resource use for the equity of present and future generations, requiring *radical innovation* in SPD.

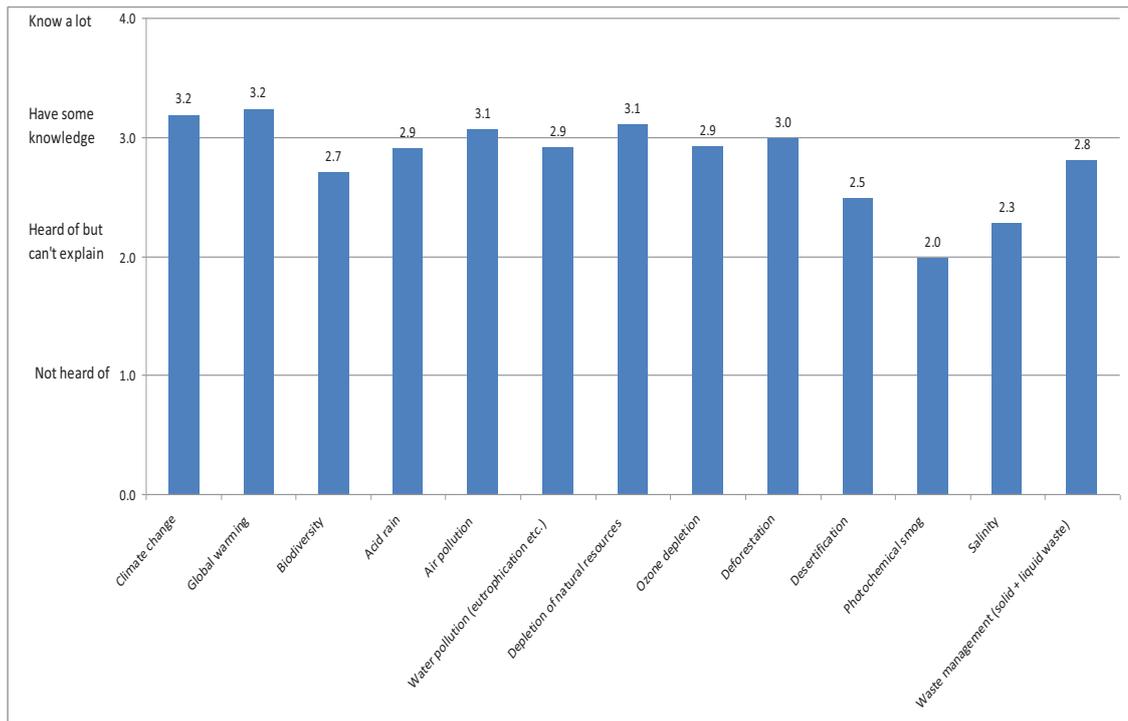


Figure 29: Environmental Issues, NZ Survey 2010

Comment: Students mostly 'have some knowledge', but not for photochemical smog and salinity.

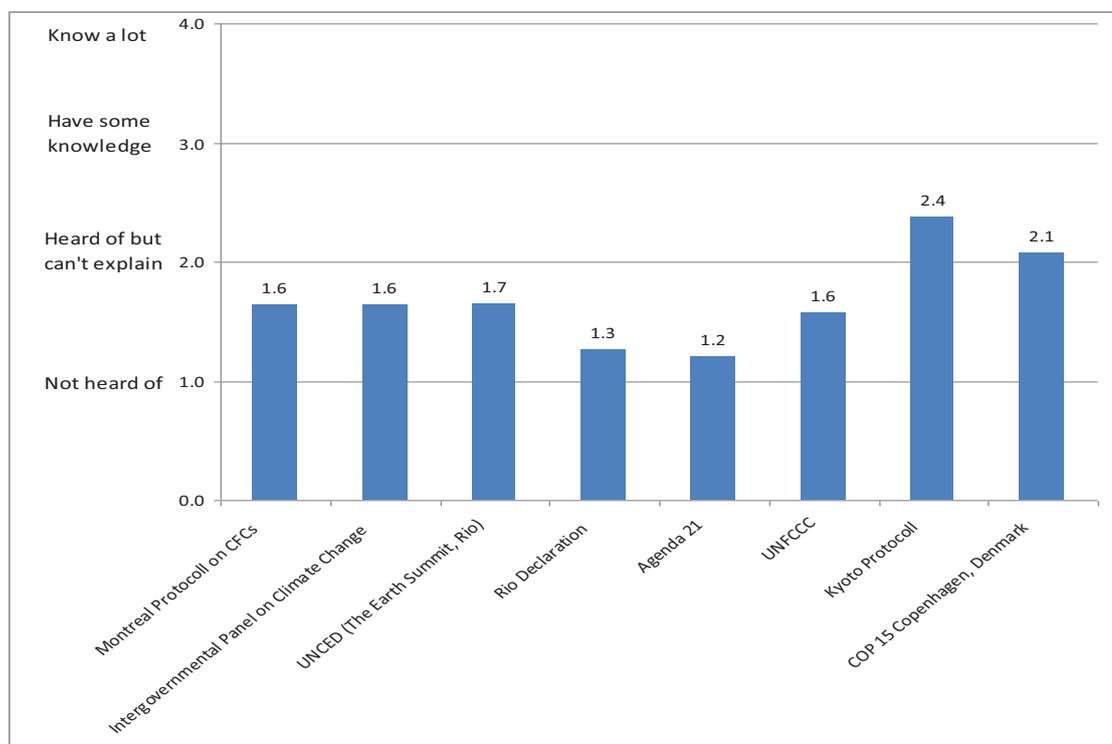


Figure 30: Environmental Product Policy (EPP), NZ Survey 2010

Comment: With the exception of the Kyoto Protocol, NZ students had mostly 'not heard of' the majority of EPP; showing a need to know about the international frameworks of a global economy.

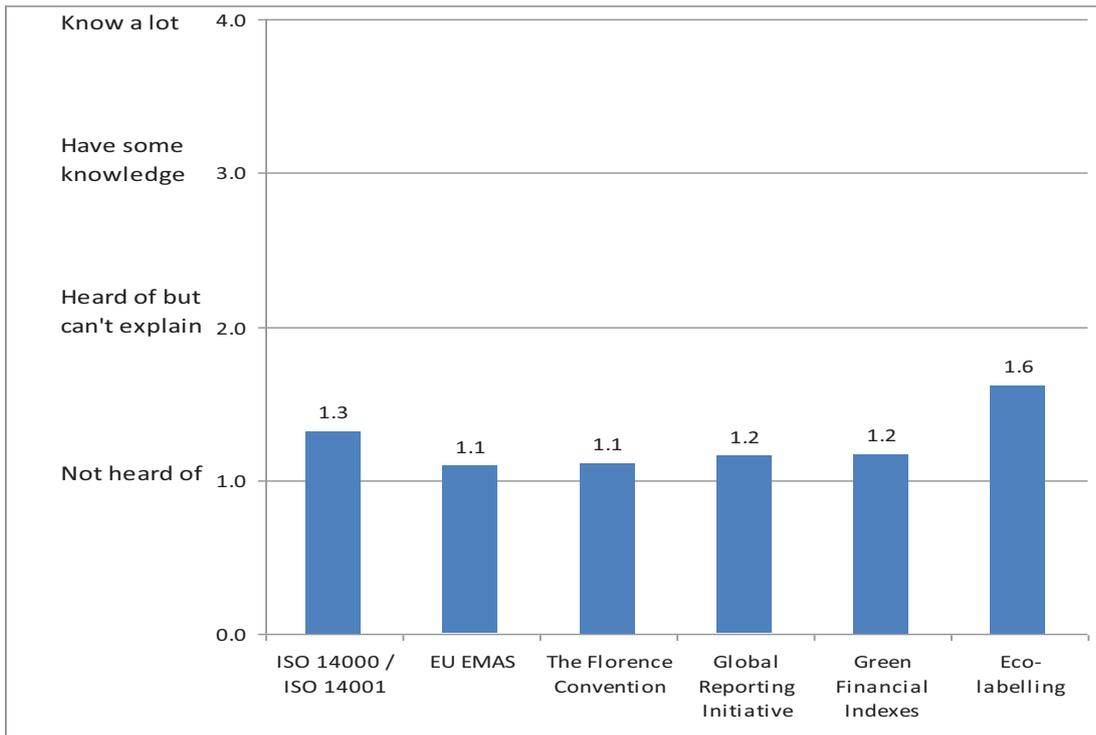


Figure 31: Standards and Environmental Management Systems (EMS), NZ Survey 2010

Comment: NZ students had mostly 'not heard of' European and/or international standards and EMS, but knowledge of these are particularly important for exporting SMEs in the NZ economy.

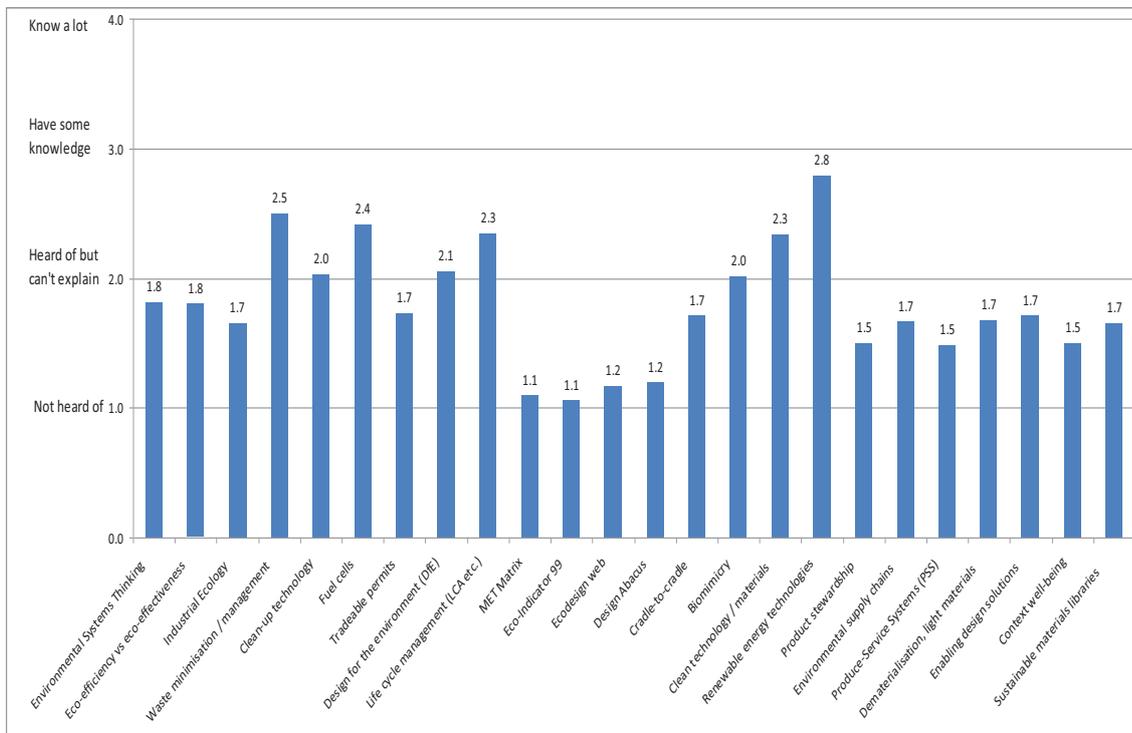


Figure 32: Tools, Technologies and Approaches, NZ Survey 2010

Comment: NZ students had low values for the majority of tools and approaches, and therefore do not possess adequate skills for *practical implementation* of SPD in design and engineering.

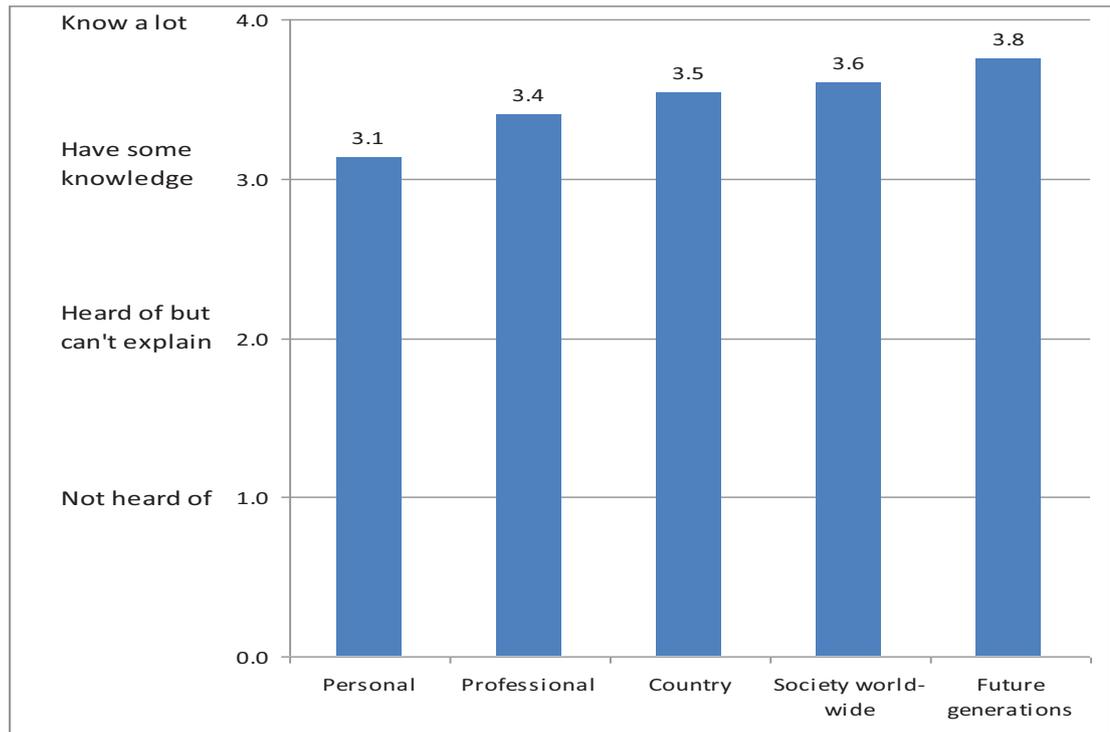


Figure 33: Ratings of the Importance of Sustainable Development, NZ Survey 2010

Comment: Overall high ratings of the importance of SD contrast sharply with the lack of knowledge in major areas. These gaps in knowledge were identified within SD concepts, international EPP, standards and other frameworks, as well as the tools and approaches for practical application of SPD. From this it can be concluded that NZ students in industrial design and engineering currently have insufficient SD/SPD knowledge and do not possess adequate skills for designing sustainably.

4.3 Differences between NZ and International Studies / T-Test

4.3.1 Rationale for using a Statistical T-Test

A statistical t-test was executed in order to examine whether the two sets of survey results were similar or significantly different from one another. From the International survey only means and variances for each of the question were available. Hence a Chi-Square test could not be performed, which requires knowing how many times each category (from 1 = have not heard of to 4 = know a lot) has been selected. However, given the large sample size of both surveys (NZ 175, internationally 3134), one can reasonably be confident that a commonly used test, such as the t-test for continuous

values, is adequate (personal communication with Associate Professor David Scott, The University of Auckland). The two surveys (i.e. the final year student survey of industrial designers and engineers in New Zealand in 2010, and the international engineering student survey carried out for years 1-5 by Azapagic et al (Azapagic et al., 2005), were therefore statistically compared using the t-test.

This t-test was used in order to determine whether the two sets of survey data were significantly different from one another, statistically speaking. For this, the means and variance values were taken for both the New Zealand and International surveys, and computed using the formula for the t-test.

These t-test values were then converted to a significance meaning, i.e. whether the t-value ratio is large enough to say that the difference between the groups is not likely to have been by chance. A t-test table value of 0.01 probability was used, (1 out of 100 chance of statistically significant difference between means, even if there was no difference, i.e. by chance). The degrees of freedom (df) were determined, as the sum of the persons in both groups, minus 2: $(n_1 + n_2) - 2$.

This was (NZ) 175 + (Azapagic et al., 2005) 3134 - 2
= 3309 - 2 = 3307 (sample size)

Therefore 'infinity' was chosen as the df appropriate for the sample size (the greatest df number prior to infinity was 120, and not appropriate). In the t-test table, using infinity and 0.01 probability, the value of 2.58 was given. Therefore all t-values greater than 2.58 were deemed significantly different, and *highlighted in colour* in the extended table found in *Appendix H*. These highlighted values were then brought together in a summary table (*Table 21*), showing all values that were significantly different between the NZ and international studies.

If the NZ mean was greater than the international mean, it gave a positive t-value, i.e. the NZ mean (level of topical knowledge) was better than the international mean. If

the NZ mean was less than the international mean, it gave a negative t-value, i.e. the NZ mean (level of topical knowledge) was worse than the international mean. Therefore the positive or negative values were only indicative of the relationship between each of the two survey data, with the actual value indicating the level of knowledge using the rating system by Azapagic et al (Azapagic et al., 2005) of least to most knowledge, 1 = 'Not heard of' to 4 = 'Know a lot', (see Table 21).

Topic	NZ Mean	International Mean	NZ Variance	International Variance	T-Value
<i>Sustainable Development Concepts</i>					
Components of SD	2.2	2.0	0.87	0.85	3.38
Precautionary principle	1.4	1.8	0.46	0.94	-7.64
Stakeholders' participation	2.1	1.6	0.75	0.88	7.10
Earth's carrying capacity	2.4	2.2	0.69	0.86	3.80
Social responsibility	2.9	2.5	0.55	0.79	6.75
<i>Environmental Issues</i>					
Climate change	3.2	3.0	0.26	0.45	4.70
Biodiversity	2.7	2.2	0.62	0.84	8.24
Air pollution	3.1	3.2	0.24	0.32	-3.45
Water pollution (eutrophication etc.)	2.9	3.2	0.33	0.42	-6.35
Ozone depletion	2.9	3.2	0.25	0.48	-6.87
Salinity	2.3	2.0	0.76	0.81	4.04
<i>EPP and Legislation</i>					
Rio Declaration	1.3	1.6	0.26	0.63	-8.17
Kyoto Protocol	2.4	1.7	0.72	0.75	10.20
<i>Standards and EMS</i>					
ISO 14000 / ISO 14001	1.3	1.6	0.39	0.79	-5.75
EU EMAS	1.1	1.2	0.10	0.28	-4.33
The Florence Convention	1.1	1.2	0.10	0.30	-3.59
Eco-labelling	1.6	1.8	0.63	0.75	-2.96
<i>Tool, Technologies and Approaches</i>					
Industrial Ecology	1.7	1.9	0.61	0.65	-4.01
Life cycle management (LCA etc.)	2.3	2.1	0.78	0.79	3.55
Product stewardship	1.5	2.6	0.56	0.76	-18.79

Table 21: Summary of significantly different Data between Studies

Of particular interest to educators in New Zealand is to know where New Zealand students have, statistically speaking, *significantly less* awareness and knowledge of

particular topics. These were all *minus values indicated by additional shading* (see Table 21). They are referred to again within individual tables for significantly different data, also with additional shading, and listed below (positive values greater than 2.58 are shown in blue in the tables). However, these comparative values should not detract from the *equally low values* of the majority of additional topics of this New Zealand survey, which *have not been compared to other surveys*. A complete listing of topics in which New Zealand students fared significantly worse than International students (as below), plus low ratings of additional topics of the New Zealand survey are therefore given in the summary of this chapter, see 4.4.

Topics that received minus values

(indicating that New Zealand students had less knowledge than international students):

Sustainable Development Concepts

- Precautionary principle t-value -7.64

Environmental Issues

- Air pollution t-value -3.45

- Water pollution t-value -6.35

- Ozone depletion t-value -6.87

EPP and Legislation

- Rio Declaration t-value -8.17

Standards and EMS

- ISO 14000 / ISO 14001 t-value -5.75

- EU EMAS t-value -4.33

- The Florence Convention t-value -3.59

- Eco-labelling t-value -2.96

Tools/Technologies/Approaches

- Industrial Ecology t-value -4.01

- Product Stewardship t-value -18.79

4.3.2 Evaluation of Studies for Sustainable Development Concepts

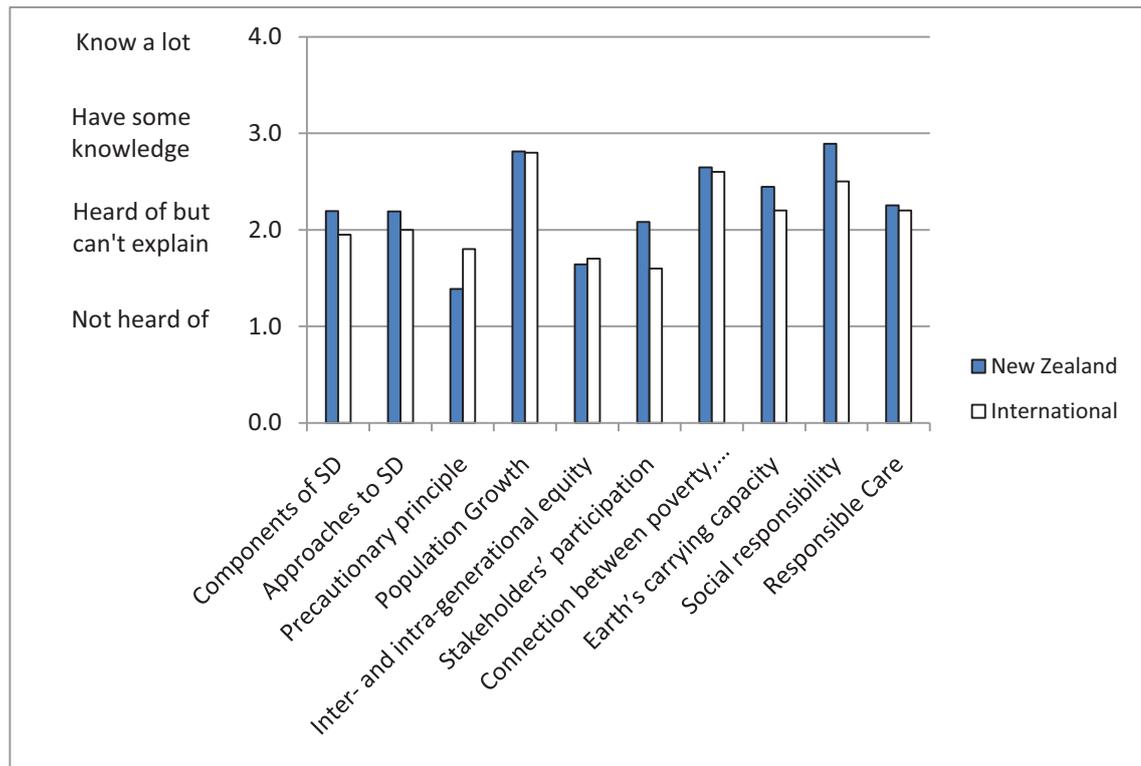


Figure 34: Comparison of Studies for Sustainable Development Concepts

Comment: refer to Table 22, Table 23, and the evaluation comparing values of significant difference.

Topic	NZ Mean	International Mean	NZ Variance	International Variance	T-Value
Sustainable Development Concepts					
Components of SD	2.2	2.0	0.87	0.85	3.38
Approaches to SD	2.2	2	0.89	0.89	2.58
Precautionary principle	1.4	1.8	0.46	0.94	-7.64
Factors 4, 10, 20	1.1		0.20		
Population growth	2.8	2.8	0.56	0.76	0.20
Inter- and intra-generational equity	1.6	1.7	0.59	0.97	-0.99
Stakeholders' participation	2.1	1.6	0.75	0.88	7.10
Connection between poverty, population, consumption & environment degradation	2.6	2.6	0.60	0.87	0.75
Earth's carrying capacity	2.4	2.2	0.69	0.86	3.80
Social responsibility	2.9	2.5	0.55	0.79	6.75
Fair Trade	2.8		0.51		
Responsible Care	2.3	2.2	0.90	0.92	0.70

Table 22: Evaluation of Studies for Sustainable Development Concepts / T-Values

Evaluation of Studies for Sustainable Development Concepts

The majority of both sets of results were around 1.6 to 2.8. Azapagic et al listed the following international student knowledge gaps (less than 2.5) for SD concepts:

- Components of SD;
- Approaches to SD;
- Precautionary Principle;
- Inter-and intra-generational equity; and
- Stakeholders’ participation.

Topic	NZ Mean significantly worse (less knowledge)	NZ Mean significantly better (more knowledge)
<i>Sustainable Development Concepts</i> Precautionary principle	NZ 1.4	
Components of SD		NZ 2.2
Stakeholders’ participation		NZ 2.1
Earth’s carrying capacity		NZ 2.4
Social responsibility		NZ 2.9
<i>Additional Topics in NZ Survey</i> Factors 4, 10-20	<i>Not compared to other Surveys</i> NZ 1.1	
Fair Trade	NZ 2.8	

Table 23: Significantly different Data for Sustainable Development Concepts

NZ students fared significantly worse than international students for ‘precautionary principle’, indicating they had mostly ‘not heard of’ this topic. NZ students showed a significantly better understanding than international students of the *general* themes of SD ‘components of SD, stakeholder’s participation, earth’s carrying capacity and social responsibility’. However, the overall values of both surveys were below 2.5, indicating gaps in knowledge, as defined by Azapagic et al, and requiring improvement. Exceptions with values over 2.5: ‘population growth, connection between poverty/population and social responsibility’; also ‘fair trade’ (NZ survey only). Within the additional topics of the NZ survey, ‘factors 4, 10-20’ rated especially low with the NZ value of 1.1. This marks a total lack of knowledge of the necessity of achieving higher reduction levels (factors 10-20) in the global use of resources, and most importantly, how this is linked to *radical innovation* for SPD, dematerialization through PSS, and how this could be implemented on a practical level by industrial designers and engineers.

4.3.3 Evaluation of Studies for Environmental Issues

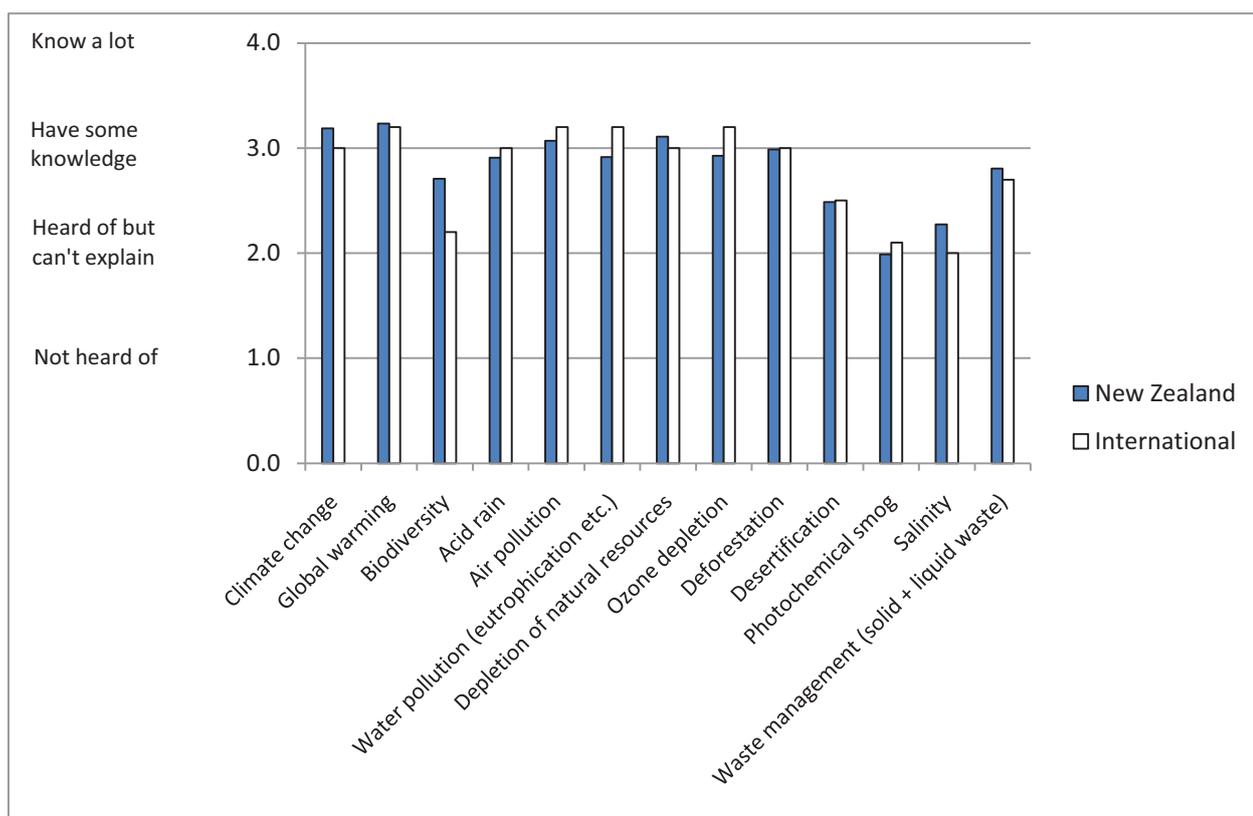


Figure 35: Comparison of Studies for Environmental Issues

Comment: refer to Table 24, Table 25, and the evaluation comparing values of significant difference.

Topic	NZ Mean	International Mean	NZ Variance	International Variance	t-value
Environmental Issues					
Climate change	3.2	3.0	0.26	0.45	4.70
Global warming	3.2	3.2	0.25	0.48	0.86
Biodiversity loss	2.7	2.2	0.62	0.84	8.24
Acid rain	2.9	3.0	0.39	0.45	-1.87
Air pollution	3.1	3.2	0.24	0.32	-3.45
Water pollution (eutrophication etc.)	2.9	3.2	0.33	0.42	-6.35
Depletion of natural resources	3.1	3.0	0.30	0.58	2.48
Ozone depletion	2.9	3.2	0.25	0.48	-6.87
Deforestation	3.0	3.0	0.32	0.51	-0.26
Desertification	2.5	2.5	0.69	0.81	-0.22
Photochemical smog	2.0	2.1	0.71	0.83	-1.69
Salinity	2.3	2.0	0.76	0.81	4.04
Waste management (solid + liquid)	2.8	2.7	0.46	0.69	1.99

Table 24: Evaluation of Studies for Environmental Issues / T-Values

Evaluation of Studies for Environmental Issues

Overall, both sets of students knew more about environmental issues than SD concepts, as previously explored in the preceding evaluation. The majority of means scores for environmental issues were around 3, indicating that they 'have some knowledge'. Lesser scores were achieved around 2 for the topics listed as knowledge gaps below, indicating students had 'heard of but could not explain' them. Azapagic et al listed international student knowledge gaps (less than 2.5) for environment issues:

- Biodiversity loss;
- Salinity; and
- Photochemical smog.

Topic	NZ Mean significantly worse (less knowledge)	NZ Mean significantly better (more knowledge)
<i>Environmental Issues</i>		
Air pollution	NZ 3.1	
Water pollution	NZ 2.9	
Ozone depletion	NZ 2.9	
Climate change		NZ 3.2
Biodiversity loss		NZ 2.7
Salinity		NZ 2.3

Table 25: Significantly different Data for Environmental Issues

NZ students fared significantly worse than international students for 'air pollution, water pollution and ozone depletion'. It is interesting to note that all three topics could be linked to the opposite of the 'clean, green' image of New Zealand, implying that students do not necessarily link these as applicable and/or relevant to this country. However, New Zealand is directly affected by 'ozone depletion' in the Southern Hemisphere, with local concern regarding 'water pollution' also appearing in the media (Worrell, 2010).

The reason for this lack of knowledge regarding environmental issues, and specifically the topics mentioned above, could be that environmental issues have historically not been part of the New Zealand cultural background, with no leading New Zealand experts. The New Zealand industrial design and engineering professions and tertiary

education in particular, need to *respond to international experts*, such as the international keynote speakers of the Better by Design CEO Summit on Sustainability, held in Auckland, 2008 (<http://www.betterbydesign.org.nz/events/ceosummit2008>).

Little has changed since this summit, which included some of the international experts referenced in this thesis: Prof. Michael Braungart, co-author of 'Cradle to cradle: remaking the way we make things', founder of EPEA Internationale Umweltforschung GmbH and co-founder of MBDC, Ray Anderson, founder and chairman of Interface Inc., Janine Benyus, author of 'Biomimicry: innovation inspired by nature' and founder of the Biomimicry Guild, Lee Weinstein, former director of Nike's US and global public relations, and Alex Steffan, executive editor of 'Worldchanging: a user's guide for the 21st century' and co-founder of Worldchanging.com .

Yet one would expect New Zealand industrial design and engineering students to be especially aware of SD/SPD concepts of *national relevance*, to be able to address them within their professional sphere, i.e. design projects. Otherwise they would be out of step globally. Scores on environmental issues could be improved with local knowledge relevant to the New Zealand environment, and reflected within the *Educational Framework Guidelines*.

4.3.4 Evaluation of Studies for Policy, Standards and EMS

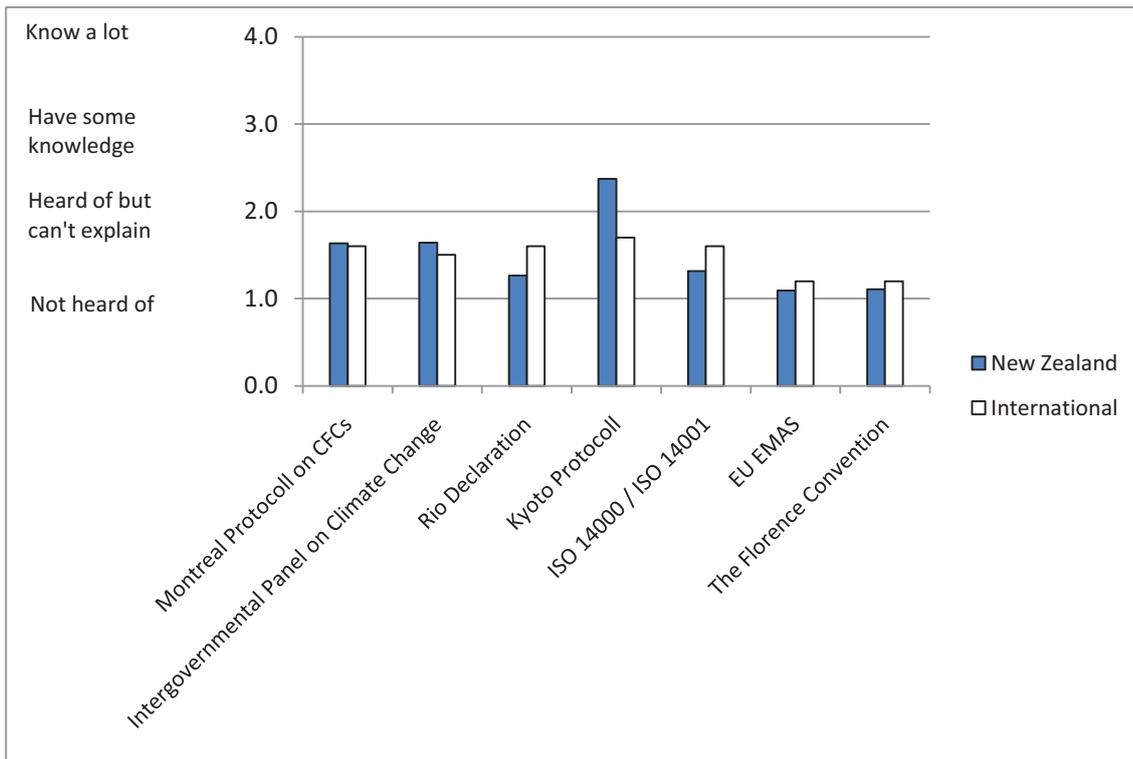


Figure 36: Comparison of Studies for Policy, Standards and EMS

Comment: refer to Table 26, Table 27, and the evaluation comparing values of significant difference.

Topic	NZ Mean	International Mean	NZ Variance	International Variance	T-Value
EPP and Legislation					
Montreal Protocol on CFCs	1.6	1.6	0.58	0.66	0.58
Intergovernmental Panel on Climate Change (IPCC)	1.6	1.5	0.55	0.56	2.42
UN Conf. on Environment & Dev. UNCED (The Earth Summit, Rio)	1.7		0.48		
Rio Declaration	1.3	1.6	0.26	0.63	-8.17
Agenda 21	1.2		0.22		
UN Framework Convention on Climate Change (UNFCCC or FCCC)	1.6		0.56		
Kyoto Protocol	2.4	1.7	0.72	0.75	10.20
UN Climate Change Conference, DK	2.1		0.81		
Standards and EMS					
ISO 14000 / ISO 14001	1.3	1.6	0.39	0.79	-5.75
EU EMAS	1.1	1.2	0.10	0.28	-4.33
The Florence Convention	1.1	1.2	0.10	0.30	-3.59
Global Reporting Initiative	1.2		0.19		
Green Financial Indexes	1.2		0.17		
Eco-labelling	1.6	1.8	0.63	0.75	-2.96

Table 26: Evaluation of Studies for Policy, Standards and EMS / T-Values

Evaluation of Studies for Policy, Standards and EMS

Here, Azapagic et al, 2005, identified the largest knowledge gaps overall, with both sets of students with a low score range of between 1 – 1.7. This indicated that students had either 'not heard of' these topics with a score of 1, or 'heard of but could not explain' with a score of 2 and below.

Topic	NZ Mean significantly worse (less knowledge)	NZ Mean significantly better (more knowledge)
<i>EPP and Legislation</i>		
Rio Declaration	NZ 1.3	
Kyoto Protocol		NZ 2.4
<i>Additional Topics in NZ Survey</i>	<i>Not compared to other Surveys</i>	
UNCED (Earth Summit ,Rio)	NZ 1.7	
Agenda 21	NZ 1.2	
UNFCCC	NZ 1.6	
UN Climate Change Conference, Denmark	NZ 2.1	
<i>Standards and EMS</i>		
ISO 14000 / ISO 14001	NZ 1.3	
EU EMAS	NZ 1.1	
The Florence Convention	NZ 1.1	
Eco-labelling	NZ 1.6	
<i>Additional Topics in NZ Survey</i>	<i>Not compared to other Surveys</i>	
Global Reporting Initiative	NZ 1.2	
Green Financial Indexes	NZ 1.2	

Table 27: Significantly different Data for Policy, Standards and EMS

NZ students fared significantly worse than international students for 'Rio Declaration, ISO 14000 series, EU EMAS, The Florence Convention and eco-labelling', with a low mean score close to 1. However, one result was significantly better; 'Kyoto Protocol', with a mean score of 2.4. Additional topics in the NZ survey of 'UNCED – (The Earth Summit, Rio), Agenda 21, UNFCCC, global reporting initiative and green financial indexes' all received low mean scores between 1.2 – 1.7, showing that students had mostly 'not heard of' these topics. The additional topic of 'UN Climate Change Conference, Copenhagen, Denmark' received a NZ mean of 2.1, showing that students had 'heard of but can't explain'.

These results show that, in general, NZ and international students have a poor knowledge of historical Environmental Product Policy (EPP), with NZ students also showing poor knowledge of current affairs concerning SD/SPD, such as the UN Climate Change Conference in Denmark, given above. This will need to be remedied, as products and PSS, especially those destined for export, are governed by international legislation and standards. The basic levels and requirements of such legislation should be comprehended, in order to promote aspiring above and beyond these basic necessities, and to achieve higher levels of *radical innovation* in SPD.

4.3.5 Evaluation of Studies for Tools, Technologies and Approaches

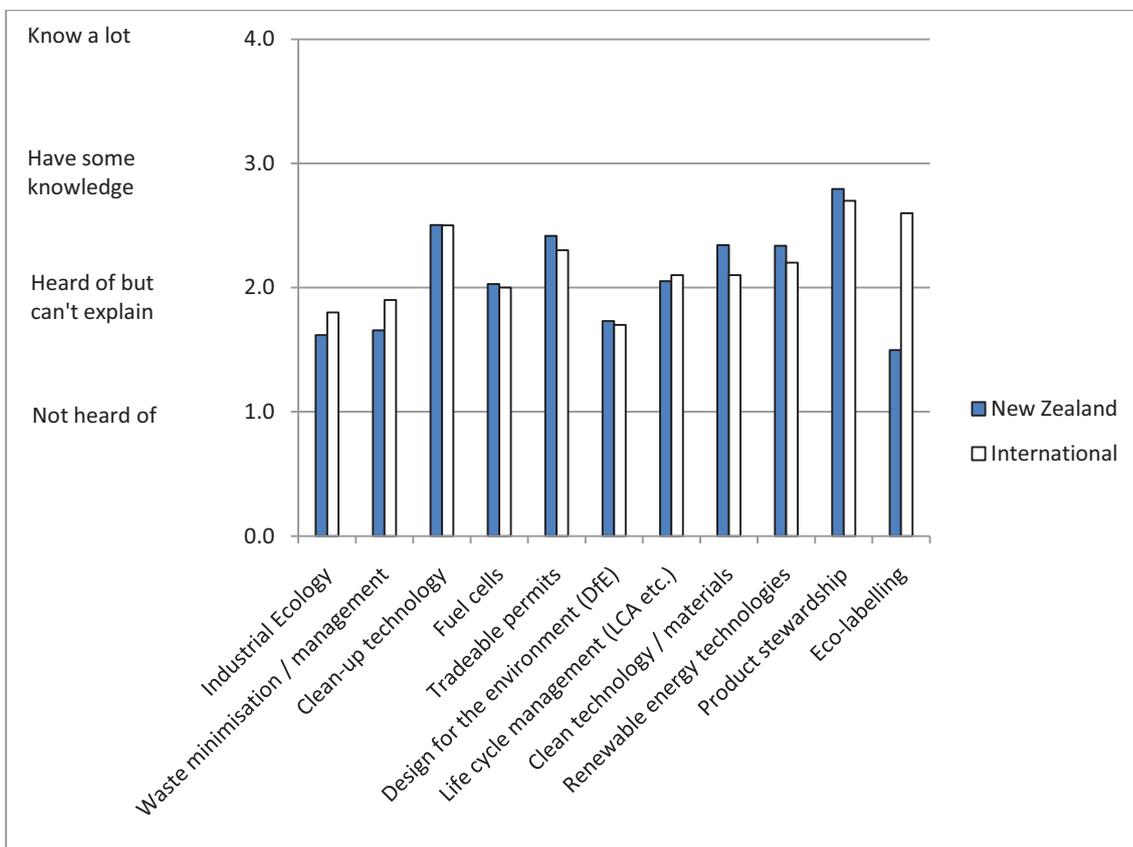


Figure 37: Comparison of Studies for Tools, Technologies and Approaches

Comment: refer to Table 28, Table 29, and the evaluation comparing values of significant difference.

Topic	NZ Mean	International Mean	NZ Variance	International Variance	T-Value
<i>Tool, Technologies and Approaches</i>					
Environmental Systems Thinking	1.8		0.71		
Eco-efficiency v eco-effectiveness	1.8		0.66		
Industrial Ecology	1.7	1.9	0.61	0.65	-4.01
Waste minimization/management	2.5	2.5	0.46	0.75	0.05
Clean-up technology	2.0	2.0	0.53	0.77	0.50
Fuel cells	2.4	2.3	0.59	0.87	1.94
Tradable permits	1.7	1.7	0.67	0.89	0.49
Design for the environment (DfE)	2.1	2.1	0.75	0.76	-0.72
Life cycle management (LCA etc.)	2.3	2.1	0.78	0.79	3.55
MET Matrix	1.1		0.12		
Eco-Indicator 99	1.1		0.05		
Ecodesign Web	1.2		0.20		
Design Abacus	1.2		0.25		
Cradle-to-cradle	1.7		1.02		
Biomimicry	2.0		1.08		
Clean technology/materials	2.3	2.2	0.70	0.72	2.12
Renewable energy technologies	2.8	2.7	0.60	0.90	1.55
Product stewardship	1.5	2.6	0.56	0.76	-18.79
Environmental supply chains	1.7		0.58		
Product-Service Systems (PSS)	1.5		0.58		
Dematerialization, light materials	1.7		0.68		
Enabling design solutions	1.7		0.68		
Contextwell-being	1.5		0.53		
Sustainable materials libraries	1.7		0.67		

Table 28: Evaluation of Studies for Tools, Technologies and Approaches / T-Values

Evaluation of Studies for Tools, Technologies and Approaches

Here, both sets of students had a score range from between 1.5 – 2.8. This indicated that students had either 'not heard of' these topics with a score of 1, or 'heard of but could not explain' with a score of 2, with 'some knowledge' of the score 3 not quite achieved.

Topic	NZ Mean significantly worse (less knowledge)	NZ Mean significantly better (more knowledge)
<i>Tools, Technologies and Approaches</i>		
Industrial Ecology	NZ 1.7	
Product stewardship	NZ 1.5	
Life cycle management (LCA etc.)		NZ 2.3
Additional Topics in NZ Survey	Not compared to other Surveys	
Environmental Systems Thinking	NZ 1.8	
Eco-efficiency v eco-effectiveness	NZ 1.8	
MET Matrix	NZ 1.1	
Eco-Indicator 99	NZ 1.1	
Ecodesign Web	NZ 1.2	
Design Abacus	NZ 1.2	
Cradle-to-Cradle	NZ 1.7	
Biomimicry	NZ 2.0	
Environmental supply chains	NZ 1.7	
Product-Service Systems (PSS)	NZ 1.5	
Dematerialization, light materials	NZ 1.7	
Enabling design solutions	NZ 1.7	
Context well-being	NZ 1.5	
Sustainable materials libraries	NZ 1.7	

Table 29: Significantly different Data for Tools, Technologies and Approaches

Azapagic et al, 2005, listed international student knowledge gaps, i.e. under 2.5:

- Industrial Ecology
- Product Stewardship
- Tradable permits

NZ students fared significantly worse than international students for 'industrial ecology and product stewardship', with a low mean score of 1.7 and 1.5 respectively. They scored significantly better for 'Life cycle management, LCA etc.', with a mean score of 2.3. Additional topics in the New Zealand survey ranged from 1.1 to 1.8, indicating that students had mostly 'not heard of' the following: environmental systems thinking; eco-efficiency v eco-effectiveness; MET matrix; eco-indicator 99; ecodesign web; design abacus; cradle-to-cradle; environmental supply chains; product-service systems (PSS); dematerialization + light materials; enabling design

solutions; context well-being; and sustainable materials libraries. Biomimicry achieved a mean score of 2.0, showing that students had 'heard of but can't explain' this topic.

These results show that New Zealand and international students alike have little or no knowledge of actual tools and approaches to implement SD/SPD, rendering Sustainable Design practically impossible. This contrasts sharply with the high ratings that the majority of both sets of students gave for the importance of SD, given in *Figure 38*, below. Using Azapagic's definition of knowledge gaps to be less than 2.5, a lack of knowledge was clearly the case for *eco-effective* tools and approaches, such as C2C / PSS, context well-being, biomimicry etc for *radical innovation*, as well as *eco-efficient* tools and approaches such as LCA etc. for optimization.

4.3.6 Comparison of Studies for Ratings of the Importance of SD

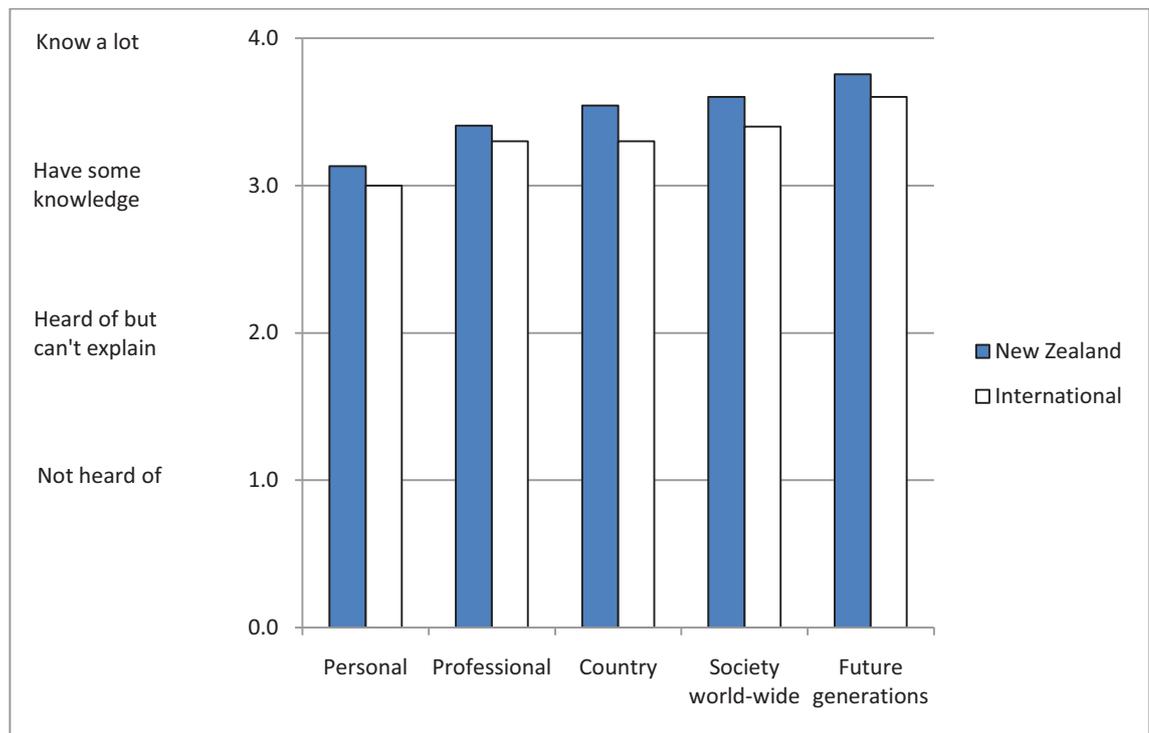


Figure 38: Comparison of Studies for Ratings of the Importance of Sustainable Development

Sustainable Development was rated highly by both New Zealand and international student groups (above 3.0). New Zealand results were higher in all instances:

- Personal (NZ 3.1 / International 3.0)
- Professional (NZ 3.4 / International 3.3)
- Country (NZ 3.5 / International 3.3)
- society world-wide (NZ 3.6 / International 3.4)
- future generations (NZ 3.8 / International 3.6)

The challenge for the future will be to build on the importance of SD for students and TEOs alike, and to integrate this into curricula. A number of open questions were formulated, and included investigating any inspirational and motivational sources towards SD/SPD for the students.

4.3.7 Evaluation of Open-ended Questions in New Zealand Survey

Final year NZ students were asked a number of open-ended questions to gain some *qualitative responses*, to counterbalance the majority of quantitative data:

1. *Give your own understanding of Sustainable Design (which contains Sustainable Product Design – SPD)*
2. *Is there any SD or SPD topic you would like to know about and why?*
3. *Describe any sources that especially inspire and motivate you towards SD/SPD*

In *Table 30* below, the responses to the first open question (*Give your own understanding of Sustainable Product Design – SPD*) are grouped under the themes of the two main umbrella headings: *eco-efficient* or *eco-effective* Sustainable Design. This allows one to see that the majority of responses (58 students), in this case twice as many, give understanding and definitions of SD that are *eco-efficient*, with a reduced number (29 students), with understanding and definitions of SD that are *eco-effective*. Many students did not respond at all to the question, indicating that they did not know how to define Sustainable Design, or that this was not at all clear for them.

Eco-efficient	
(reduction, minimization or avoidance of negative, harmful impacts)	NZ Student Nos.
Reduction, minimal or no negative impacts	23
Durable, long-life	10
Ecodesign, using LCM	7
Green design (single-issue focus)	2
DfE	1
Recycling, recyclable	7
Causing no harm for future resources and/or generations	8
Total	58
Eco-effective	
(increase and growth of positive, beneficial impacts)	NZ Student Nos.
Environment, society and economy – current SPD definition	2
Environment and society (incomplete definition)	1
Environment and economy “ ”	3
Environment OR society only “ ”	3
Positive, life-improving, enabling solutions	4
Cradle-to-cradle	2
PSS and/or closed-loop systems thinking	2
Materials selection, environmentally friendly materials	2
Renewable resources, including energy	8
Use of product and/or materials	2
Total	29

Table 30: Final Year ID / Eng. Student Definitions of Sustainable Design, New Zealand, 2010

In Table 31 below, taught courses with sustainability components are shown, as listed by the students. Of the total 175 New Zealand students of participating TEOs, (32 – design and 87 – engineering students) listed taught courses with sustainability. A number of students, (14 – design), considered that sustainability issues were integrated within the curricula. Individual courses can sometimes be electives. Course information from the respective websites was sparse, with no detailed information regarding sustainability content.

Industrial and Product Design Courses / Papers	
	NZ Student Nos.
Industrial Design & Manufacture	3
Industrial Design Studio IV	1
Industrial Design R & D	1
Industrial Design Research Project	2
Sustainable Practice	14
Design Fundamentals	1
Industrial Design Theory	3
Industrial Design Project	2
Environmental Design Theory	2
Environmental Design Project	1
Thermo-processes 1	1
Energy Resources	1
Total	32
Mechanical and Mechatronics Engineering Courses / Papers	
	NZ Student Nos.
Professional & Sustainability Issues	74
Energy Technology	9
Technology Management	1
Final Year Project	1
Quality Systems Design	2
Total	87

Table 31: Design and Engineering Taught Courses / Papers with Sustainability Components

It can be concluded that teaching SD/SPD at undergraduate level for industrial design and engineering in New Zealand is currently in a sparse and ad hoc manner, with no overall framework. The low values of *actual knowledge* of final year students, as clearly indicated by the New Zealand survey, means that current teaching of SD/SPD is *insufficient*. This was further emphasized by the responses to an open question within the survey, indicated by Table 32, below, which shows the requested topics by students:

Industrial and Product Design / Requested Topics	
	NZ Student Nos.
Majority of SD/SPD Topics	6
EPP, Legislation, Policy & Standards	3
ALL Tools, Technologies & Approaches	2
Cradle to Cradle	2
Biomimicry	1
Sustainable Manufacture (LCM, LCA)	2
Total	16
Mechanical and Mechatronics Engineering / Requested Topics	
	NZ Student Nos.
Majority of SD/SPD Topics	3
Components of SD, General Issues	2
Climate Change	1
Social Sustainability	1
Population, Society & Technology	2
ALL Tools, Technologies & Approaches	2
Biomimicry	1
Sustainable Manufacture (LCM, LCA)	1
Renewable Energy Technologies (Solar Panels, Hydrogen Fuel Cells)	6
Total	19

Table 32: SD/SPD Topics requested by Final Year ID / Eng. Students, New Zealand, 2010

For the second open question (*Is there any SD or SPD topic you would like to know about and why?*) the overall response was poor, yet a number of students requested teaching on the 'majority of SD/SPD topics' as well as 'ALL tools, technologies and approaches' listed in the survey questionnaire (see Table 32). The poor number of responses, even with some negative responses (1 – design and 22 – engineering) of either not needing or not caring about any sustainability information, indicates a real complacency about integrating SD/SPD into their chosen professions. It also indicates that students have a total lack of information – they cannot ask about anything because they don't know about anything. *This is in stark contrast to the high ratings of the importance of SD.* Therefore the low levels of actual SD/SPD knowledge must clearly be rectified.

Both industrial design and engineering students requested discipline-specific knowledge, *relevant* to design or engineering respectively, in the application of SD/SPD:

- *For designers:*
 - design-led solutions;
 - how to integrate sustainability into design?
 - industry-relevant applications; and
 - ethics, responsibilities and importance for designers.
- *For engineers:*
 - SD specific to mechatronics engineering;
 - how to integrate sustainability into mechanical design?
 - sustainable materials for engineering; and
 - interested if topics include technical aspects and/or measurable benefits.

Hence, this validates the necessity and rationale for the *Conceptual Educational Framework and Guidelines* of this research: to provide an *overall educational framework* for teaching SD/SPD in an integrated and cohesive way, for *both* disciplines. There is also a need for discipline-specific relevance, i.e. articulation of the subject matter in a manner appropriate to the discipline.

In *Table 33* below, sources of inspiration and motivation towards SD/SPD are given. Responses to the final open question were limited, but showed that sources of inspiration were mostly of a social nature (*46 students*), under the following themes:

- personal values, upbringing and family;
- culture, country and indigenous peoples;
- ethics, social well-being and awareness; and
- religion and politics.

A smaller number (*37 students*) were motivated by:

- lectures, courses and academic staff;
- final year projects;
- environment and environmental technologies; and
- personal experience and travel.

The least number (*11 students*) had been motivated by:

- information via the media.

Social:	NZ Student Nos.
Personal Values, Upbringing & Family	18
Culture, Country, Indigenous People	10
Ethics, social well-being and awareness	8
Religion & Politics	10

Education:	NZ Student Nos.
Lectures, Courses, Academic Staff	22
Final Year Projects	3
Environment & Environmental Technologies	8
Personal Experience & Travel	4

Media:	NZ Student Nos.
General	4
Literature	3
Websites	4

Table 33: Sources of Inspiration and Motivation for Final Year ID / Eng. Students towards SD/SPD, New Zealand, 2010

One can conclude that the first two sources of inspiration, with (46 and 37 students) respectively, need to be combined to achieve the greatest positive results towards SD/SPD. Therefore, tertiary education needs to be a driver of inspiration towards sustainability, especially targeting lectures, courses and final year multidisciplinary projects, that combine with and reflect values, culture (including indigenous knowledge and culture), religion, ethics, and social well-being. This can also contribute positively to creating sustainable entrepreneurs. This is therefore reflected in the *Conceptual Educational Framework and Guidelines*.

4.4 Summary of Evaluation of NZ and International Studies

When compared and evaluated against an international study (Azapagic et al., 2005), it was found that awareness and knowledge of SD/SPD for New Zealand final year industrial design and engineering students was relatively low on a number of key issues. The New Zealand survey highlighted that although students gave high ratings for the importance of Sustainable Development (SD), as did international students, by their final year they had little or no knowledge of *how to* implement sustainability within their disciplines. This renders Sustainable Product Design (SDP) practically impossible. A similar lack of knowledge was determined for major ecological and environmental issues, as well as for international policy and standards. The latter are especially important for New Zealand graduates, who will require this knowledge in a global economy and for export markets.

Azapagic et al, 2005, indicated gaps in knowledge to be less than 2.5. Comparative values for New Zealand and International students can be read directly from the first two columns of tables for evaluation of studies – please refer to individual sections of this chapter. Topics where *New Zealand students fared significantly worse* than International students, are listed below. Additional topics from the New Zealand survey with equally low values are also given. Hence, appropriate topics have been taken into account in the *Conceptual Educational Framework* under their respective umbrella headings, in order to address these major gaps in knowledge.

Sustainable Development Concepts: Precautionary Principle.

Additional Topics (NZ Survey only): Factors, 4, 10-20.

Environmental Issues: Air pollution;
Water pollution; and
Ozone depletion.

Policy, Standards and EMS: Rio Declaration;
ISO 14000 / ISO 14001;
EU EMAS;

	The Florence Convention;
	Eco-labelling;
<i>Additional Topics (NZ Survey only):</i>	UNCED (Earth Summit, Rio);
	Agenda 21;
	UNFCCC;
	UN Climate Change Conference, Denmark;
	Global Reporting Initiative; and
	Green Financial Indexes.
<i>Tools, Technologies & Approaches:</i>	Industrial Ecology;
	Product Stewardship;
<i>Additional Topics (NZ Survey only):</i>	Environmental Systems Thinking;
	Eco-efficiency v eco-effectiveness;
	MET Matrix;
	Eco-Indicator 99;
	Ecodesign Web;
	Design Abacus;
	Cradle-to-Cradle;
	Biomimicry;
	Environmental Supply Chains;
	PSS (Product-Service Systems);
	Dematerialization, light materials;
	Enabling design solutions;
	Context well-being; and
	Sustainable materials libraries.

The open-ended questions gave an insight into values and opinions, providing valuable data for curricula builders. In general, New Zealand students rated SD highly, and are motivated mainly by social values. *The challenge will be to motivate and inspire students through education*, to enhance motivating factors through appropriate courses that will contribute to them becoming future sustainable entrepreneurs. To this end, the *Conceptual Education Framework* incorporates *elements of fun*. The rationale for this is to engender deep learning, direct understanding and appreciation of SD/SPD issues, in an enjoyable way for students and academic staff alike.

5. EDUCATIONAL FRAMEWORK AND GUIDELINES

5.1 Overview

As found from the literature and the New Zealand final year student survey, the individual components of sustainability have previously been taught in isolation within design and engineering curricula, and not in a comprehensive, integrated way at undergraduate level. The *Conceptual Educational Framework and Guidelines* provided within this chapter are a model. A model has to be purposeful, useful and capable of revision. It has the *design intent* of bringing SD/SPD into *mainstream* tertiary education for industrial design and engineering at undergraduate level, with a generic degree structure that can be modified to combine with discipline-specific core content of degrees. The *Conceptual Educational Framework and Guidelines* are therefore offered as a plausible and feasible underpinning to a syllabus or curricula, as a *prototype, but are not the actual curricula*.

The latter will be achieved, firstly through curricula builders, and secondly through testing of more detailed teaching modules, as suggested within the *Guidelines*. Therefore the *Conceptual Educational Framework and Guidelines* are the best progression of SD/SPD principles of this research, which are consistent in their rational analysis, alignment and synthesis, supported by expert views of the literature. The next phase of future delivery, testing, evaluation and refinement by educators will be necessary to prove the success, and defined under 6.3, *Future Research*.

This research therefore had the objective of highlighting what is important to achieve *radical innovation for sustainability* in tertiary education, and formulated these as key concepts, based on a comprehensive literature review:

1. *Emphasis on the Social Element of SD/SPD*
2. *Transition towards Systems Thinking via PSS*
3. *Complementary Sustainable Design Strategies*
4. *Transition towards Strategic Design*

These concepts advocate *emphasis on the social element of SD/SPD* through context and creativity, *systems thinking* through PSS (*Product-Service Systems*), *eco-effectiveness first*, with Cradle-to-Cradle design principles (C2C), *followed by eco-efficiency for optimization*. A design/technology interface can promote and support sustainable behaviour through *Strategic Design*. These are concepts for practitioners and tertiary education. It was evident from the New Zealand final year student survey that double the number of students connected SD/SPD with eco-efficiency rather than eco-effectiveness. At the same time, inspirational and motivational factors towards SD/SPD were identified from student responses. Successful examples within industrial design and engineering tertiary education were investigated.

A 'sea-change' is therefore necessary in industrial design and engineering tertiary education. SD/SPD needs to be totally integrated within all regular disciplinary courses, as it is insufficient to just introduce one basic course on SD/SPD. Input is needed from all TEO strata, from bottom up and top down, for an effective cultural change towards SD/SPD in the curriculum and in the classroom. Interfaculty communication, as well as between design and engineering TEOs, will be essential for the ongoing discussions necessary for the required changes and multidisciplinary. Further, international cooperation is needed to gain knowledge about experiences and best practices already gained, as the challenges and implications of SD/SPD are global.

This thesis aimed to provide a 'helicopter viewpoint' of the important themes, and to promote systems thinking of 'macro' issues when approaching problem definition. It means that practitioners and students in industrial design and engineering must engage with the societal component of SD/SPD to a far greater depth, to consider *social behaviour* and how to influence this positively with a design/technology interface through *Strategic Design*, towards more sustainable ways of living.

The implications of this with the current arts/humanities focus of design and technology-driven engineering, is that the two complementary disciplines of industrial

design and engineering must learn how to communicate and collaborate with each other. There also needs to be greater involvement of other disciplines such as social sciences and ecology. This applies both to practitioners and tertiary education; the latter should be facilitated through multidisciplinary student projects.

This research gained knowledge from three sources:

- LITERATURE REVIEW;
- TEACHING (international curricula and professional bodies), and
- LEARNING (New Zealand final year student survey).

These research strands shown above were synthesized and refined into the follow outcomes, and detailed within this chapter.

- *Synthesis of Expert Views, Appendix I*
- *Strategic Design Cycle:*
 - Model of complementary but sequential SPD strategies*
- *The terms 'design-max' and 'eco-max' as design intent for Radical Innovation*
- *Guiding Principles of Radical Innovation for Sustainability*
- *Core Structure underlying Framework, using Design Process*
- *Conceptual Educational Framework*
- *Educational Framework Focus – Years 1-4*
- *Educational Framework Guidelines*

It was beyond the scope of this research to address the entirety of expanding ecological knowledge, but rather to uncover *visible shortcomings* in tertiary education for design and education. The latter has been achieved. The New Zealand survey indicated gaps in SD/SPD knowledge of final year industrial design and engineering students (summarized in 4.4). These have been addressed under the umbrella headings within the *Conceptual Educational Framework*, and listed individually under *Educational Framework Focus – Years 1-4*, and *Educational Framework Guidelines* (see 5.6 and 5.7 respectively).

5.2 Strategic Design Cycle Model

The *Strategic Design Cycle* (see *Figure 39*) is a graphical representation of the knowledge gained from the three strands of investigation undertaken within this research (LITERATURE REVIEW, TEACHING AND LEARNING). This is that SPD needs to be context-driven (with emphasis on the social context) rather than technology-driven, as derived from a digest of the literature and expert views, see *Chapter 2, and the Synthesis of Expert Views, Appendix I*.

The *Synthesis of Expert Views* needed to be *simplified*, and the design process moved from complex to simple, within the converging 'define' phase of the double diamond design process (see *Figure 27*). This resulted in the sequential phases of the *Strategic Design Cycle Model*. The *simplified* themes (and order within the model) are a construct, and build on and are supported by above mentioned expert views. This resulted in the sequential phases of the *Strategic Design Cycle Model*. This model was designed in its entirety by the author of this research, to *clearly and simply illustrate* the necessary sequential order between phases, which should happen within iterative cycles.

- 'design-max' – *designing for maximum* benefits, macro issues of context in 'wicked' problem definition;
- *eco-effectiveness* - *for positive effects*, using C2C 12 principles and 5 steps for result-oriented, functional PSS problem solutions;
- *eco-efficiency* - *for positive processes*, optimization and maximization of positive, beneficial C2C/PSS; and
- 'eco-max' – *economy for maximum equity*, maximization of social equity within environmental supply chains using 'blue ocean' business strategies.

The terms '*design-max*' and '*eco-max*' have been designated by the author of this thesis. This is to accentuate and emphasize the thinking and design intent necessary for *radical innovation through maximization* of positive, beneficial systems promoted by this thesis, that are inherent to *eco-effective* principles, and

to strive towards at all levels (Anastas & Zimmermann, 2003; Braungart et al., 2007; William McDonough & Braungart, 2002; William McDonough et al., 2003).

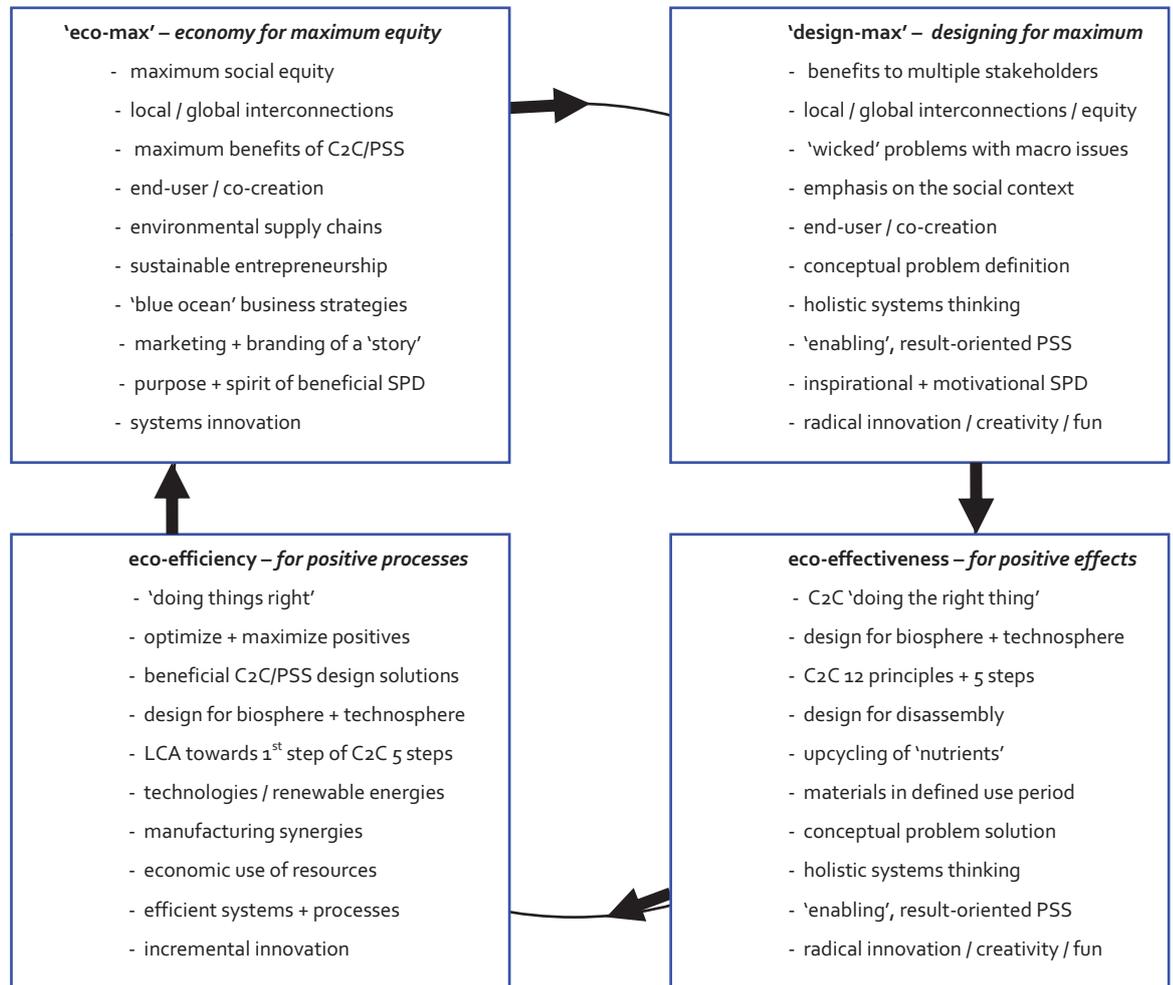


Figure 39: Strategic Design Cycle - model of complementary but sequential SPD Strategies (Haemmerle, 2011)

It is therefore essential to uphold the *sequence* of phases in relation to each other (Figure 39: Strategic Design Cycle - model of complementary but sequential SPD Strategies (Haemmerle, 2011)), to achieve 'doing the right thing' of *eco-effectiveness first*. For this we must redirect our emphasis away from the current product focus, which emphasizes *eco-efficiency* first and reductionist design, to a much wider viewpoint, towards a needs analysis and a redefinition of the problem: the 'what?' must come before the 'how?' This is achieved by a needs focus with emphasis on the social element, holistic systems thinking, C2c and result-oriented, functional PSS set within strategic design.

It enables the potential for radical new concepts and innovation. In concurrence with the above authors, *eco-effectiveness placed foremost*, 'doing the right thing', offers a wider perspective as the design platform, to achieve positive, beneficial SPD for the environment, economy and society. *Eco-efficiency placed later* then becomes a way to optimize and maximize positive, beneficial growth and C2C systems, rather than the purely reductionist understanding previously attached to the eco-efficiency design strategy.

However, the point of entry into this cycle will determine the starting point, such as economic interests - '*eco-max*', or the actual design brief - '*design-max*'. Yet it remains imperative to uphold the sequential order of phases relative to each other, and to fulfil a complete cycle, most likely a number of iterative cycles, so that *all* phases are covered, in the sequence shown.

This is important both for practitioners and tertiary education. For the latter, the order of teaching (deciding the point of entry into the cycle and the initial focus) will be governed by the rationale of tutors, to modify by bringing their own knowledge and examples.

This research shows how opposing design strategies, and disciplines, can *complement* each other. Therefore the *Strategic Design Cycle* indicates not only a design process for *radical innovation for sustainability*, but also where the strengths of individual disciplines can best be implemented within iterative cycles. Creative strategic design (with emphasis on the social element of SD/SPD) *for eco-effectiveness first*, requires input from industrial design at the conceptual design phase. Creative implementation of *eco-efficient* technologies requires input from engineering at the refinement phase of PDP. These processes are not hierarchical, but complementary, with the aim to achieve a design/technology interface to *promote and support* sustainable behaviour and quality of life. The *Strategic Design Cycle* therefore shows a clear pathway, which is circular and cyclical.

5.3 Guiding Principles of Radical Innovation for Sustainability

This section provides *Guiding Principles* for each of the key concepts of radical innovation for sustainability, as shown below.

5.3.1 Guiding Principles for Emphasis on the Social Element of SD/SPD

1. SPD is people centred.
2. SD/SPD has 3 components: *environmental, economic and social*, which need to be considered simultaneously, within *systems thinking*.
3. Emphasis on the social and behavioural elements of SD/SPD is now urgent, and integral to problem definition. This is due to humans becoming recognized as part of the whole earth system (Carson, 1962), and human behaviour as part of the problem (Vlek & Steg, 2007).
4. Behavioural scientists believe that negative environmental effects are primarily based on *social and behavioural problems*, caused by *population*, combined with the multiplication of other factors such as: *affluence, technology, institutions and culture* (Vlek & Steg, 2007).
5. There is a clear need for the reintegration of humans with their environment. Similarly, the domains of design and engineering need to engage positively with *radical innovation* (E. L. Dewberry & Monteiro de Barros, 2009).
6. Cumulative effects of present, mostly unsustainable, growth need to be tackled through design briefs covering macro issues:
 - increased clearing of vegetation for human settlement;
 - growing separation from nature;

- increased technology;
 - intensified consumption of raw materials/fossil fuel energy;
 - expanding transport infrastructure and mass motorisation; and
 - computer revolution and use of PCs (Vlek & Steg, 2007).
7. *Human aspiration* for growth and improvement is natural (Takacs-Santa, 2004), cited in (Vlek & Steg, 2007) which should be supported in a beneficial way for the environment, economy and society.
 8. *Well-being and quality of life* need to be achieved through an extended system, larger than the present consumption model, to fulfil needs and values sustainably through *systems thinking* (T. Bhamra & Lofthouse, 2007; Manzini, 2002; J.H. Spangenberg et al., 2010; Vezzoli & Manzini, 2008).
 9. *Significant psychological / sociological transformations are necessary* for the reintegration of environmental and social concerns, with a greater input from the social and behavioural sciences (Vlek & Steg, 2007).
 10. *Human needs*: Instead of further increasing human comfort with a diminished 'workload' and diminished individual and communal knowhow and capacities, future SPD needs to review our ideas of 'work' and to provide *enabling solutions* (Vezzoli & Manzini, 2008), to reflect human and environmental needs for positive ways of being and doing.
 11. The education of industrial designers and engineers will also need to reflect a greater emphasis on the social/behavioural aspects. They will need to give increased consideration to *collective* rather than *individual* product use and user behaviour, the human/technology interface, and to *promote* positive sustainable user behaviour *through design and technology* (Midden et al., 2007).
 12. *Multidisciplinary* research and tertiary education is necessary, to include psychologists/behavioural scientists/ecologists/scientists/industrial designers/

product designers/ mechanical and mechatronics engineers. Specialists need to collaborate and deal with holistic problems/macro issues (Carson, 1962).

5.3.2 Guiding Principles for Transition towards Systems Thinking via PSS

1. *Sustainable product design* addresses the 3 elements of SD (environmental, economic and social). The latter can include ethics, equity, services and dematerialization (PSS), and is capable of achieving more radical system innovation *towards eco-effectiveness*.
2. *A broadening of scope within systems thinking* is required, to consider macro issues, instead of just optimizing already existing systems or product features.
3. *Wider search space by redefining the problem*: Using the C2C framework supports a new way of thinking and a different design approach.
4. *Creativity is required to look holistically at the problem source* rather than its effects, and the most direct way to design *radical, innovative solutions and PSS*.
5. *Product-service systems (PSS) are necessary that are beneficial, enabling solutions*, contain 'context well-being' that reflect inspirational/spiritual and cultural requirements, to satisfy real 'needs', not 'wants'.
6. *Result-oriented, functional PSS* has the most potential for environmental benefits (Arnold Tukker, 2004), producing functional results and outcomes, rather than products.
7. *'Light' products*, with reduced materials, size, weight etc., can cause a 'rebound' effect through multiplication of original volumes.

8. *PSS + 'Light' products* by themselves are insufficient to resolve all the issues, but should be seen as desirable components within systems thinking (Vezzoli & Manzini, 2008),.
9. *Enabling solutions* are the priority and responsibility of all those involved in the design of PSS, in order to 'live better, consume less" (Vezzoli & Manzini, 2008, p. 22), and to address issues concerning *quality of life*.
10. *Context well-being / life-context* needs to be addressed, for an offering *beyond* product well-being (Vezzoli & Manzini, 2008).

5.3.3 Guiding Principles for Complementary Sustainable Design Strategies

1. Sustainable Design strategies can be complementary when used in this order: *Cradle-to-Cradle design principles (C2C) first*, followed by eco-efficiency for optimization.
2. '*design-max*' – *designing for maximum*, and '*eco-max*' – *economy for maximum equity*, are designated by the author of this research, to emphasize the design intent of *radical innovation through maximization* of positive, beneficial growth inherent to eco-effective C2C principles.
3. Moving *from a product focus (which emphasizes eco-efficiency first) to a needs focus (which emphasizes eco-effectiveness first)*, through systems thinking, C2C and PSS.

4. *Creativity is required for eco-effective problem definition* in the conceptual design phase, to best achieve *radical innovation for sustainability*. The design scope narrows further along and is more concerned with incremental improvements, optimization and *eco-efficient, technical issues* (manufacturing processes, fixtures etc.).
5. C2C: creating triple *value* ('triple top line' of ecology, economy, equity) with PSS that are beneficial in their expansion, growth is positive and to be welcomed, instead of unwanted detrimental effects having to be minimized (William McDonough & Braungart, 2002).
6. Rather than the limitations of Industrial Ecology within a contained, physical location, *eco-efficient design* should be adapted to optimize and maximize the positive, beneficial effects of C2C/PSS. Synergies need to be found between companies in the supply chain, for a symbiosis between sustainable products, services and systems (PSS) and a flow-on effect to their materials, manufacturing processes and supply chains, supporting an *eco-effective* C2C framework.

5.3.4 Guiding Principles for Transition towards Strategic Design

1. "...industrial design is commonly seen as 'people-centred' and engineering design is commonly seen as 'technology-centred'" (Bates & Pedgley, 1998), cited in (Sherwin & Evans, 2000), and reiterated by Sherwin (Sherwin, 2004).
2. Industrial design and engineering professions are complementary to each other, and therefore need to collaborate for Sustainable Design. Sherwin and Evans, 2000, suggest that industrial design is best utilized at the primary or conceptual design phase, for radical innovation of Factors 10 –20 and PSS (product-service systems). Where the PDP (product development process) is

already more advanced, where eco-efficiency and technical solutions are required, this is an area for design engineering (Sherwin & Evans, 2000).

3. *Context*: designing *value* within the 'equity' sector, PSS must also satisfy real human 'needs' and not 'wants', be beneficial, enabling-solutions, context-based to provide quality of life, that are a pleasure and delight in all ways possible, to benefit human and other life forms (*Functional + Social / Positional + Inspirational / Spiritual*) (Walker, 2006).
4. *Context*: intentional design can *promote sustainable behaviour*, ascending through philosophies of resources, form and function, purpose and spirit (Stegall, 2006).
5. *Context*: participation (co-creation) of the user through *direct encounter* in the creation of material goods, recognizable *transience* of products and *localisation* of design and production or post-use input (Walker, 2003).
6. Sherwin (Sherwin, 2004) declared that the current dominant practice of the life cycle approach (techno-centred) achieves only incremental improvements; instead, *creativity and radical innovation* is necessary at the conceptual design phase.
7. Manzini (Manzini, 2009) presented many ways for designers to be proactive, calling for *radical* changes in lifestyle. Manzini, 2009, gave 3 important points:
 - i. *Research on eco-efficiency has been successful, but is insufficient.*
New ways of living and interacting with PSS are now necessary
 - ii. *Recognition of environmental danger without positive solutions can be counter-productive.* Designers need to be proactive towards SPD.
 - iii. *Indication of new qualities:*
enabling capacities; qualities of self, private and public spaces; physical 'commons' such as air, water, landscape; social 'commons' such as neighbourhoods and communities; the use of time; and the integration of 'local' and culture.

5.4 Core Structure underlying Framework, using Design Process

As shown below (Figure 40), the core structure of the *Conceptual Educational Framework* uses a diverging and converging design process. It is a model for *radical innovation for sustainability*, which targets SPD as the final result. It can be used by students and teachers, as well as practitioners. Within tertiary education, each year can be built up with a first phase primarily of 'discovery' of material taught within lectures, tutorials etc., followed by a second phase of 'define', where the material taught needs to be *applied* within (multidisciplinary) projects. At the end of each cycle, there will be an 'outcome', which can be assessed.

Core Structure underlying Framework

using Diverging/Converging Design Process

Source: Linda Haemmerle, 2011

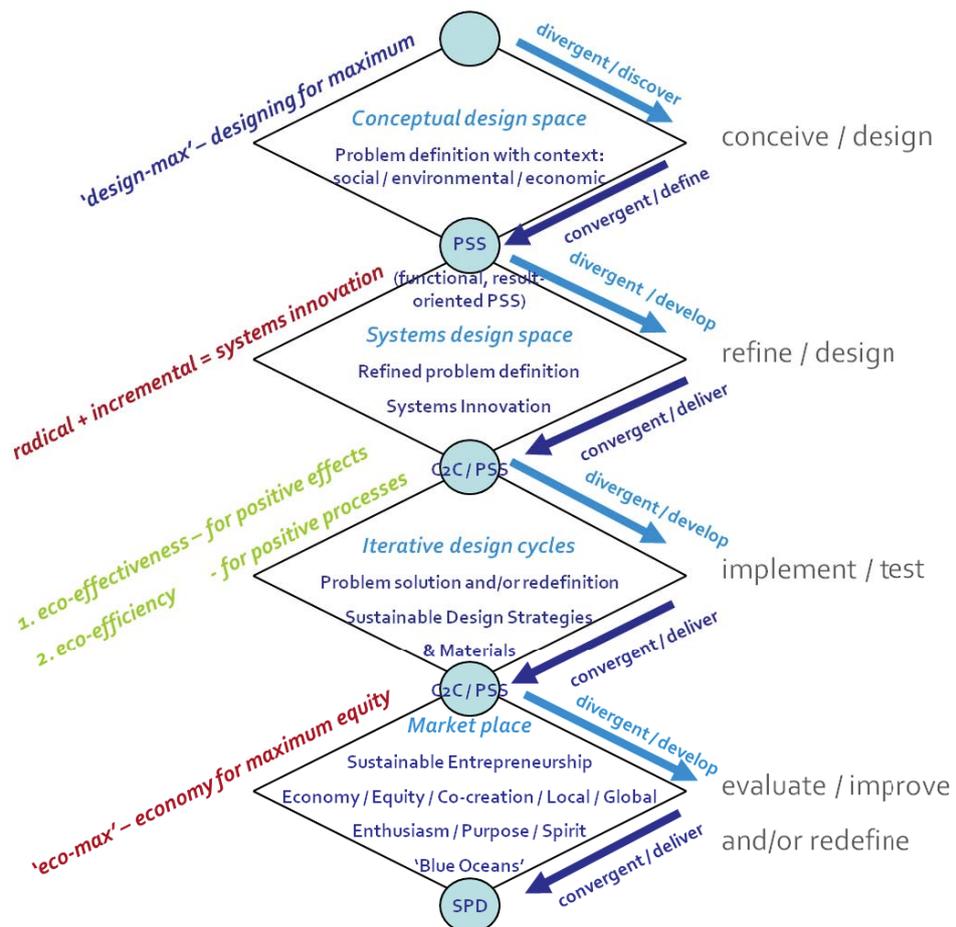


Figure 40: Core structure underlying framework, using diverging/converging design process

(Haemmerle, 2011)

5.5 *Conceptual Educational Framework*

From a New Zealand perspective, it was evident from the survey that final year industrial design and engineering students still had inadequate knowledge of SD/SPD issues. To improve this situation, the *Conceptual Educational Framework and Guidelines* of this research offer a simple, coherent structure for an *integrated* approach of sustainability within an undergraduate degree syllabus, and across disciplines. They have been synthesized directly from the three sources of research, LITERATURE REVIEW, TEACHING and LEARNING, and are conceived as a *base structure* for curricula, rather than the curricula itself.

The *Conceptual Educational Framework* (see *Figure 41*) is intended as an underlying structure, to highlight important components towards embedding *radical innovation for sustainability* in Industrial Design and Engineering curricula, and a starting point for curricula building. The *Curricula Guidelines* provide recommendations and guidance towards individual components and topics for years one to four, of how to integrate sustainability knowledge from simple to complex, and in a logical progression of deepening this knowledge without overwhelming students.

Together, they show how themes can relate to each other within a 4-year undergraduate degree structure for industrial design and engineering (years 1 and 2 should be combined for a 3-year design degree programme, where appropriate). The systems-based *Conceptual Educational Framework and Guidelines* are intended as a draft generic degree structure, to combine with discipline-specific industrial design and engineering core courses. Further refinement will be necessary, i.e. by curricula builders, to accommodate requirements of individual faculties, accreditation and multidisciplinary collaboration. Inherent to this degree structure is problem-based learning (PBL) and multidisciplinary (MD). Participation of industrial design and engineering disciplines is essential, either as inter-faculty collaboration within a TEO where both disciplines are taught, or as 'twinning', for collaboration between TEOs.

Conceptual Educational Framework

Generic Degree Structure to combine with discipline-specific Industrial Design / Engineering Core Courses

Source: Linda Haemmerle, 2011

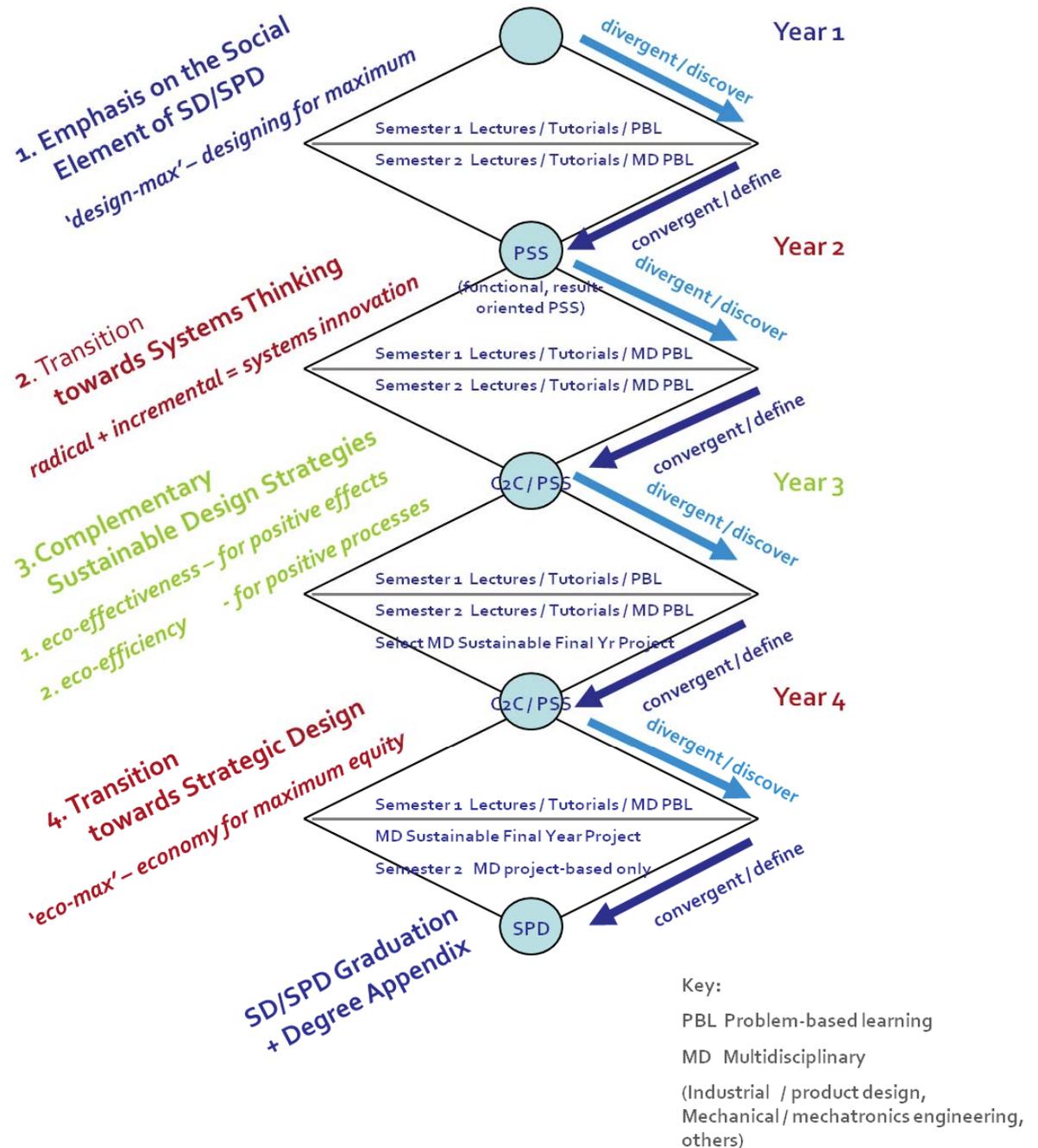


Figure 41: Conceptual Educational Framework, a structure to combine with discipline-specific courses

(Haemmerle, 2011)

5.6 Educational Framework Focus – Years 1-4

An undergraduate program could be structured so that SD/ SPD / ecology and ethics / sociology knowledge were introduced at a basic level and then progressively deepened within study years 1-4, an approach that is currently implemented in design-based degrees in the European Union (Morris et al., 2007). Each year could still have a major focus, as follows:

- Year 1** **Emphasis on the Social Element of SD/SPD**
SD/SPD and 'Wicked' Problems / Ecology / Ethics / Socio-cultural
macro issues / Sustainable materials / Renewable energies /
Creativity / SCALES core principles;
- Year 2** **Transition towards Systems Thinking via PSS (Product-Service Systems)**
Systems Thinking / Functional, result-oriented PSS /
Servitization of Products, Productization of Services / Material culture /
Dematerialization / 'Enabling' design solutions;
- Year 3** **Complementary Sustainable Design Strategies**
Eco-effectiveness: C2C 12 principles and 5 steps, biomimicry /
Eco-efficiency: LCA towards 1st step of C2C 5 steps, optimizing
resource use and processes /
'Design-Max': *designing for maximum*
Strategic Design,
Beneficial, positive C2C/PSS design strategies,
Redefinition of the problem / design briefs with a wide perspective;
Selection of multidisciplinary (MD) Sustainable Final Year Project;
- Year 4** **Transition towards Strategic Design**
'Eco-Max': *economy for maximum equity*
Strategic Design + Economy,
Sustainable Entrepreneurship / Blue Ocean Business Strategies
Management (leadership, teamwork), Environmental Supply Chains
Environmental Product Policy (EPP) / Legislation / IP /
Environmental Management Systems (EMS) /
Multidisciplinary (MD) Sustainable Final Year Project / competitions.

Years 1/2 should be combined where study is conducted within 3 years. Multidisciplinary projects to include Industrial and Product Design, Mechanical and Mechatronics Engineering and others. This can be facilitated through interfaculty collaboration where both disciplines are present within a TEO, or collaboration agreements (twinning) between TEOs.

5.7 Educational Framework Guidelines

Curricula recommendations are given as guidelines within the themes of the *concepts of radical innovation for sustainability*, as in the following *Tables 34 - 37*. The guidelines are to be combined with discipline-specific core content of design and engineering degrees. All guidelines have been synthesized directly from the three sources of research: LITERATURE REVIEW, TEACHING and LEARNING. The guidelines support the *Conceptual Educational Framework*; together they are conceived as a *base structure* for curricula, rather than the curricula itself. Actual curricula necessitate further refinement according to individual faculties and incorporating multidisciplinaryity.

Table 34: Curricula Guidelines for Emphasis on the Social Element of SD/SPD

<p>Year 1: Emphasis on the Social Element of SD/SPD</p> <p>Curricula Guidelines for Radical Innovation for Sustainability</p>	
1.	<p>Designed artefacts and processes will have consequences. We must now embrace a more cyclical worldview that is circular instead of hierarchical, supportive of other life forms and reflected in the products, services and systems we design and manufacture: negative impacts need to become positive, beneficial growth. Industrial design and engineering education need to encompass larger issues, and to promote and support <i>positive sustainable behaviour</i>.</p>
2.	<p>Additional non-technical courses to address developing social and ecological knowledge, supported by the respective faculties.</p>
3.	<p><i>Ecology + technology + social/philosophy/ethics</i>: introductory teaching modules on ecosystems and the <i>interrelatedness</i> of all things, including the place and responsibilities of humans within these ecosystems. The human/technology interface is paramount to how sustainable behaviour can be achieved, and therefore must not be considered in isolation, but simultaneously. Basic knowledge acquired in Year 1 should be progressively deepened.</p> <ul style="list-style-type: none"> • <i>Elements of fun</i>: field trips to gain a first-hand impression of ecological problems of <i>national relevance</i> (e.g. New Zealand - air/water pollution, ozone depletion, other).
4.	<p>Interfaculty collaboration and equal teaching to be promoted , involving Faculties of Ecology, Philosophy, Sociology, Applied Sciences, Design, Engineering, Business etc., culminating in hybrid lecturers with cross-disciplinary knowledge, where possible.</p>
5.	<p>Application of knowledge through PBL, with 'intentional design' in design briefs to promote positive sustainable behaviour, both individual and collective.</p>
6.	<p>Team essay writing for future sustainable scenario building of macro issues, with broad essay topics from Year 1 curricula, to develop into design briefs.</p>
7.	<p>Teaching of creativity techniques, including 'backcasting', and based on design pedagogy, as <i>creativity</i> is essential for achieving levels of <i>radical innovation</i> required by <i>sustainable design</i>, rather than the lesser levels of <i>green or ecodesign</i>. Refer to the Centre of Excellence in Teaching and Learning (CETL) in Creativity project at the Universities of Brighton and Sussex, (www.sussex.ac.uk).</p> <ul style="list-style-type: none"> • <i>Elements of fun</i>: Creative Labs (conceptual design and prototyping, sustainable materials and technologies), 'playing with' sustainable materials combined with

context and redefinition of problems: when you re-define the problem, it opens up the search space and the scope of divergent thinking necessary to arrive at innovative PSS. For designers and engineers, it will be *reinvention* where they will have the most direct positive influence, to re-define the problem and create radical new concepts using PSS, and to *promote* positive user behaviour through a design/technology interface.

- See point 10, sustainable materials library: Material Connexion, (<http://www.materialconnexion.com/Home/tabid/36/Default.aspx>)

8. Teaching modules from DEEDS (Design Education & Sustainability) and the SCALES core principles.

9. Teaching modules on state-of-the-art renewable energies and technologies.

- *Elements of fun*: field trips to view New Zealand and/or Southern Hemisphere examples (solar, wind, geothermal, hydroelectricity, other).

10. TEO and student membership of sustainable materials library Material Connexion (<http://www.materialconnexion.com/Home/tabid/36/Default.aspx>).

- *Elements of fun*: field trips to branches of Material Connexion sustainable materials libraries, located in the Southern Hemisphere (please see website above for other locations):

Material ConneXion Bangkok

6th Floor, The Emporium Shopping Complex
622 Sukhumvit 24, Bangkok 10110 Thailand
Phone: 66 (0) 2.664.8448
Fax: 66 (0) 664.8459
Email: infothailand@materialconnexion.com
Hours: 10:30AM - 9:00PM, Tues. - Sun.

Material ConneXionDaegu

701-824 3F, DaeguGyeongbuk Design Center
107-4 Shincheon 3-dong, Dong-guDaegu, Korea
Phone: 82 53.740.0032
Fax: 82 53.740.0000
Email: infokorea@materialconnexion.com
Hours: 9:00h - 12:00h, 13:00h - 18:00h, Mon. – Fri

<http://materialconnexion.com/Home/Matter/MATTERMagazine/InnovationintheClassroom/tabid/751/Default.aspx>

<http://materialconnexion.com/Home/Matter/MATTERMagazine/PastIssues/Matter72/MATTERInterviewJasonCastriota/tabid/737/Default.aspx>

Table 35: Curricula Guidelines for Transition towards Systems Thinking via PSS

<p>Year 2: Transition towards Systems Thinking via PSS</p> <p>Curricula Guidelines for Radical Innovation for Sustainability</p>	
1.	For innovative solutions in SD and SPD, it will be essential to take a 'helicopter view' for systems innovation, i.e. 'wicked' problems of environmental, economic and social issues, human spirit and body, human and non-human life forms, humans living within nature and being part of nature, humans at the end of the food-chain and simultaneously part of the earth's biodiversity.
2.	<p>"Power of 10" film by Charles and Ray Eames, to stimulate a widened perspective.</p> <ul style="list-style-type: none"> • <i>Elements of fun</i>: self-directed film to illustrate multiple design planes of a particular problem, as a precursor to problem definition using systems thinking.
3.	Teaching modules on strategic design of functional, result-oriented PSS, that provide <i>enabling solutions</i> and address issues concerning the quality of life, offering dematerialization whilst satisfying human need through (<i>inspirational and spiritual</i>) experiences, events and interactions. PSS to ideally offer user participation and/or co-creation, combining the local (materials, craftsmanship, habitat and environmental conditions) with the global, and also the integration of culture. This can be approached in 2 ways: 'servitization of products' and 'productization of services'.
4.	Collaboration between the disciplines of design and engineering to be promoted to achieve system innovation, as they are complementary to each other (arts and humanities focussed design versus technology driven engineering), see 2.6.
5.	Multidisciplinary problem based learning (PBL) with design briefs, including industrial and product designers, mechanical and mechatronics engineers (interfaculty collaboration where both design and engineering disciplines are offered, or collaboration between TEOs).
6.	Team essay writing for future sustainable scenario building of macro issues, with broad essay topics from Year 2 curricula, to develop into design briefs, i.e. 'wicked' problem definition, questioning 'How to benefit stakeholders 1, 2, 3...?'
7.	Community as a stakeholder in a design brief.
8.	Ecosystems services personified as stakeholders within a design brief.
9.	Communications lectures, for improving multidisciplinary communication and teaching presentation skills (oral, written, multimedia) for academic and student peer review, as well as teamwork building.

Table 36: Curricula Guidelines for Complementary Sustainable Design Strategies

<p>Year 3: Complementary Sustainable Design Strategies</p> <p>Curricula Guidelines for Radical Innovation for Sustainability</p>	
1.	Use model (Figure 39: Strategic Design Cycle - model of complementary but sequential SPD Strategies), designing and teaching in the order: context, eco-effectiveness, eco-efficiency.
2.	Teaching modules on eco-effectiveness i.e. doing 'the right thing', of holistic systems thinking, through extended team essay writing plus multimedia to explore future sustainable scenarios, with macro issues within problem definition, and benefitting environment, economy and society.
3.	Teaching modules on C2C 12 principles and 5 steps.
4.	Teaching modules on biomimicry, to design <i>like nature, for nature</i> .
5.	Advanced teaching modules with in-depth knowledge of new sustainable materials, technologies and renewable energy sources.
6.	Team essay writing for future sustainable scenario building of macro issues, with broad essay topics from Year 3 curricula, to develop into design briefs.
7.	Teaching modules on LCM / LCA, for efficient use of materials and manufacturing processes. Eco-efficient technologies can support optimization and maximization of beneficial C2C/PSS. LCA can be used in the first instance to assess the impact of all product materials and processes, then to revert to eco-effective C2C design strategies and cycles of 5 steps.
8.	Design for disassembly and 'upcycling' of materials.
9.	<p>Selection of multidisciplinary Sustainable Final Year Project.</p> <ul style="list-style-type: none"> • <i>Elements of fun</i>: rewarding students choosing a multidisciplinary Sustainable Final Year Project with a 2 week symposium, comprising: <ul style="list-style-type: none"> - 1 week on board a boat with in-depth tutorials, linking to 'Spirit of Adventure Trust' in New Zealand – or a TEO-owned boat for such purposes – see: http://www.spiritofadventure.org.nz/index.php?page=10--day-youth-development-voyage - 1 week continued tutorials, with inter-faculty collaboration for multidisciplinary topics, design, technology, ecology, sociology; and - Academic staff assistance as above in selection of MD Final Year Project.

Table 37: Curricula Guidelines for Transition towards Strategic Design

<p>Year 4: Transition towards Strategic Design</p> <p>Curricula Guidelines for Radical Innovation for Sustainability</p>	
1.	'Intentional design' should be promoted in multidisciplinary sustainable final year projects; to <i>promote</i> and enable sustainable behaviour and ways of living in the <i>use</i> of a product or PSS, rather than the product itself. Emerging issues to be investigated (Manzini, 2009).
2.	PSS to strive for beneficial, enabling design solutions that encompass the highest motives: <i>Functional + Social/Positional + Inspirational/Spiritual, for purpose and spirit.</i>
3.	Equally learning from indigenous people and technologies; the developed world can equally learn from local, endemic knowledge rather than a one-way dominance of know-how from North to South.
4.	Teaching module on environmental supply chains.
5.	Sustainable Entrepreneurship, encompassing international and New Zealand EPP (Environmental Product Policy), international and New Zealand EMS (Environmental Management Systems) and Legislation, Intellectual Property, business and management skills, leadership skills, 'blue ocean' business strategies.
6.	<p>Multidisciplinary Sustainable Final Year Project, with C2C and PSS criteria. The environment, economy and society to be personified as stakeholders within the design brief, with clear <i>benefits</i> to all.</p> <ul style="list-style-type: none"> • <i>Elements of fun</i>: dramatization of future scenario setting, with personification of stakeholders (social, environmental, economic) and problems within role-play. Set within a debate and collective compromise framework, for academic and student peer review.
7.	Multidisciplinary team to include industrial/product designers and mechanical/mechatronics engineers and other specialists, involving collaboration between faculties and/or TEOs.
8.	Writing a Business Plan for the above, within a multidisciplinary team.
9.	Entering Sustainable Design competitions.
10.	TEO/web-based communication portal for SD/SPD multidisciplinary students and alumni, to break down current barriers between design, engineering, social sciences, ecology etc., to develop a sustainable network between disciplines.

6. CONCLUSIONS

6.1 Overview

This thesis had the main aim to develop an educational framework for curricula builders in Industrial Design and Engineering tertiary education. This has been achieved and documented within *Chapter 5*. The *Conceptual Educational Framework and Guidelines* are intended as a primary aid for curricula builders for *both* industrial design and engineering, to combine with discipline specific core content. The research outcomes combined knowledge from the objectives of this research:

- key concepts of *radical innovation for sustainability*;
- *international examples of successful practices within industrial design and engineering tertiary education*; and
- results from the *NZ final year student survey in industrial design and engineering*.

The contribution to knowledge that this thesis makes, is new and original in relation to SPD literature, in spite of this is not being required at Master's degree level. The originality lies in the novel formation of *key concepts of radical innovation for sustainability* from the literature. These key concepts are inherent to the structure of this thesis and the *Conceptual Educational Framework and Guidelines*, the final contribution. The key concepts comprise an educational construct that enables you to form a pathway through the complexity of material, using a design process of *complex to simple*, which can be used by practitioners and tertiary educationalists, i.e. curricula builders.

The value of this research to the literature is that it shows how opposing Sustainable Design strategies, and opposing disciplines, can *complement each other*. This is shown within the *Strategic Design Cycle Model (Figure 39)*, which shows the essential

relationship of phases to each other. The terms '*design-max*' and '*eco-max*' have been created to accentuate and emphasize the design intent necessary for *radical innovation through maximization* of positive, beneficial growth. This can be achieved through eco-effective C2C/PSS design strategies, and beneficial distribution through the economy for maximum equity. The '*Strategic Design Cycle Model*' and designated terms '*design-max*' and '*eco-max*' all originate from the author of this research.

DESIGN PROCESS	from complex to simple:
LITERATURE REVIEW	<p><u>Research Objective 1</u></p> <p>Show the <i>key concepts of radical innovation for sustainability</i> through a review of the literature;</p>
RESEARCH OUTCOMES	<p><i>Key concepts of radical innovation for sustainability:</i></p> <p><i>Concept 1: Emphasis on the Social Element of SD/SPD</i></p> <p><i>Concept 2: Transition towards Systems Thinking via PSS</i></p> <p><i>Concept 3: Complementary Sustainable Design Strategies</i></p> <p><i>Concept 4: Transition towards Strategic Design</i></p> <p><i>Synthesis of Expert Views, Appendix I;</i></p>
TEACHING	<p><u>Research Objective 2</u></p> <p>Highlight <i>international examples of successful practices within industrial design and engineering tertiary education;</i></p>
RESEARCH OUTCOMES	<p>International examples of successful practices within industrial design and engineering tertiary education were examined. These were from TEOs and/or researchers mainly from the Netherlands, UK and Italy, see 1.3. Academic design research projects in the EU also contributed to knowledge, such as EMUDE, DEEDS, LiMe (Living Memory) and SusHouse projects, see 2.7. These all contributed to the <i>Conceptual Educational Framework and Guidelines</i>.</p>
LEARNING	<p><u>Research Objective 3</u></p> <p>Investigate <i>NZ final year students in Industrial Design/Engineering:</i> to measure current awareness, understanding and knowledge of SD/SPD and compare NZ and international studies, as well as motivating and inspiring factors towards sustainability.</p>

RESEARCH OUTCOMES *Survey results and evaluation;*

A triangulation of data was provided by the final year industrial design and engineering student survey, conducted in NZ in 2010. This enabled measurement of *actual knowledge* of SD/SPD, and valuable comparisons between NZ and international studies, in view of the importance of sustainability given by professional bodies and accreditation. The survey results showed alarmingly low levels of actual knowledge of SD/SPD topics, in spite of the high student ratings of the importance of sustainability. It was evident that students had insufficient knowledge, and did not know *how* to integrate SD/SPD into their chosen disciplines. The gaps in knowledge of NZ students, indicated within the survey results and listed in 4.4, were therefore reflected in the *Conceptual Educational Framework and Guidelines* under their respective umbrella headings.

RESEARCH AIM *Develop an educational framework with supporting guidelines, combining knowledge gained from Objectives 1, 2 and 3; as an aid and underlying structure for curricula builders to integrate SD/SPD in Industrial Design and Engineering curricula.*

RESEARCH OUTCOMES *Strategic Design Cycle*

Model of complementary but sequential SPD strategies;

'DESIGN-MAX'- *designing for maximum*, as design intent for *radical innovation through maximization*, designated by this author;

'ECO-MAX' – *economy for maximum equity*, as design intent for *radical innovation through maximization*, designated by this author;

Guiding Principles of Radical Innovation for Sustainability;

Core Structure underlying Framework, using Design Process;

Conceptual Educational Framework;

Educational Framework Focus – Years 1-4; and

Educational Framework Guidelines.

All of the above contributed to creating a *base structure* for SD/SPD curricula for industrial design and engineering, rather than *actual* curricula. The latter necessitate further refinement beyond the scope of this thesis, and are dependent on blending with discipline-specific core content, individual faculties, accreditation requirements and facilitating multidisciplinary.

The *Conceptual Educational Framework* is based on a 'helicopter viewpoint' of the important themes and key concepts of radical innovation for sustainability. It combined knowledge gained from a review of the literature, international examples of successful practices within industrial design and engineering education, and an evaluation of a New Zealand survey executed in 2010. It is intended to serve as an overview roadmap to include what are essential topics towards radical innovation, generically for both industrial design and engineering disciplines, as an aid to curricula builders.

The findings of this research were that, from a comprehensive review of the literature, SD/SPD understanding has been driven mainly by *eco-efficiency and incremental innovation*, with the focus of incremental refinements through technology. This is where harmful, negative environmental effects are accepted as the norm, with reduction and minimization as the goal, and supported by Life Cycle Management (LCM) and Life Cycle Analysis (LCA). The literature has shown that this is insufficient to achieve the levels of Factors 10-20 improvements, i.e. reduction of resource use to a 10th – 20th of levels in the present production and consumption model (see *Chapter 1, Introduction, section 1.1, Motivation and Rationale for this Research*).

Instead, *radical innovation* is required through *eco-effective* design strategies which aim for positive, beneficial growth, supported by *Cradle-to-Cradle (C2C) and Product-Service Systems (PSS)*. These two main Sustainable Design strategies currently oppose one another: *eco-efficiency* promotes minimizing harmful environmental effects, whereas *eco-effectiveness* promotes maximising positive, beneficial effects in excess. The 2010 New Zealand final year student survey found, similar to prior surveys

(Humphries-Smith, 2008; Ramirez, 2007), that current definitions of Sustainable Design, are mainly those of *eco-efficiency*, see 2.4, 2.7.7 and *Chapter 4*.

The literature has shown that SPD is people-centred: human behaviour is at the heart of detrimental changes to the environment and therefore will also be at the heart of positive changes. By using the principles of the *Strategic Design Cycle* of this research, (see *Figure 39*), industrial design can contribute to a user-focused, human behaviour/technology interface in the conceptual design phase for *eco-effectiveness first (doing the right things)*. Equally, technology and engineering can *promote* positive, sustainable lifestyles within the human behaviour/technology interface, and optimize and maximize positive technologies and processes for *eco-efficiency afterwards (doing things right)*, once *eco-effectiveness has been achieved*. All processes and use of resources have to be managed efficiently, yet this is in contrast to the purely reductionist understanding of eco-efficiency that was previously the case.

Therefore, the relationship of design strategies to each other is crucial, as illustrated in (*Figure 39: Strategic Design Cycle - model of complementary but sequential SPD Strategies*). This underpins that products are user-focussed, become part of systems in PSS using C2C design strategies, and require input and collaboration from both industrial design and engineering, all of which needs to be reflected within tertiary education for these two disciplines. Therefore the main themes to consider for sustainable curricula building are: *Emphasis on the Social Element of SD/SPD, Transition towards Systems Thinking via PSS, Complementary Sustainable Design Strategies and Transition towards Strategic Design*.

The findings of the survey conducted within this research, of New Zealand final year Industrial Design and Engineering students, was that, in general, SD/SPD knowledge was still at an alarmingly low level. This was in contrast to the high level of importance of SD given by student ratings. Radical changes are required in the products and PSS that are designed and manufactured, to achieve improvements of Factors 10-20 for sustainability. It calls for *radical innovation*, and consequently,

changes to the current curricula for Industrial Design and Engineering disciplines. Tertiary education needs to not only instil awareness and responsibility for SD/SPD issues, but also provide students with the tools and capabilities of practical implementation. As well as this, educators can contribute towards enthusiasm, motivation and inspiration; to create sustainable entrepreneurs and change agents for the future.

6.2 Limitations of this Study

Certain limitations of this study were recognized. The main thrust of the *Conceptual Educational Framework* is that multidisciplinary PBL between Industrial Design and Engineering is not only necessary but also *urgent* (also with other faculties). This research recognized the current separation between these two disciplines, and that this should be reversed. How this should be achieved, further to the recommendations already made within the *Conceptual Educational Framework and Guidelines*, was beyond the scope of this thesis. The *Educational Framework Guidelines* also recommended communications courses to improve the relationship, which is additional to the prominence of PBL and multidisciplinaryity advocated by this author.

Further, the *voluntary* final year student survey contained data acquired from respondent TEOs willing to participate, but not from *all* design and engineering TEOs within New Zealand. In some cases, TEOs were unwilling to participate, a factor beyond the control of the researcher. However, a reasonable sample size of 175 students was achieved.

6.3 Future Research

Further research possibilities were identified for the future, but which are beyond the scope of this Master's thesis:

- in-depth research is required urgently, on ways to promote understanding, communication and collaboration between the disciplines of Industrial Design and Engineering;
- pilot studies to document experiences gained, both from student and academic staff perspectives, when implementing the recommendations of the *Conceptual Educational Framework and Guidelines* of this research: for gaining insight into successful practices and ways of improvement ;
- longitudinal studies to gauge the improvement in awareness and knowledge of SD/SPD among (final year) industrial design and engineering tertiary students in New Zealand;
- alumni networking and lines of communication (via TEO-based web portals) with industry-based multidisciplinary graduates interested in SD/SPD, to gain their experiences after graduation and to investigate whether their education had contributed to and/or enabled sustainable entrepreneurship; and
- state-of-the-art additional training in all SD/SPD issues for academic staff, in keeping with the *Strategic Design Cycle Model* and *Guiding Principles* of this research.

6.4 *Executive Summary and Recommendations*

Radical innovation for sustainability needs to become the norm, as confirmed by a digest of the literature and expert views. This requires radical changes in the way that products are designed. It will also mean changing the way that industrial designers and engineers are educated, by the nature of the design projects, and facilitating the complimentary roles of these two disciplines, which are not trivial problems. For this to be advanced in practice, this must first happen within *mainstream* tertiary education at undergraduate level.

The present arts and humanities focus of industrial design complements the technology focus of engineering. SD/SPD has been recognized in the literature to be *people-centred*, yet up to now has largely been driven by incremental improvements in *technology through eco-efficiency*. This must now change, with an *emphasis on the social element of SD/SPD*, requiring industrial design input at the conceptual design phase towards *eco-effectiveness first*, using C2C and result-oriented, functional PSS design strategies. Rather than the incremental improvements via technology alone, a combined design/technology interface can achieve *radical innovation to promote*

sustainable behaviour, whilst also providing purpose and spirit, enthusiasm and fun for the user.

Therefore technology must not be considered in isolation, but in combination with design, so that *eco-efficient* use of resources and manufacturing processes then *become ways to optimize and maximize* the positive effects of C2C and PSS. Macro issues and systems thinking need to be addressed for holistic problem definition, resulting in positive, enabling *strategic design solutions*, that are beneficial for society, the environment and the economy.

It has now become URGENT to close the damaging gap between expert knowledge and *mainstream* educational practice in industrial design and engineering, so that new knowledge and skills for the next generation are enabled. *The Conceptual Educational Framework and Guidelines* are based on a synthesis of expert views regarding SD/SPD, and are first steps towards this target, within a rational framework as a prototype to be tested and refined through trial and implementation at undergraduate level. This thesis is therefore a call to action.

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