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Chemistry Education for Sustainability: Assessing the chemistry curricula at Cardiff University

Rodrigo Lozano,[*] [1] *Mary Katherine Watson* [2]

ABSTRACT
As more universities become interested in, and engaged with, sustainability, there has been a growing need to assess how their curricula addresses sustainable development and its myriad issues. Different tools and assessment exercises have looked at course descriptors. This paper presents the Sustainability Tool for Assessing Sustainability in UNiversities' Curricula Holistically (STAUNCH®) assessment of the School of Chemistry, Cardiff University. The results indicate that STAUNCH® can be instrumental in identifying courses that more adequately capture the breadth and depth of sustainability and exhibit high contribution scores. The curricula assessment can help university leaders and directors of teaching and learning better understand where they should engage in changes to make chemistry education more sustainability-oriented, and, ultimately, to have the greatest impact in helping make societies more sustainable. Overall, STAUNCH® can provide a systematic method for evaluating the strengths and weaknesses of the chemistry curriculum for the purpose of devising curriculum reform strategies to promote student sustainability learning.

KEYWORDS: sustainability in higher education, curricula assessment, STAUNCH® tool, Cardiff University, chemical education

Resumen (Educación Química para la Sustentabilidad. Evaluación del currículo de química en la Universidad de Cardiff)
Conforme más universidades se vuelven interesadas y atraídas hacia la sustentabilidad, se da una necesidad creciente de evaluar cómo sus currículos tratan la sustentabilidad y su miríada de aspectos. Los descriptores de los cursos han sido estudiados con diferentes herramientas y ejercicios de evaluación. Este artículo presenta la Herramienta de Sustentabilidad para Evaluar Holísticamente la Sustentabilidad en el Currículo Universitario (STAUNCH® es su acrónimo en inglés) aplicada en la Escuela de Química de la Universidad de Cardiff. Los resultados indican que STAUNCH® puede ser un instrumento que identifique los cursos que captan más adecuadamente la amplitud y profundidad de la sustentabilidad y los identifica con una contribución de alto puntaje. La evaluación curricular puede ser de ayuda para que los líderes universitarios y los directivos de enseñanza y aprendizaje comprendan de mejor manera hacia dónde debieran orientarse para cambiar la educación química al hacerla más orientada hacia la sustentabilidad para, de esa forma, lograr finalmente tener un impacto mayor para ayudar a la sociedad a ser más sostenible. De manera general, STAUNCH® provee un método sistemático para evaluar las fortalezas y debilidades del currículo de química con el propósito de concebir estrategias de reforma curricular que promuevan el aprendizaje de la sustentabilidad por los estudiantes.

Palabras clave: sustentabilidad en la educación superior, evaluación curricular, herramienta STAUNCH®, Universidad de Cardiff, educación química

Introduction

Sustainable Development (SD) has emerged as an alternative for overcoming activities (such as over-population, resource over-consumption, and environmental degradation) that have resulted in damage to the Earth's environment and quality of life for this generation and future ones (Carley & Christie, 2000; Dalal-Clayton & Bass, 2002; Korten, 2001; WCED, 1987). The most widely cited definition is that from the Brundtland Report, which states that SD development should meet the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987).

In many cases, sustainability has been perceived as being highly anthropocentric, compartmentalised, and lacking completeness and continuity (Lozano, 2008). In many other cases, there has been a bias towards considering sustainability

* Corresponding author Rodrigo Lozano (PhD, AMIChemE)

[1] Assistant Professor, Copernicus Institute of Sustainable Development. Heidelberglaan 2. Utrecht University, The Netherlands.

E-mail: r.lozano@uu.nl

[2] Georgia Institute of Technology. School of Civil and Environmental Engineering Sustainable Education Building. 790 Atlantic Drive Atlanta, GA 30332-0355.

as only focussed upon environmental sustainability (*e.g.* Atkinson, 2000; Costanza, 1991; Rees, 2002; Reinhardt, 2000). Salzmann *et al.* (2003) indicate that this emphasis is due to social issues being less developed than environmental ones. However, it is becoming recognised, more and more, that SD must take a holistic perspective, where the four dimensions of sustainability (economic, environmental, social, and time) and their inter-relations are properly addressed (Lozano, 2008).

An increasing number of higher education institutions (HEIs) (*see* Boks & Diehl, 2006; Lozano, 2006a, 2010; Wemmenhove & de Groot, 2001) are engaging in activities to embed the principles of sustainability into their systems, including: education, research, operations, outreach, and assessment and reporting (Cortese, 2003; Lozano, 2006a). However, Education for Sustainable Development (ESD) has not fully permeated all disciplines, scholars, and university leaders (Fien, 2002), or the curricula (Matten & Moon, 2004).

In general four main approaches can be found for incorporating SD into higher education curricula:

1. Some coverage of particular environmental and/or social issues and material in an existing course (Thomas, 2004);
2. A specific SD course added to the curriculum (Abdul-Wahab, Abdulraheem, & Hutchinson, 2003; Thomas, 2004; von Blottnitz, 2006);
3. SD intertwined as a concept within pre-existing disciplinary-oriented courses, with the relevant SD component issues matched to the nature of each specific course (Abdul-Wahab, *et al.*, 2003; Boks & Diehl, 2006; Peet, Mulder, & Bijma, 2004; Quist *et al.*, 2006), and
4. SD offered as a specialisation within the framework of particular faculties or schools (Kamp, 2006).

Multi-disciplinary integration of sustainability across the curricula can help students make connections between sustainability and traditional content, which may encourage application of sustainability concepts in their professional practices (Ceulemans & De Prins, 2010; Peet, *et al.*, 2004).

For science to contribute to sustainable development, future scientists must be trained to understand and apply sustainability concepts and principles in their professional work (Eilks & Rauch, 2012; Karpudewan, Ismail, & Roth, 2012). Current curricula in higher education emphasise disciplinary specialization and reductionist thinking (Cortese, 2003; Lovelock, 2007; Lozano, 2010). As a result, many graduates are "unbalanced, over-specialised, and mono-disciplinary graduates" who use their narrow skill sets to solve problems by analysing system components in isolation (Lozano, 2010). In contrast, the complex nature of global and local dilemmas necessitates that scientists exercise interdisciplinary and systems thinking to understand and balance the interrelated technical, economical, environmental, and social dimensions of a problem (Davidson *et al.*, 2007). Thus, significant changes are needed to integrate sustainability content into undergraduate science curricula to properly equip students to tackle complex global dilemmas.

A systematic evaluation of a curriculum's current incorporation of sustainability content can help to identify strengths and weakness related to sustainability education (Lozano, 2010; Lozano & Peattie, 2011). Many tools have been developed to assess the sustainable development initiatives of universities, including the Auditing Instrument for Sustainable Higher Education (Roorda, 2001), the Graphical Assessment for Sustainability in Universities tool (Lozano, 2006b), and the Environmental Management System Self-Assessment (Shriberg, 2002). However, many of these assessments focus on the broader sustainability of a university's operations, while providing little or no insight into sustainability content of the curricula. The Sustainability Tool for Assessing Sustainability in UNiversities' Curricula Holistically (STAUNCH®) system is aimed at overcoming this shortcoming by assessing the extent to which a curriculum addresses the economic, environmental, social, and cross-cutting sustainability dimensions (Lozano, 2010; Lozano & Peattie, 2009, 2011).

This research discusses the results from the STAUNCH® assessment of the School of Chemistry at Cardiff University, and how the School's curriculum can be improved to better contribute to sustainability. The paper starts by presenting a literature review of sustainable chemistry, followed by a brief description of the STAUNCH® system, then the results from the School of Chemistry, their discussions, and finally how the chemistry curricula could be improved to be made sustainability oriented.

Reviewing Sustainability in Chemistry

Although technological innovation has contributed to current unsustainable practices, sustainability science is important for developing and implementing sustainable development strategies (Grassian *et al.*, 2007). Sustainability science is a rapidly evolving area that challenges professionals and academics from all scientific disciplines to apply their expertise to promote sustainability (Clark & Dickson, 2003). The main goal of this inherently collaborative field is to study the dynamic interactions between nature and society (Clark, 2007; Clark & Dickson, 2003; Kates *et al.*, 2001). As a result, sustainability science, such as the agricultural and health sciences, is fundamentally "defined by the problems it addresses rather than the disciplines it employs" (Clark, 2007). Sustainability science has been termed a "metadiscipline" because the knowledge required to develop and advance the field transcends an understanding of any single disciplinary specialty (Mihelcic *et al.*, 2003). Overall, sustainability science is a unique nexus that brings together experts from numerous disciplines to devise more holistic and sustainable solutions to complex global problems.

Within this context, chemistry has been recognised as an important discipline for contributing to the design and implementation of sustainable development strategies. Green and sustainable chemistry have emerged in response to evolving multi-dimensional global dilemmas. While there is debate over the interchangeability of the terms, incorporating sustainability concepts and principles into undergraduate chemical education is becoming imperative for equipping future scientists to tackle complex problems (Collins, 2001; Grassian *et al.*, 2007).

Green chemistry involves the "design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances" (Anastas & Kirchhoff, 2002). Specifically, green chemistry can aid in achieving sustainability through: (1) the development of economical renewable energy sources; (2) the use of reagents derived from renewable materials; and (3) replacing pollution-generating technologies with clean alternatives. Green chemistry tackles complex global issues, such as climate change, energy supply, and environmental quality. Central to this is an emphasis on design, specifically systematic human interventions to promote advancement toward sustainability. The Twelve Principles of Green Chemistry (Anastas & Warner, 2000), which include calls to use renewable feedstock, protect human health, and prevent pollution, have become a fundamental framework for guiding chemists in engaging in sustainable chemical design. Essentially, green chemistry is the response of the chemical field to evolving global needs (Anastas & Eghbali, 2010; Anastas, Heine, & Williamson, 2000; Anastas & Kirchhoff, 2002; Anastas & Warner, 2000; Collins, 2001).

Much debate surrounds the question of whether green chemistry and sustainable chemistry are synonymous terms (Tundo *et al.*, 2000). While the goal of green chemistry is to advance sustainability (Anastas & Eghbali, 2010), some authors propose that green chemistry under-emphasises the social dimension of sustainability (Böschen, Lenoir, & Scheringer, 2003). Green chemistry has been described as a field that "harness[es] chemical innovation to meet environmental and economic goals simultaneously" (Anastas & Eghbali, 2010). Thus, green chemistry does not completely encompass sustainability because efforts are not always considered in the context of social impacts and needs (Abraham, 2006). Whether the term 'green chemistry' or 'sustainable chemistry' is used, the need to educate future chemists to contribute to more sustainable societies is regarded as a critical challenge for chemistry education (Grassian *et al.*, 2007).

As early as 1998, the Organisation for Economic Cooperation and Development's (OECD) Sustainable Chemistry Initiative Steering Group cited incorporating sustainability into chemical education as one of the top five highest priorities of sustainable chemistry (van Roon *et al.*, 2001). Promoting sustainable development requires scientists to simultaneously consider and balance sustainability dimensions in design (Davidson, *et al.*, 2007; Mihelcic, *et al.*, 2003). Instructors and teachers should discuss the economic value, ecological impacts, and human health dangers in conjunction with traditional content across the curriculum (Collins, 2001). In addition, it is suggested that deficiencies in sustainable education be identified and remediated using empirically proven educational materials (OECD, 1999). Despite the OECD's call for sustainable chemistry education, it is claimed that most teachers do not incorporate sustainability into their classroom activities, even though this effort is critical for equipping students to tackle complex technical problems in a broad social and environmental context (Grassian *et al.*, 2007). Thus, reforms in undergraduate chemical education curricula are imperative for training future sustainability-conscious chemists.

Methodology: the Sustainability Tool for Assessing UNiversities' Curricula Holistically (STAUNCH®) tool

The STAUNCH® system[1] was developed in 2007 with the aim of moving university curricula beyond the current emphasis on anecdotal evidence, and non-comparable *ad hoc* reviews.[2] The STAUNCH® system relies on the explicit published course descriptors, including aims and outlines, as a data source. This means that all the necessary information is (or should be) easily accessible, but it also means that the accuracy of the results depends on the accuracy/specifics of the published information. SD education delivered in the classroom but not reflected in the course documentation will not be captured.[1]

The assessment is done on the course descriptors, or syllabi. It has two objectives: (1) to assess systematically how a university's curricula contributes to SD (*i.e.* SD issue coverage, depth and breadth), by assessing its courses, degrees and schools; and (2) to facilitate consistent and comparable auditing efforts capable of handling a large quantity of data, and its application across multiple institutions. The validity of STAUNCH® results relies on the accuracy and comprehensiveness of published descriptors.

STAUNCH® is based on two combined equilibria: firstly, cross-cutting theme issues (such as Holistic thinking, and SD statement, see Table 1), which are considered to be those that integrate economic, environmental, and social dimensions; and secondly, the SD contribution, which is calculated using formulae that look for the balance among the four dimensions, taking into consideration their strengths.

STAUNCH® follows four steps:

1. **Criteria selection:** The STAUNCH® list of 36 broad criteria (see Table 1) is divided into four categories, which follow the characteristic SD dimensions (economic,

[1] To obtain information about the use and licensing of STAUNCH® refer to www.org-sustainability.com/STAUNCH®

[2] For a more detailed explanation of the STAUNCH® system refer to Lozano, 2010; Lozano & Peattie, 2009, 2011.

Table 1. STAUNCH® 2007 curricula contribution to sustainable development assessment criteria.

Economic	*Environmental*	*Social*
• GNP, Productivity • Resource use, exhaustion (materials, energy, water) • Finances and SD • Production, consumption patterns • Developmental economics	• Policy/Administration • Products and services (inc. transport) • Pollution/Accumulation of toxic waste/Effluents • Biodiversity • Resource efficiency and eco-efficiency • Global warming, Emissions, Acid rain, Climate change, Ozone depletion • Resources (depletion, conservation) (materials, energy, water) • Desertification, deforestation, land use • Ozone depletion • Alternatives	• Demography, Population • Employment, Unemployment • Poverty • Bribery, corruption • Equity, Justice • Health • Social cohesion • Education • Diversity • Cultural diversity (own and others) • Labour, Human rights
	Cross-cutting themes	
	• People as part of nature/Limits to growth • Systems thinking/application • Responsibility • Governance • Holistic thinking • Long term thinking • Communication/Reporting • SD statement • Disciplinarity • Ethics/Philosophy	

Source: (Lozano, 2010; Lozano & Peattie, 2011.)

environmental, and social), with the addition of 'cross-cutting themes';

2. **Data collection**: STAUNCH® relies on using explicit published course information, including aims, outlines, and descriptions as data sources;
3. **Data input and grading against the selected criteria**: When all the available data has been collected it is entered and graded against the issues presented in Table 1, according to the following strength criteria:
   - ***Blank*** "*Ignored*" (effectively a score of zero): indicating that a particular issue is not mentioned;
   - 1 "*Mentioned*": the issue is mentioned, but no explanation is given about how it is addressed;
   - 2 "*Described*": the issue is mentioned and there is a brief description of how it is addressed;
   - 3 "*Discussed*": there is a comprehensive and extensive explanation of how the issue is addressed;
4. **Analysis of degrees, schools, and the university's contribution to SD**: STAUNCH® offers two types of reports for each part of the university (typically a School or Faculty): a summary report, and a detailed report, as well as four graphs: (1) A map of contribution vs. percentage of courses; (2) A chart representing the relative contribution to each SD dimension (economic, environmental, social, and cross-cutting themes); (3) A relative frequency chart of criteria strength; and (4) A map of contribution vs. weighted average strength.

The analysis is three tiered, taking the basic unit of analysis as the published course description: firstly, analysis of course descriptors against the 36 criteria provides the results for the specific degree; secondly, the results for the degrees form the specific school's contribution to SD; and finally, the schools collectively provide the university SD results.

Two of the key points in the analysis reports are: (1) the level of contribution, indicating the 'breadth' and 'depth' of coverage of sustainability issues (the higher the contribution's value the better the balance amongst economic, environmental, social, and cross-cutting dimensions); and (2) the percentage of courses contributing to SD, given by the number of courses that relate to SD, divided by the total number of courses in each degree. Table 2 provides an illustration of this, as well as the qualitative level.

The STAUNCH® system is aimed at helping universities assess the depth and breadth of their SD-related curricula in a holistic and systematic way to produce standardised and comparable results. STAUNCH® results provide a 'snapshot' of how SD is currently being addressed within a university. Its reports detail the percentage of courses currently addressing SD, and their balance among the conventional dimensions of SD (economic, environmental and social) plus those themes that cut across them. This information offers the possibility to detect whether SD is integrated across the curricula, or is being broken down into individual issues to be addressed as a portfolio throughout the curricula. The

Table 2. SD Contribution and qualitative levels.

Hypothetical degree	*Contribution*	*Level*
CU001	0.00	None
CU101	0.01-0.67	Very low
CU201	0.67-1.29	Low
CU301	1.30-1.99	Medium
CU401	2.00-3.50	High
CU501	>3.50	Very high

reports can also serve to question current programs and discuss how they could better contribute to SD, and to help the institution to better align with the Decade of Education for Sustainable Development (DESD) (von Blottnitz, 2006).

The STAUNCH® system is thus appropriate for broadly assessing the contribution of curricula to sustainability (Lozano, 2010; Lozano & Peattie, 2011), including sustainable chemical education. It has been used by a number of universities, such as Cardiff University (see Lozano, 2010; Lozano & Peattie, 2009, 2011), Monterrey Tech, Worcester University, Georgia Institute of Technology, the University of Leeds, and, through the Higher Education Funding Council for Wales (HEFCW), by the other 11 Welsh universities.

Case Study: School of Chemistry, Cardiff University

A study was conducted to assess the curricular contribution to sustainability of Cardiff University (see Lozano, 2010; Lozano & Peattie, 2009, 2011). This paper focuses on the results from the School of Chemistry. The School offers an undergraduate BSc degree in chemistry, with specialisations in physics or bioscience. In addition, students may opt to complete an industrial experience year to enrich their education. Approximately 85 students enter the school each year to pursue three-year BSc or four-year MSc degrees. These students complete six courses each semester for a total of two semesters per year to prepare them for a career in chemistry or a related discipline (Cardiff University, 2012).

Descriptors for the 44 undergraduate chemistry courses (see Table 3) at Cardiff University were collected for analysis during 2007. The documents were first obtained online at the school's webpage, while missing descriptors were gathered through email communication and/or personal visits with school representatives.

Each of the descriptors was assessed according to the STAUNCH® methodology by the first author of the current paper, who has assessed over 8,000 courses in different universities. The data set for each of the courses was inputted into the STAUNCH® system to quantitatively examine their sustainability content.

The following findings from the STAUNCH® report were used to infer the current quality of, and suggestions for improving, sustainable chemical education:

— The percentage of courses contributing to sustainability education;
— The contribution, indicating the 'breadth' and 'depth' of coverage of sustainability issues (the higher the contribution's value the better the balance amongst economic, environmental, social, and cross-cutting dimensions);
— The strength, computed as the weighted average of scores from all courses, and

Table 3. Summary of courses offered to BSc chemistry students at Cardiff University.

Year One	*Year Two*	*Year Three*
• Spectroscopy and kinetics	• Main group chemistry	• Catalysis and electro-catalysis
• Bonding and structure	• Stereochemistry and reactivity	• Medicinal and enzyme chemistry
• Molecular structure and reactivity	• Spectroscopic methods	• Environmental chemistry
• Techniques and methods in chemistry	• Energy and structure	• Soft Solids
• Energy changes in molecules and atoms	• Analytical and separation science	• Advanced chemistry practical (double course)
• Metals in solids and solutions	• Symmetry and bonding	• Key skills in chemistry
• Synthetic chemistry	• Co-ordination chemistry	• Organometallics
• Characterisation of molecules	• Organic mechanisms and synthesis	• Dynamics
• Special topics I	• Atomic and molecular spectroscopy	• Structure determination
• Forensic chemistry	• Kinetics from enzymes to polymers	• Project (double course)
• Biological chemistry	• Key skills for chemists	• Organic synthesis and biopolymers
• Special topics II	• Business studies	• Polymers
• Chemistry of the cosmos	• The chemistry of functional devices	
• Mathematical methods for chemistry	• Language, or other free standing course	
• Biological macromolecules		
• Biotechnology, metabolism and regulation		
• Cell and molecular biology		
• Language		

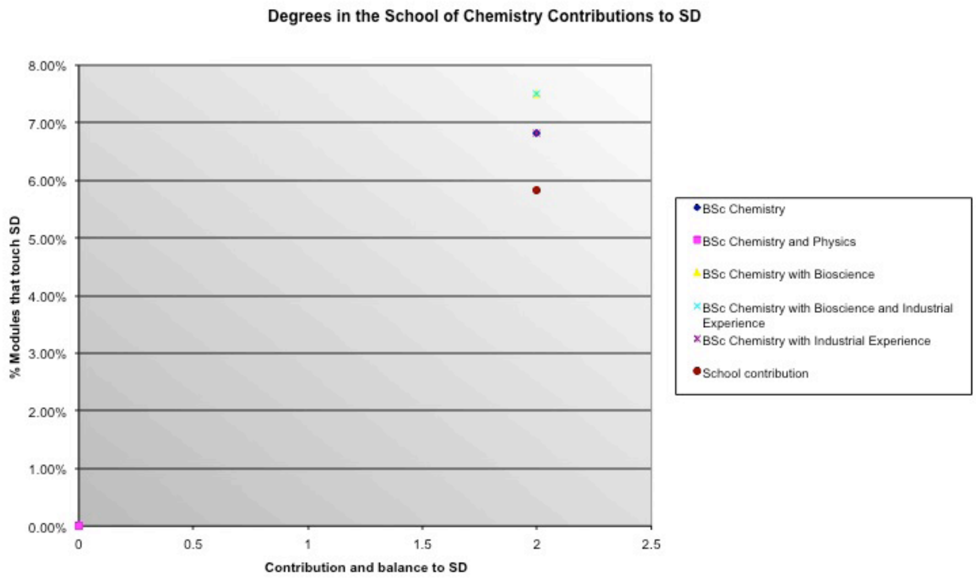

Figure 1. Sustainability contribution *vs*. strength graph for the School of Chemistry's degrees

— Identification of the most and least emphasised sustainability dimension to provide insights for future curriculum improvements.

A set of STAUNCH®-prescribed benchmarks were used to judge the overall contribution and strength metrics, see Table 2.

STAUNCH® results of the School of Chemistry

The results from the STAUNCH® assessment shows that very few courses contributed to sustainability. For example, Environmental Chemistry (CH 2312), which is completed by all students, except those specialising in physics, addressed the Resource depletion and conservation criterion; however, the criterion is only 'mentioned', *i.e.* it has a low strength. A similar case is the Medicinal and Enzyme Chemistry course (CH 2311) with respect to the Health criterion. The Business Studies course (CH 2214), offered to students within the School of Chemistry pursing degrees with several different emphases, received a score of 1 in the Disciplinarity criterion, since it is offered to students in different schools. No course explicitly addressed criteria from the economic dimension of sustainability. Overall, only descriptors for 3 of the 44 different undergraduate chemistry courses addressed sustainability criteria.

Based on course requirements, the percentage of courses that addressed sustainability varied for each of the six BSc degrees (Table 4). Although each BSc degree, except for chemistry with physics, requires students to complete the three courses addressing sustainability criteria, each degree offers a different number of courses overall. Thus, on a percentage basis, the chemistry degrees with a focus on bioscience included the most sustainability content, followed by the degrees in chemistry without a specific emphasis. The chemistry degree with an emphasis in physics does not require any of the sustainability-related courses. Overall, 5.83 per cent of the courses offered by the School of Chemistry contribute to sustainability.

Figure 1 shows the contribution *vs.* percentage of courses contributing to sustainability graph for the five degrees and for the school. As can be seen, the contribution is high (2.0); however, the percentage of courses contributing to sustainability is fairly low. This indicates that the courses that are addressing sustainability are doing it with a good balance. These could be used as examples to help integrate sustainability into other courses.

Figure 2 shows the breakdown for the sustainability dimension, which, it will be observed, is not being addressed. Figure 3 shows the contribution strength of the degrees, which is low. These two figures illustrate that there is fairly good coverage of three of the four sustainability dimensions; however, the incorporation is only 'mentioned' in the course descriptors.

Table 4. Courses addressing key sustainability criteria by chemistry degree.

Degree	*No. Contributing Courses*	*Total Courses*	*Contributing Courses (%)*
Chemistry: (No specialisation)	3	44	6.82
Chemistry: Physics	0	38	0.00
Chemistry: Bioscience	3	40	7.50
Chemistry: Bioscience, Industrial Experience	3	40	7.50
Chemistry: Industrial Experience	3	44	6.82
School of Chemistry (overall)	12	206	5.83

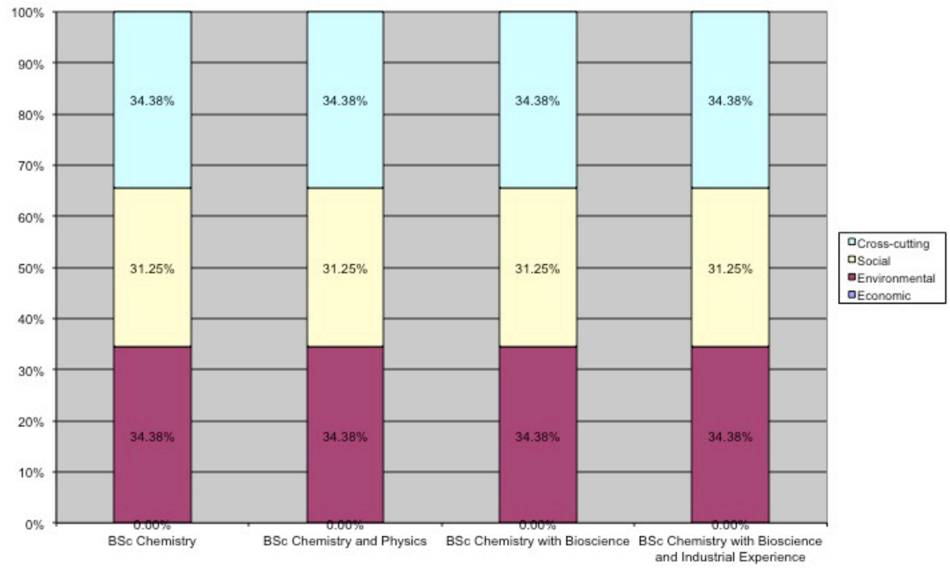

Figure 2. Breakdown of the sustainability dimensions' contribution of the School of Chemistry's degrees

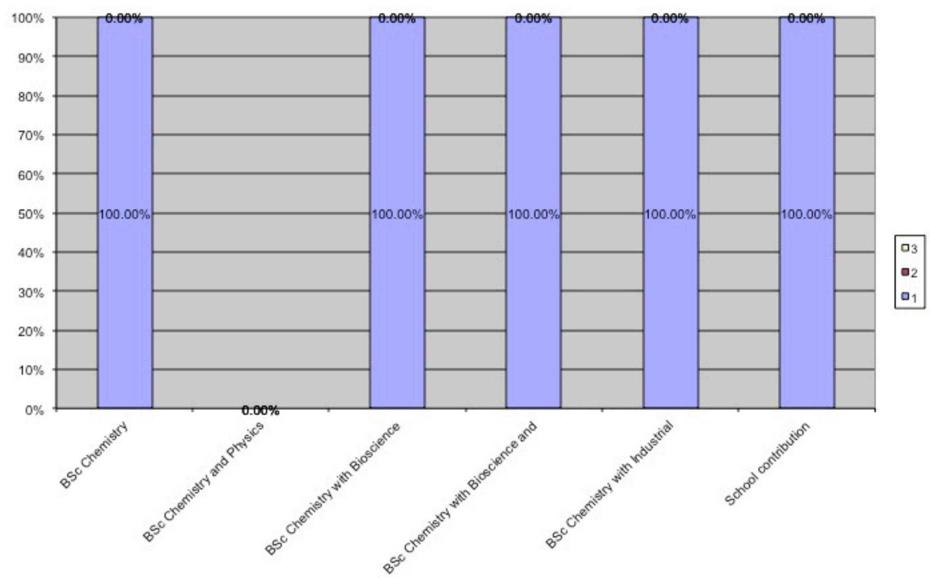

Figure 3. Strength of the sustainability contribution of the School of Chemistry's degrees

Discussion: Improving chemical education contribution to sustainability

The STAUNCH® assessment of the curricula for undergraduate chemistry at Cardiff University reveals that several strategies are needed to improve the contribution of chemical education to sustainability. The results further indicate that there is some coverage of environmental and/or social issues in some courses (as posited by Thomas, 2004). Such contribution is high; however, the percentage of courses contributing to sustainability and their strength is quite low. This reinforces Fien's (2002) and Matten & Moon's (2004) position that sustainability has not yet permeated throughout the different disciplines and curricula. In addition it supports arguments that many chemistry educators, even those that conduct sustainability-related research, do not incorporate sustainability into their class activities (see Grassian *et al.* 2007).

To improve the contribution of chemical education to sustainability, as advocated for by the OECD Sustainable Chemistry Initiative Steering Group (van Roon, *et al.*, 2001), sustainability concepts must be intertwined within existing modules (see Abdul-Wahab, *et al.*, 2003; Boks & Diehl, 2006; Peet, *et al.*, 2004; Quist, *et al.*, 2006). Courses that can serve as examples include: Environmental Chemistry, Medicinal and Enzyme Chemistry, and Business Studies. Nonetheless, the coverage of sustainability issues in such courses should move from merely 'mentioned' to 'described' and 'discussed'. Promoting inter-school collaboration and teaching can help increase the scores for the crosscutting themes, specifically in the disciplinary criterion. In the absence of curricula reform efforts, programs may produce "unbalanced" and "over-specialised" graduates that are unequipped to tackle increasingly complex global dilemmas (Lozano, 2010).

While incorporating sustainability concepts, it is important for educators and directors of teaching and learning (*see* Lozano, 2010; Lozano & Peattie, 2011) to consider both the contribution (*i.e.* balance and depth) for the four sustainability dimensions, as well as the coverage strength. Over- or under-emphasising any one dimension in their undergraduate education may lead graduates to do the same in their careers (refer to Davidson, *et al.*, 2007; Mihelcic, *et al.*, 2003). Thus, sustainable chemical education requires coordination between educators to ensure broad, deep, and balanced consideration of sustainability content.

Conclusions

Participation of chemists in the collaborative field of sustainability science is critical for developing and implementing sustainable stratagems for dealing with complex global dilemmas. However, chemists must first be trained to understand how their decisions affect sustainability. In other words, they must internalise an informed sustainability orientation to everything they do in their professional lives.

To ensure that the next generation of chemists is equipped with this knowledge, efforts are needed to update undergraduate curricula. For this purpose, the STAUNCH® system can serve as a valuable tool for benchmarking the current sustainability content of curricula to provide insights for guiding reform efforts. The system can help in assessing the depth and breadth of SD-related chemistry education curricula in a holistic and systematic way to produce standardised and comparable results.

The STAUNCH® results offer the opportunity to question current programmes and discuss how they could better contribute to SD, and thereby help institutions to better align with the DESD. Chemical education must train students to integrate the basic principles of chemistry (*e.g.* inorganic and organic reactions, analysis, and mass and energy balances) with the development of technological innovations, as well as understand how their decisions impact issues such as productivity, resource use, cost of chemicals and their application, pollution, global warming, poverty, health, labour and human rights, systems thinking, long-term thinking, and trans-disciplinarity

While the curricula assessment tool can facilitate reform efforts, it must be complemented with other pedagogical efforts, such as interviewing teaching staff, and instituting an 'Educate the Educators' programme (*see* Huisingh and Mebratu, 2000). Additionally, the university needs to incorporate SD into its other key dimensions of operations, research, outreach, and assessment and reporting.

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