Science and Sustainability: evaluation of integration of science concepts with global issues

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Abstract
Science and Sustainability is an innovative Grade 10 SEPUP course which aims to integrate important concepts of science with the study of global sustainability in a motivating and interactive fashion to address National Science Education Standards. The purpose of this study was to examine the extent of integration in principle and in practice and is based on documentary analysis of the teaching materials and detailed analysis of a succession of evaluation questionnaires to teachers at field test centres. Integration happened effectively in principle, but contradictions were evident in teachers' expectations of the balance between coverage of key science concepts and their contextualisation for citizenship. The course was considered very motivating with a high conceptual demand. The tensions between developing understanding of science concepts and encouraging wider skills of social responsibility are not easy to resolve. The maintenance of the sustainability concept throughout the course promoted change in teachers' practice.

Background
National Science Education Standards in the US expect pupils to consider social, ethical and environmental applications of science. Yet there are barriers to such curriculum implementation. Science curricula are rooted historically in teaching and learning approaches which emphasise the acquisition of knowledge and understanding of science concepts. Curricula and teachers have to adapt to both contextualise the science and consider concepts of citizenship. Curriculum change requires innovative approaches, such as those devised by the SEPUP (Science Education for Public Understanding Program) team at the University of California at Berkeley (Their, 2001). Curriculum innovations run the risk of their purposes being altered in enactment (Black and Atkin, 1996). Teacher change to adapt to curriculum innovation is not easy, requiring commitment and support (Joyce and Showers, 1995). *Science and Sustainability* is a one-year high school course which aims for learners to relate their developing understanding of science concepts to the global issues of sustainability and social responsibility. Support materials and workshops aim to assist teachers with practical teaching and learning strategies in dealing with integration of science concepts with global issues. The course could be considered to be an STS (science-technology-society) course, but is unusual in the science and citizenship concepts being fully integrated during the course whereas many courses view STS as enrichment (Aikenhead, 1994). An STS approach has been seen as providing motivation and interest yet brings many demands in terms of changing pedagogical approach and dealing with controversial issues (e.g. Lumpe *et al*, 1998; Ratcliffe and Grace, 2003). This paper draws upon documentary analysis and evaluation evidence, by a researcher external to both the SEPUP team and the US, to discuss teachers' perceptions of achievement of the course aims and consider the extent of change required of teachers in expectations of learning outcomes.

Science and Sustainability consists of 40 topics, exploring science concepts set in the common context of global sustainability. Hands-on practical activities are combined with analysis of global impact, using 'The Material World' (Menzel, 1994) as background. Analysis questions and embedded assessment complete the integration. To give a flavour of the course, the first five topics are outlined, as these were the subject of some in-depth analysis. The first five topics of the course set the scene through integration of science concepts with the idea of survival, drawing on global contexts.

1. Human Survival. Identifying and comparing needs for survival in polar and equatorial climates, using information from 'Material World' a Sierra club publication showing differences in life style around the world.
Key integrating concept: Understanding energy flow is essential for survival

2. The Biology of Survival. Identifying the functions of living organisms necessary for survival and the impact on environmental conditions - through an experiment to determine optimum conditions for yeast fermentation.
Concepts: environmental conditions affect organisms with an optimum temperature for most biological reactions.

3. The Physics of Survival. Relating survival, life style and quality of life to energy storage requirements and energy transfer, through simple investigation of cooling curves and consideration of how 'heat flow' is modified in different cultures and environments.
Concepts: First and second law of thermodynamics
Key integrating concepts: Modifying heat flow is essential for survival. Different environments & lifestyles employ different techniques to modify 'heat flow' - they differ in effectiveness, availability & desirability.

4. The Technology of Survival. Students design an 'ideal' cup for either a polar or equatorial expedition. In so doing they investigate the concepts of scientific modelling, heat flow and the thermal properties of different materials.
Concepts: Scientists and engineers use different types of models to solve problems; second law of thermodynamics
Key integrating concept: Technology as 'simple' as insulation is very important to sustainability and quality of life.

5. The issue of human sustainability. Developing a personal definition of sustainability, identifying key issues and investigating ways in which science and technology can contribute to a sustainable future, through reading, discussion and consideration of life styles across the world.
Concepts: Sustainable development is the goal of meeting the needs of today without compromising the ability of future generations to meet their own needs. Quality of life is one's personal qualitative view of one's own life style.

Figure 1 Summary of first five topics of *Science and Sustainability*

Methods

The study sought to examine the extent of integration of science concepts with ideas relating to sustainability and social responsibility in principle and in practice.

Documentary analysis of course materials explored integration in principle. Teachers' responses to evaluation questionnaires formed the evidence base for integration in practice. Although observation of practice would give fuller evidence, evaluation questionnaires are revealing of teachers' perceptions of the course and their own practice – an important dimension in further development of the course.
The documentary analysis scrutinised the course materials including students' guide, teachers' guide and text to categorise the 40 main learning topics into four groups from their objectives and content. The four groups represent a spectrum from concentration on science concepts only, through full integration of science and sustainability, to sustainability only:

A. Activities focussed on science concepts only requiring any contextualisation to come from the teacher;
B. Activities where the science concepts were encountered in a particular, given context;
C. Activities in which science and sustainability were fully integrated;
D. Activities which emphasised the social context of sustainability only.

Teachers in field test centres were expected to complete an evaluation form for each activity. In addition, at the end of the year's course, they were asked to complete an evaluation questionnaire on the course as a whole. Evaluations of activities sought comments on: content and 'teachability'; conduct and length of the activity; appropriateness of the background information provided for teachers and that for students; reactions from students and methods of improving student learning.

Evaluation of the whole course sought comments on: concept coverage; student learning of concepts; integration of science concepts with global context of sustainability; perceptions of strengths and weaknesses of the course; whether the course could be recommended to other teachers.

Seven school districts at different locations, urban and rural, within the US were field test centres for the whole year's course, teaching to grade 10 (or 9 in a few cases). This involved a total of 27 schools and 41 teachers. Twenty five teachers from six school districts provided detailed evaluations of all or most of the first 16 of the 40 topics of the course, with all 41 teachers contributing some evaluations. Sixteen teachers from four school districts returned detailed evaluations of the whole year's course. The questionnaires were analysed by means of categorisation and comparison as most of the responses were to open questions, with a few relying on completion of Likert scales. The course evaluations provide a general indication of the strengths and weaknesses of an integrated STS approach. The evaluations of different topics provide evidence for types of teaching and learning strategy which assist integration of science concepts with the global concept of sustainability

Results and Discussion

Concept coverage

Documentary analysis showed the 40 topics, which each lasted several teaching sessions, could be categorised into 57 discrete activities as follows:
A science concepts only - 18;
B contextualised science - 21;
C science and sustainability integrated - 15;
D social emphasis only - 3.

Details of the topics, sessions and categories are shown in Table 1.

	A - science only require teacher to contextualise	B - science in a particular given context	C - Activities which integrate science & sustainability	D - Activities which emphasise social context of sustainability
1			BB human survival MW	
2	BB bio survival			
3		PP laws thermodynamics	P physics survival MW	
4		PPPP energy transfer		
5				XXX sustainability MW
6	CC elements		CC use of materials MW	
7		CCC metal extraction		
8	CC modelling molecules			
9	PP heat capacity		P building material MW	
10		CCC oil distillation		
11	CCC mols & bonding			
12		CCC models polymers		
13		CCC degradation aspirin		
14	CCC catalyst	C Haber process		
15		CCC byproducts waste		
16		PP energy use	PP energy use MW	
17	BBBBBB homeostasis			
18	PPP theories of heat			
19	CCC chem reactionns	C exo/endothermic		
20		CCC fuels	C sustainable fuel	
21		CCC air pollution	XXX decision making	
22	BB food webs		B eating habits MW	
23	BBB respn & photsyn			
24		CCC fermentation	BB food energy ratio	
25			CP sustainable energy	
26		BB fast plants	BB food for world	
27	BBB soil nutrient cycle			
28			XX remote sensing MW	
29				XXX population growth
30	BBB popn dynamics			
31				XXX changing popns
32		BBB genetics	B plant genetics	
33		BBB improved crops		
34	B DNA	BB genetic eng crops		
35		BBB food preservation		
36	P convection	PP ice box technology		
37	P latent heat	P change of state		
38	PP gas laws	PP refrigerators		
39	PPP EM spectrum		PP food irradiation	
40			XX food preservation	
	45 sessions 20 Bio, 13 Chem 12 Phys	52 sessions 13 Bio, 26 Chem, 13 Phys	26 sessions 8 Bio, 4 Chem, 7 Phys	9 sessions

(processes of science are not indicated in this analysis, although present in topics)
B – Biology session; C – Chemistry session; P – Physics session; X – no major science concepts
MW - where Material World book is used

Table 1. Documentary analysis of topics for concept integration.

Sixteen topics had tasks which together fell into more than one of the categories. Thus the course achieved a broad range of activities with many but by no means all fully integrating science concepts with sustainability. This range is perhaps inevitable when the purpose of a course is to develop both an understanding of fundamental science concepts and global sustainability – i.e. some activities have to focus on the science concepts only to allow understanding to be used in the integration of science and sustainability.
The evaluation questionnaire evidence provides details of teachers' views of the 40 topics.

Table 2 shows teachers' perceptions of the extent and depth of concept coverage. Teachers were asked to comment on all these concepts which are identified in the learning objectives of topics during the course.

CONCEPT	S	R	D	E	L	CONCEPT	S	R	D	E	L
1 Organisms	8	4		9		19 Kinetic energy	10	5		5	
2 Optimum conditions	5	10		11		19 Exo-/endothermic		15		10	
3 4 18 36 Heat (flow)	1	10	4	6	3	20 Combustion		15		7	
3 Thermodynamics		12	2	10	3	21 38 Pollution	2	12	1	12	3
3 18 Temperature	1	12	2	7		22 Food chains	5	7	2	9	
6 Periodic Table	10	5		8		23 Photosynthesis	6	7		10	1
6 8 Elements compds	5	10		11		23 Respiration	7	6		9	1
7 Metal extraction	1	13	1	3		24 25Renewable res.	6	8		13	2
8 Atoms & molecules	4	8	3	8	1	24 Fermentation	1	12	1	6	
9 Specific Heat	1	12	3	3		24 Quality of Life	1	12	1	8	
11Structural formulae	1	12	1	6	1	25 Fossil fuels		12	2	9	
11Bonds	10	5		8		26 Ecosystem	10	5		11	
11Hydrocarbons	1	13	1	4		26 Carrying capacity	7	4	1	10	
12 Props of materials		9	6	6		27 Soil	2	9	1	6	
12Props & structure	4	7		4		27 Nutrient cycles	9	5		11	
12 Models	4	9		7		30 Growth curves	5	7		11	
13 Degradation		14	1	5		32 Genes & Traits	6	3		6	
14 Rate of reaction	5	10		6		39 Energy as waves	9	2		1	
14 Catalysts	5	9	1	4		33 Genetic crosses	5	4		5	
15 20 35 Tradeoffs	5	11		14		34 DNA	7	3		5	
15 Waste disposal	5	7	1	9	1	35 Food Preservation	1	4	4	2	
1 16 Energy flow		12	2	12	12	37 Change of state	7	8		5	
17 Homeostasis	7	6	1	14		37 Refrigeration		2	6	1	
17 Enzymes	6	8	1	5		38 Evaporation / boil	3	9		3	
17 Cell Structure	10	2	2	6		39 EM Spectrum	6	3		1	
17 Cellular transport	3	9	2	5		39 Radioactivity	6	3		2	
18 Mechanical energy	7	4		2		Use of Evidence	3	12		9	
5 6 16 24Sustainability					5	Data collection					3
Human intervention					5	Scientific method					2
31 Graphs					5	Designing expts					2

Key: First number refers to the activity number. Concepts are shown in the order in which they are encountered. Shaded boxes show concepts integral to sustainability implied in the course materials
Concept coverage: Numbers of teachers regarding coverage as: S - too superficial; R - about right; D - too much depth. E - considered an essential concept
L - indicated in response to a separate question 'What are the main concepts you think you students have learned. Cite any evidence'

Table 2 Conceptual demand and coverage

Concepts and depth
There appears to be better targeting of chemistry and physics concepts in terms of depth of coverage than biological concepts.
Very few concepts are perceived as being too detailed – properties of materials, refrigeration and food preservation being the only ones.

There appears a <u>good</u> match between coverage and concepts regarded as essential by teachers and for a good understanding of sustainability in the following areas: energy flow; thermodynamics; pollution; quality of life; use of evidence.

There appears a <u>poor</u> match between coverage and concepts regarded as essential by teachers and for a good understanding of sustainability in the following areas: ecosystem; nutrient cycles; carrying capacity; food chains; waste disposal.

Some concepts nor integral to 'sustainability' are regarded as important by teachers: organisms; homeostasis; photosynthesis; respiration; elements and compounds; fossil fuels; exo-/endothermic. These may be regarded as underpinning concepts - i.e. not closely related to sustainability but essential building blocks for understanding concepts which contribute to an appreciation of sustainability.

Energy flow and air pollution are not only identified as essential, they are also identified as topics which help integrate science concepts with sustainability. It is worthy of note that these are also concepts which most teachers regard as being treated at appropriate depth - i.e. with these concepts effective teaching and learning approaches appeared to coincide to the benefit of the students.

The overarching definition of sustainability give in the course materials appears to have been addressed effectively, regarded of high importance by teachers and perceived as learnt by students:
Sustainable development requires the achievement of a steady state between energy use and total energy resource.

Integration in practice
In order to illustrate the issues of integration further, in-depth evaluation of the first five topics of the course, from 25 teachers, provided valuable information on the aspects which assist student learning and integration of science and sustainability. One example is given here.

Activity 5 is important to the course in introducing and developing the concept of sustainability. The activity in outline is:
Developing a personal definition of sustainability, identifying key issues and investigating ways in which science and technology can contribute to a sustainable future, through reading, discussion and consideration of life styles across the world.
Concepts: Sustainable development is the goal of meeting the needs of today without compromising the ability of future generations to meet their own needs. Quality of life is one's personal qualitative view of one's own life style.

Evaluations from teachers indicated that a quarter felt this activity needed major revisions. There is a sense in which the dissatisfaction from some teachers on this activity reflects their insecurity in engaging in, to them, innovative teaching.

One can detect in teachers' responses to open questions, differences in the ways in which teachers were approaching the innovation. Some embraced it, supporting the integration of concepts and students' ideas:
'I had the students write their responses to how the world would be like in 35 yrs on butcher paper and present information to the class/ They got so involved in the discussion and presentation. It was a very rewarding activity for the students and myself included. They brought up information, facts and points from all the previous labs and activities which really showed me how much they had learned.' T5

'This activity was by far my favorite as well as my students - more such activities need to be organised.' T3

At the other extreme, a very few seemed to have difficulty in moving from a perspective of teacher as provider of consensual scientific knowledge to integration of science and society:

'Low level of interest. Poor lesson overall. Going back to 'Material World' at this time seemed like overkill. Leave this unit out.' T12

While there is no observational data of these two teachers' practice, one can speculate that T3 and T5 had strong empathy with the course aims and were skilled in developing their own approach. T12 in contrast, from this quote and others, was operating from a focus on developing understanding of key science concepts only.

The contrast between the extremes of uptake of the innovation as expected can be further illustrated by T3 and T12. T12 provided no evaluations after activity 6, suggesting, perhaps, that the course had limited value for him. In contrast, T3 evaluated all topics commenting on later activities:
Good activity. However we need to relate this back to developed and developing coutries. Petroleum and plastics are very important in distinguishing between developed and developing. T3 (on activity 10)

I think we need to add more information on toxic waste, hazardous waste disposal systems and how we affect our global environment. Environmental education, sustainability and developed and underdeveloped countries should be discussed here. T3 (on activity 15)

Teacher 3 was able from the outset to develop a focus on integrating science concepts with global sustainability and sought such integration throughout the course. She was not alone in this stance – about a third of the teachers maintaining full evaluations (five out of 16) provided positive and constructively critical feedback. For such teachers, the course stimulated and sustained changes in their teaching.

A further insight into the necessary adaptation for teachers in teaching *Science and Sustainability* can be gained from their evaluation of analysis questions, where just under a third of teachers spontaneously argued that their use was too extensive. Analysis questions are intended for students to explore the meaning of their experimental results, reading or other activity in terms of depth of understanding of the key science and sustainability concepts for the activity and, importantly, interrelationships of concepts. The fact that teachers commented on the difficulty and frequency of these is open to a number of interpretations. These could include: the difficulty for any student, but particularly some of the low achievers, in understanding and interpreting relationships between abstract concepts; the difficulty for teachers in adapting to change from an emphasis on traditional science content. One possible explanation is given in T8's comments:

Unless I know what the analysis questions are getting at they are often difficult for students (& myself) to answer. It's like we're trying to read someone's mind.' T8

It appears that for this teacher the purpose of particular analysis questions had not been sufficiently clarified in the material.

Overall evaluation

Although the course received very positive recommendations from 88% of the 16 teachers providing full evaluations of the topics and the whole year's course, 69% considered that the course was conceptually demanding with too many concepts being covered.

Of the 16 teachers providing evaluation of the whole course, 11 considered that there were too many concepts in the course, 3 that there were about the right number and 2 that there were too few.

Fourteen of the 16 teachers were very positive in their recommendations of the course.

Particular strengths of the course were perceived as:
- the integration of science concepts with a global theme (10 teachers)
- interest and critical enquiry generated in students (6)
- 'hands-on' approach (5)
- pre-prepared activities and materials (4)

Weaknesses were perceived as:
- too many science concepts - lack of time for coverage (5)
- balance of science concepts towards the physical sciences (5)
- extensive use of analysis questions (5)

Conclusion

Despite the great enthusiasm and student motivation resulting from a science course which has global sustainability as an underpinning concept, teachers regard the conceptual demand of the course as high in perceiving that too many concepts are covered. This is compounded by the fact that a considerable number of science concepts are regarded as being treated superficially. An important outcome from the course evaluations is the tension apparent between concept coverage and depth, particularly in a course seeking to integrate science concepts with more global considerations. The integration of concepts is both demanding in terms of course design and in teaching in practice. The integration of science and sustainability has been achieved in many topics in principle resulting in a motivating and wide-ranging course which promotes active and responsible learning. In practice, the integration is even more demanding, resulting in difficulties in teachers moving from a 'traditional' to a context driven course. Some teachers want science concepts covered in great depth and consider topics which focus on the integration of understanding of science concepts with sustainability as too frequent – i.e. even among teachers who are generally welcoming of an integrated approach and receive support and training, there are issues in adapting their teaching approach. There is a demanding and, to some extent, unresolved tension for both curriculum developers and teachers in devising and teaching a course which adequately addresses both citizenship and the understanding of science concepts. Despite the difficulties of such an integrated approach, few curriculum attempts to address the global social, ethical and environmental applications of science are as developed as those in *Science and Sustainability.*

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