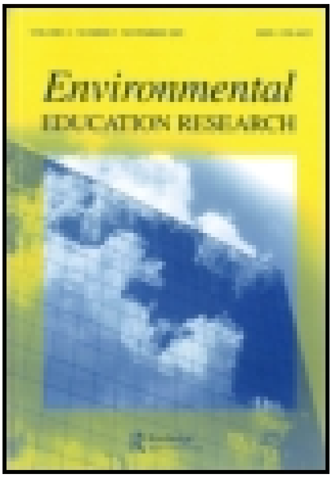

Environmental Education Research
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ceer20

High school students' decision making about sustainability

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Published online: 15 Aug 2006.

To cite this article: Marcelle A. Siegel (2006) High school students' decision making about sustainability, Environmental Education Research, 12:2, 201-215, DOI: 10.1080/13504620600689003

To link to this article: http://dx.doi.org/10.1080/13504620600689003

Environmental Education Research,
Vol. 12, No. 2, April 2006, pp. 201–215

High school students' decision making about sustainability

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This study examined decision making in an urban US high school classroom in which tenth-grade students analyzed scientific evidence about current issues of sustainability, technology and society. A full-year course, called Science and Sustainability, was used in both groups, and a computer program, called *Convince Me*, provided scaffolding for making evidence-based decisions for one group. During the course of instruction, both the groups completed open-ended written assessments. Limited student progress, in using evidence to support claims and in weighing benefits and drawbacks, was demonstrated. The *Convince Me* group showed more significant gains than the Science and Sustainability group alone. Implications for instruction are discussed.

Sustainability and science education

One of the most important responsibilities educators have is to improve students' abilities to make decisions about challenging issues. Making complex decisions involves many aspects of critical thinking—for example, coordinating hypotheses and evidence, evaluating the relevance and reliability of evidence, and weighing multiple alternatives. One challenging issue facing society is how to maintain essential resources for future generations—or 'sustainability.' In general terms, 'sustain' means 'to keep going continuously.' The following definition of sustainability framed the curriculum that was studied:

> To be sustainable is to provide for food, fiber, and other natural and social resources needed for the survival of a group—such as a national or international society, an economic sector, or residential category—and to provide in a manner that maintains the essential resources for present and future generations. (Wimberly, 1993, p. 1)

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ISSN 1350-4622 (print)/ISSN 1469-5871 (online)/06/020201–15

DOI: 10.1080/13504620600689003

Environmental educators have further defined the concept of sustainability by including risk, uncertainty and complexity. For example, Jickling (2001) explains the need to study more than a moment in time and to explore the assumptions that underlie competing views of sustainability. The environmental justice movement defines sustainability more broadly, with three areas of focus: (1) environment, (2) economy, and (3) equity. Environmental justice proponents argue that all people, regardless of race, ethnicity or income, should enjoy access to a safe and healthy environment (The First National People of Color Environmental Leadership Summit, 1991). From this perspective, the environment is not 'people-free,' as idealized by deep ecologists, or 'people-neutral,' as assumed by mainstream environmental educators, but a system linked to people through everyday activities: residence, labor, school and recreation (Novotny, 2000; Taylor, 2000). A 'just environment' means that all groups of people have equal opportunity for benefit and influence (Romm, 2002). This study did not prepare students to fully engage in the types of thinking and action proposed by an environmental justice stance. The study was designed to help students learn to identify scientific and societal issues and to make decisions about local and global issues by analyzing scientific evidence. A stronger focus on social justice will be discussed as a way to improve the work. (For more on environmental and justice education research, see Hart & Nolan, 1999; Bowers, 2001; Rickinson, 2001.)

The need to prepare students for decision making on socio-scientific issues has been recognized by organizations such as the American Association for the Advancement of Science (1989) and the National Research Council (1996). The field has responded with student curriculum (e.g. Science Education for Public Understanding Program, 1995; Education Development Center, 1997), teaching models on decision making (e.g. Kortland & Lijnse, 1996; Ratcliffe, 1996), and teacher education materials (e.g. Swartz & Parks, 1994; DiRanna & Siegel, 2004). Student materials that excel in using current issues, engaging students in decision making and/or providing environmental science content have also been criticized for being tacked onto traditional curricula and/or for advocating for particular causes. The approach taken in this study was to use core curriculum to help students develop an understanding of science and the decision making processes related to socio-scientific issues, without taking an advocacy position. Participants used the field test version of a full-year integrated science course called Science and Sustainability that focuses on: (1) the understanding that there is no single answer for how to maximize sustainability; (2) the importance of decision making based on scientific evidence; and (3) scientific, technological and ethical advances for informing solutions to societal problems.

Coherent reasoning about evidence

Another aspect of this study is investigating students' reasoning and decision making skills in using evidence. Other studies have examined these skills as well. For example, in the Web-based Inquiry Science Environment (WISE) project, students interpret and critique scientific information garnered via the Internet and make conjectures about it, forming a scientific argument. WISE researchers have hypothesized that engaging students in the creation of an argument facilitates conceptual change (e.g. Bell & Linn, 1997). In Biology Guided Inquiry Learning Environments (BGuILE), students conduct observational investigations and articulate theories by connecting hypotheses and evidence. Students study a complex problem, such as a crisis in an ecosystem, and need to explain the death and differential survival of organisms in that ecosystem by applying the theory of natural selection (Reiser *et al.*, 2001). BGuILe research demonstrated that by studying complex issues, students often learned more content than was available in traditional textbooks (Smith & Reiser, 1998) and identified plausible and relevant claims for their explanations, although they had some difficulty navigating the complex data-set to find the 'best' explanations (Reiser *et al.*, 2001).

The decision-making software used in this project, *Convince Me* (CM) (Schank *et al.*, 1996), possesses a connectionist network (called ECHO) that simulates human reasoning. While using the program, a student enters alternatives, beliefs and evidence about an issue and then evaluates the plausibility of his decision. CM's interface provides scaffolding for making a decision through prompts for entering hypotheses and evidence. Students are also asked to make links between and among hypotheses and evidence and must choose whether each link they make is supportive ('explain') or contradictory ('conflict'). Students rate the reliability of each piece of evidence, as well as how much they believe each statement that they have entered. Next, they run the ECHO simulation, and then they contrast their ratings with ECHO's activations by pressing the 'Model's Fit' button, that calculates a correlation score and responds with, for instance: 'The correlation between your ratings and ECHO's evaluations is: 0.29 (mildly related)….'

Using ECHO, CM offers feedback as to whether the student's evaluation of each proposition matches the values that are simulated by the computer. ECHO's principles of reasoning are based on the Theory of Explanatory Coherence, established by the philosopher Thagard (1989). The theory is based on basic principles for sound arguments, for example that the more support a statement has, the more believable it is. The plausibility of a belief increases with, for instance: (a) the simplicity with which it is explained, (b) increasing breadth of evidential coverage, and (c) decreasing competition with alternative beliefs (Ranney & Schank, 1998). Table 1 lists these principles in more detail. ECHO embodies the theory in a computer network by representing each statement as a node, with explanations as excitatory links and contradictions as inhibitory links. Belief evaluation is treated as the satisfaction of

Table 1. Some of ECHO's principles for a coherent argument

Plausibility increases with more support from explanatory statements.
Plausibility increases with less competition from contradictory statements.
Simplicity: The plausibility of a belief is inversely related to the number of co-hypotheses it needs to explain a proposition.
Data priority: Results of observations, such as evidence and acknowledged facts, have a degree of acceptability on their own.

many constraints, determined by the structure of the network and additional computational parameters (Schank & Ranney, 1992). Activation in the network represents plausibility. The theory and ECHO have been tested empirically and were repeatedly found to be a useful predictor of participants' beliefs (Schank & Ranney, 1991, 1992; Read & Marcus-Newhall, 1993).

Prior studies with CM indicate that it is a useful tool for learning about reasoning. Students using the program performed better than students doing similar pen and paper exercises, perhaps because of the computer's feedback (Schank, 1995). Also, undergraduates working with CM improved at distinguishing between hypotheses and evidence (Ranney *et al.*, 1994).

Science and Sustainability curriculum

The Science and Sustainability course was developed with funding from the National Science Foundation (Science Education for Public Understanding Program, 1999). Course materials include a student book with activities, readings and discussion questions; a teacher's guide with instructional details, scientific background information, and assessment and literacy resources; a photographic book (published by the Sierra Club) illustrating 39 representative families with their worldly possessions, along with demographic and other statistical information about each country; and a kit with supplies and equipment. The course is intended for high school use, particularly tenth-grade integrated science. Science and Sustainability encourages students to explore the science and tradeoffs involved in obtaining their desired 'quality of life' while helping to develop a global perspective by investigating issues from the point of view of people in different regions of the world.

The course is divided into four parts related to sustainability: basic needs, food, earth's resources and energy. Each part uses a guided inquiry approach to teach science concepts and skills in chemistry, biology, physics and earth science. This study focused on the biology unit related to growing food for the world. Research using the field test version of the course demonstrated that students' attitudes about the relevance of science became more positive over time (Siegel & Ranney, 2003).

Research focus

This study investigated whether instructional materials helped high school students become better at weighing evidence in decisions related to sustainability. Group S used only the Science and Sustainability materials and Group CM used the Science and Sustainability materials partly replaced with *Convince Me* activities. The hypothesis was that *Convince Me*'s principles of coherence (Table 1) would help engender better decision-making skills. To test whether S and CM activities significantly improved students' uses of evidence and the weighing of tradeoffs, two classes were examined for several months. The researcher observed, taught, participated with and tested the classes daily and equally from January through June. The same teacher led both advanced Biology classes.

Assessing students' decision making

This study approached assessment by focusing on students' use of evidence and weighing of tradeoffs. Students wrote short essays or sentences in response to open-ended questions. Items varied in the amount of science content they involved and whether the items were embedded in hands-on investigations throughout the curriculum. 'Evidence and Tradeoffs' (ET) items were scored on a criterion-referenced, 0–4 scale.

Students were assessed on two elements of Evidence and Tradeoffs:

- *Using Evidence* (student supports claims with relevant evidence);
- *Using Evidence to Make Tradeoffs* (student sees drawbacks as well as benefits in choice and supports these tradeoffs with evidence).

For example, a student who provided the major objective reasons for his/her decision and supported each reason with relevant and accurate evidence would receive a score of 3, on the 0–4 scale for Using Evidence. Table 2 displays the entire rubric.

Table 2. Evidence and Tradeoffs (ET) rubric

Score	Using Evidence:	Using Evidence to Make Tradeoffs:
	Response uses objective reason(s) based on relevant evidence to argue for or against a choice.	Response recognizes multiple perspectives of issue and explains each perspective using objective reasons, supported by evidence, in order to make a choice.
4	Accomplishes Level 3 AND goes beyond in some significant way, e.g. questioning or justifying the source, validity and/or quantity of evidence.	Accomplishes Level 3 AND goes beyond in some significant way, e.g. suggesting additional evidence beyond the activity that would further influence choices in specific ways, OR questioning the source, validity and/or quantity of evidence and explaining how it influences choice.
3	Provides major objective reasons AND supports each with relevant and accurate evidence.	Uses relevant and accurate evidence to weigh the advantages and disadvantages of multiple options, and makes a choice supported by the evidence.
2	Provides some objective reasons AND some supporting evidence, BUT at least one reason is missing and/or part of the evidence is incomplete.	States at least two options AND provides some objective reasons using some relevant evidence BUT reasons or choices are incomplete and/or part of the evidence is missing; OR only one complete and accurate perspective has been provided.
1	Provides only subjective reasons (opinions) for choice; uses unsupported statements; OR uses inaccurate or irrelevant evidence from the activity.	States at least one perspective BUT only provides subjective reasons and/or uses inaccurate or irrelevant evidence.
0	Missing, illegible or offers no reasons AND no evidence to support choice made.	Missing, illegible or completely lacks reasons and evidence.
X	Student had no opportunity to respond.	

In accordance with effective classroom assessment practices, students were introduced to the assessment system before the evaluation took place (e.g. Stiggins, 2001; Siegel *et al.*, 2006). They completed practice questions and received feedback. They also used the scoring guides while constructing their responses in order to learn to distinguish the qualitative differences between score levels.

Participants

Two tenth-grade classes (usual age 16 years) participated in the study, with 28 pupils in group S and 19 in group CM. The two classes' scores on the United States' standardized TerraNova test (CTB, 1997) were not significantly different ($p = .35$) prior to instruction. The overall mean score on this norm referenced test (which assesses against specific criteria/objectives to be mastered by students at particular grade levels) was 2.45 on a five-point scale, which was below the test's 'nearing proficient' score of 3.00.

The participating school faces socioeconomic challenges typical of the US inner city: 50% of its students qualify for Aid for Families with Dependent Children; 42% of students are identified as Limited English Proficient by the school district. Several dozen different languages/dialects are spoken at the school. The participating school is the most diverse in the district. The district reports no majority racial group: 42% African-American, 15% Asian, 6% Caucasian, 1% Filipino, 34% Hispanic, 4% Native American, 1% Pacific Islander, and Other. The SAT scores reported for the approximately 41% of school seniors who took the test were far below the national average: 321 on the verbal portion (national average is 423) and 437 on mathematics (national average is 479).

Procedure

Both of the two tenth-grade classes participated in the Science and Sustainability course activities. For a period of two months (during weeks 8–15), the CM class used both the course and the CM computer activities. Due to scarcity of computer facilities, half of the class used CM one day while the other half completed decision-making activities; the next day they switched. The CM students thus spent four weeks actually using CM in the computer lab. The S class engaged in decision-making activities during the time the CM class used CM in this manner.

The 18-week study began in February, and the first three weeks consisted of activity-based instruction about biotechnology and sustainability. The next seven weeks, students studied food webs and ecology, and then learned about cells and genetics. Three weeks were spent on evolution. Then three weeks were taken to study soil and ecology again. The final two weeks consisted of review and end-of-year activities.

The regular teacher taught both classes, which were at the Advanced level of first-year Biology. The teacher was experienced in using the materials, and she taught all the other sections of Advanced Biology for the school, as well as an Environmental Science Institute.

Students in the CM group learned and practiced a model of decision making that they could use in other situations involving complex choices. Once these students were adept at using the program, each of them made decisions while working alone with CM. Students entered their alternatives/hypotheses into the program and linked them to evidence in a supporting or conflicting fashion. They also had an opportunity to use CM to make a personal decision of their own choosing. The goal was for students to learn ways to make an evidence-based, coherent decision.

Instrument

The ET questions were pilot tested for reliability, validity and difficulty in a previous study. Using this information, ET items were assigned to the two exams. The 'pretest' and 'posttest' consisted of 10 equivalent items each. The items were complex questions, often associated with a laboratory activity, and took at least half an hour to answer. Thus, it was not possible to give more than one question per day, and the pretest and posttest each took three weeks to complete. Alternative ways of defining 'pretest' and posttest' are described in the results section. Sample questions used on the ET evaluations are shown in Table 3.

Scoring

The researcher was trained to score items with the Evidence and Tradeoffs rubric through an intensive process of comparing practice scores to previously scored work from an assessment study of a related course (e.g. Wilson *et al.*, 1995). Names and times of testing were removed during analysis. While there was no bias owing to a teacher scoring work by his/her own students, only one scorer was available so inter-rater reliability was not computed.

Results: examples of student work

To provide a qualitative account of students' performance at various score levels, samples of student work are provided. Note that answers were not scored based on the correct use of English, but only on the criteria in the rubric (see Table 2). The following answers to items 1 and 2 received low scores (Using Evidence: 1, Using Evidence to Make Tradeoffs: 1), because they did not employ scientific evidence according to the question.

> **Question 1, 2:** Should we allow human cloning for research or medicine? Should any cloning experiments be done? Give evidence from the articles to support your view. Think in terms of both advantages and disadvantages.
>
> **Response:** I think that there should not be human cloning because if you clone a person you would have same DNA and everything and if the identical clone go and do something bad, like killing somebody, and when the police go catch the person, they might find the wrong person and they can not say anything because the clone and the person

Table 3. Examples of Evidence and Tradeoffs questions

Evidence and Tradeoffs Items	Question #
Do you think humans should be included in the Antarctic ecosystem? Why or why not? What role, if any, do you think humans play in the Antarctic ecosystem?	3, 4
Imagine that you are the principal of a school that is having a problem with broken windows. Your choice is to replace the broken windows with either glass or plexiglass (plastic). Glass and plexiglass have different properties, and the plexiglass costs about 25% more. What material would you use and why? Be sure to describe the tradeoffs involved in your decision. A complete answer will discuss the advantages and disadvantages of both materials.	7, 8 also 19, 20
…Table of Final Radish Heights (Calculate the average height for each treatment.) a) Would you add fertilizer to soil to increase agricultural output? Give reasons for your answer. b) Do you think that adding fertilizer to soil to increase agricultural output is a sustainable process? Explain.	13, 14
[After a laboratory investigation on nitrogen…] a) Did the nitrogen in the fertilizer get absorbed by the soil? Describe the evidence. b) Do you think that adding fertilizer to soil to increase agricultural output is a sustainable process? Explain.	15, 16
A substance is being considered for use as a preservative in dairy products. Many studies have shown that the substance is safe for both short-term and long-term use. A food company has found that at a concentration of 4000 ppm the substance is more effective than other preservatives in preventing molds from growing in dairy products…tastes bitter, may cause not to buy…[graph of taste test]… Do you think the company should use the substance in any or all of these products? Write your recommendations in the space below. Be sure to explain your recommendation thoroughly, including the advantages and disadvantages of using the substance in these products. You may use the back of this page if you need more space.	17, 18

> have everything the same. In a way I think that allowing human cloning is good because the clone could be much healthier and everything.

The answer did not use evidence according to the question, in that it did not mention specific research or medicinal uses for cloning, and it did not use evidence from the activity. For example, the student could have cited ‘the possibility of reducing genetic risk of a disease for a child,’ and the ‘danger of government-imposed’ genetics. The answer received a low score on Using Evidence to Make Tradeoffs because even though it provided two perspectives (‘should not be human cloning’ and ‘cloning is good’) not enough objective evidence is cited for either side.

As is common in assessing student work, many answers received low marks due to a lack of response or detail. For example, on items 13 and 14 (see Table 3) one student wrote:

> **Response:** 13. Yes. Some my plant will grow faster and more.
> 14. Yes to keep the plant healthy.

This response received 0s because it did not provide any evidence. The two responses below were in the 2 range because they used some evidence and weighed both sides of the issue:

> **Response:** 13. I would put fertilizer in my soil to increase agricultural output because it might help make bigger vegetables and solve world hunger.
>
> 14. It might and it might not. It depends on how much you put. If you put too much, it will stunt growth and wouldn't help much, If you put too little it wouldn't help much. In the end though, it will change the earth's soil until it cannot grow plants without fertilizer.
>
> **Response:** 13. I would add fertilizer to soil because it can help make my plants grow faster and produce better. It will be bigger.
>
> 14. I don't think that its a sustainable process because in the long run it will reduce your crop to half of if it is compared to the control.

On a later question about agricultural sustainability that specifically focused on a lab about runoff, the sample answer below received high marks:

> **Response:** 15. Fertilizer runoff would be FULL of nitrogen. Fertilizer soil would have some nitrogen because it was fertilized. The local dirt came from a house plant, so it would have SOME nitrogen, but not as much as when you add fertilizer. And the potting dirt barely had any nitrogen in it because it was like store-bought dirt, unused,…which means it shouldn't have any nitrogen in it.
>
> 16. Yes because the local soil was a lighter-purple before we added fertilizer. After the fertilizer was added, the liquid was a darker color, which means some nitrogen must have been absorbed.

This answer received a 3 on Using Evidence (#15) because it used several pieces of scientific evidence from the activity, and it received a 2 on Using Evidence to Make Tradeoffs (#16) because it did not weigh both sides of the issue citing evidence.

Evidence and Tradeoffs results for both classes

The results from comparing the ET scores, including both 'Using Evidence' and 'Using Evidence to Make Tradeoffs,' portrayed slight changes for both classes (Table 4). Note that throughout this time both classes were using Science and Sustainability activities and so would be expected to improve on ET measures. Both classes started at about level 2, which indicates the use of some evidence and tradeoffs, but not accurately or completely. Then, the S group performed non-significantly

Table 4. Average Evidence and Tradeoffs scores. The units are from the Evidence and Tradeoffs 0–4 scale

Class	Pretest (1–10)	Posttest (11–20)
S	2.23	2.14
CM	2.31	2.38
Difference	.08 (p = .19)	.24 (p = .07)

worse on the posttest, and the CM group performed non-significantly better (p = .36 for S and p = .38 for CM), such that the CM group eventually performed marginally better than the S group (p = .07, ANOVA interaction: F = .22, p = .63).

Neither class showed very significant changes over time on Evidence and Tradeoffs. A potential problem with the instruments was that the pretest (#1–10) and posttest (#11–20) lasted three weeks, during which there could have been improvement. As explained before, the reason for this design was that the open-ended items were time-consuming; some were embedded in activities and labs which made it impossible to complete all the items for a test on one day or even during a single week.

In order to see more detail, Table 5 shows the raw average scores for each class, for each item. Students improved in general if one looks at each question over time (i.e. there are some decreases, but more often increases, with a general increase between the first and last sets of questions). Both classes on average began below level 2 on the first items, and after months of work, increased to about level 3 on items 19 and 20. Moreover, the CM class ended up with a higher score than the S class. A two-way (time vs. group) analysis of variance revealed insignificant differences (time: F = .0018, p = .97, df = 1; group: F = .92, p = .34, df = 1; interaction: F = .22, p = .63, df = 1). The largest significant difference between the CM and S classes is seen on items 13–20. The S class's average was 2.07 and the CM group's average was 2.47 (significant at p = .010).

Table 5. ET Scores by Item. The score units in columns 2 and 3 are from the Evidence and Tradeoffs 0–4 scale

Items	S Averages	CM Averages
1	1.92	1.63
2	1.81	1.41
3	1.86	2.10
4	1.64	1.60
5	2.71	2.75
6	2.54	2.8
7	2.64	2.74
8	2.64	2.74
9	2.28	2.64
10	2.24	2.72
11	2.43	2
12	2.43	2.09
13	1.85	2.17
14	1.15	1.94
15	1.23	2.45
16	1.61	1.68
17	2.33	2.63
18	2.57	2.63
19	2.86	3.1
20	2.95	3.15

Table 6. Average ET Scores for selected items. The units are from the Evidence and Tradeoffs 0–4 scale. P values are shown in parentheses

Class	Pretest	Posttest	Delayed Posttest
S	1.87	2.35	2.92
CM	1.52	1.98	3.00
Difference	.35 (< .001)	.37 (< .05)	−.08 (> .05)

Another way of checking for change over time is to look at the items given on the first day of testing (1, 2 'pretest'), those given on the first day after the *Convince Me* activities were completed (11, 12 'posttest') and those given on the last day (19, 20 'delayed posttest'). Students' average scores are shown in Table 6.

All of these differences were significant, except for the difference between the S and CM class on the delayed posttest. The improvement for the CM group was numerically larger than for the S group. The gain scores were: Pretest to Posttest, .48 ($p < .001$) for the S class, .46 ($p < .001$) for the CM class; Posttest to Delayed Posttest, .57 ($p < .001$) for the S class, 1.02 ($p < .001$) for the CM class. The total gain scores from the Pretest to the Delayed Posttest were: 1.05 ($p < .001$) for the S class and 1.48 ($p < .001$) for the CM class. The CM group showed the most improvement, not immediately after using *Convince Me*, but on the delayed posttest.

Discussion

The results demonstrated that some students from both classes became more sophisticated at answering questions that required them to use evidence and make tradeoffs. The pretest and posttest with 10 items each revealed insignificant changes over time for both groups, however. One reason for this is the small number of participants. Also, the design had practical constraints preventing the administration of multiple questions on the same day. Further analysis using only selected items showed that both groups using Science and Sustainability activities scored higher on Evidence and Tradeoffs over time. This analysis could be considered a better slice in terms of timing, however it incorporated fewer items and should be considered less reliable. The group using CM had significantly better posttest scores with the selected items than the S group, which could suggest that CM was a useful tool for helping students learn to make evidence-based decisions. The CM group's average gain from the pretest to the delayed posttest was 1.48, while the S group's was 1.08—both representing qualitative differences of at least one score level. Interestingly, the CM group's greatest gain was between the posttest and delayed posttest. This result might imply that students benefited from integrating their experience with CM with additional Science and Sustainability activities and evaluations.

From the researcher's daily experience in the classroom, it appeared that students learned that to build an argument in CM, one was *obligated* to include evidence and not just opinions. Another part of the study began to explore why CM might be helpful. In that study, students' understanding of CM's principles of coherence was examined in relation to their performance on Evidence and Tradeoffs. Correlational data supported the hypothesis that CM's principles of coherence would enhance students' use of evidence (Siegel, 1999). Still, other aspects of interacting with CM could have been beneficial beyond the principles of coherence. For instance, CM scaffolded students in connecting supporting and conflicting statements into a web. This type of reasoning experience might have been helpful when answering the Evidence and Tradeoffs questions. The act of checking one's decision after receiving feedback from the computer, then revising it, might also have been useful for the students. Further studies are necessary before a full assessment of CM's assets and flaws can be made. Previous studies have targeted parts of the program that assist learning in particular ways (e.g. Ranney *et al.*, 1994).

The Science and Sustainability curriculum was limited in that it did not involve students in education for environmental justice. The Science and Sustainability course portrayed a diverse range of citizens from across the world and engaged students in critical thinking about socio-scientific problems, but focused on the scientific and technical aspects rather than the societal aspects. An environmental justice perspective that takes into account the dynamics of inequality is important for the participants of the current study, who attended an urban US high school with no majority racial group, high poverty and 10 toxic release facilities in the city. The materials were not designed to empower the environmental justice population from the study—namely poor, working-class, indigenous, refugee and communities of color who bear the disproportionate burden of environmental impacts in the places where they live, work and play (Matsuoka, 2003).

Future research and curriculum development should take an environmental justice perspective into account. Environmental justice education aims to synthesize four goals: (1) understanding the relationships between the domination of nature and the domination of oppressed groups; (2) tackling environmental racism, including the geography of social injustice and pollution; (3) rejuvenating and creating noncommercial traditions that support social justice and sustainability; and (4) reconceptualizing lifestyles in ways that will not threaten the environment for future generations (Bowers, 2001). Environmental justice education is also informed by a critical pedagogy of place which proposes that: (a) proactive pedagogy for environmental justice should be school wide and include children as well as adults; (b) pedagogy should build meaningful connections to local communities; and (c) methodologies should include natural history, cultural journalism and action research (Furman & Gruenewald, 2004). Also, an environmental justice perspective is needed to enhance the current curriculum in order to bring students to action in their communities. For example, a curricular approach from an environmental justice community organization includes the following components: (a) recognizing and lifting up people's experience by beginning with observations of what is happening locally; (b) helping the group connect personal experience to the larger picture of injustice through statistics; (c) analyzing politics and root causes; and (d) deciding to take collective action (Asian Pacific Environmental Network, 2005).

The Science and Sustainability course thus falls short in focusing on the scientific and technical solutions, rather than on social impacts or data, and on focusing on socio-scientific decisions rather than on critiquing mainstream world views and taking action locally. Furthermore, the course emphasizes the science of the 'threshold' of poison and toxicity on human health, instead of evaluating policies that affect the health of communities. It focuses on the impact of one company or development, rather than recognizing that most communities face a multitude of pollution sources that is larger than any one source alone. On the other hand, as a full-year science course in the USA, Science and Sustainability is quite unusual in its focus on sustainability issues, scientific evidence and real-world decisions.

The course was also limited in its instructional support for a process of decision making and a way to reflect on decisions. *Convince Me* offered students tools to analyze decisions that the Science and Sustainability course did not provide. CM had tools to judge the reliability and plausibility of evidence, to connect conflicting and supporting statements into a visual map and to provide feedback on the coherence of decisions. Perhaps the slightly more positive results with the group that used CM for four weeks suggest that students could benefit from more of this type of support for decision making. In addition, the assessment rubrics for the study were unusual in that they focused on the relevance of evidence that students included and how they weighed the benefits and drawbacks of multiple options. Instruction on sustainability, and on science education more generally, could probably benefit from including these types of assessments to foster and measure learning. Future work could also add criteria on students' judgments about the reliability of evidence, their ability to account for factors of risk and uncertainty, and making the values and assumptions that underlie different options explicit. With a high percentage of English learners, a major issue in assessing students' writing is how to access their science knowledge rather than language proficiency. The author is currently engaged in a study to revise middle school science assessments to be more equitable for English learners.

This study is a small step in the effort to develop ways of enhancing decision-making skills—a vital part of educating students as critically thinking citizens.

Acknowledgements

This research was supported by a traineeship from the National Science Foundation, Reforming Education through Science and Design, and other support from the University of California at Berkeley. I would like to gratefully acknowledge Professor Michael Ranney, the Science Education for Public Understanding Program, and the teachers and students involved in the study. Thanks also to Professor John Hurst, Diana Wu, Jennifer Lin and the Asian Pacific Environmental Network.

Note on contributor

Marcelle A. Siegel's interests include decision making, assessment, equity and developing resources to support instruction. She currently supports and studies

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