J Environ Stud Sci (2013) 3:30–41
DOI 10.1007/s13412-013-0109-0

Environmental connections and concept mapping: implementing a new learning technology at Lewis & Clark College

James D. Proctor · Jennifer Bernstein

Published online: 26 January 2013

Abstract What is environment? The answer to this question is fundamental to how we teach environmental studies and sciences (ESS). We follow recent scholarly literature in approaching environment as connection, not as some category of reality, and consider pedagogical implications via concept mapping, a new learning technology. Concept maps potentially offer a visually explicit means of representing and analyzing the hybrid connections between actors that define environmental issues. We explore the utility of concept mapping as pioneered by Joseph Novak and others via the Cmap Tools application, in which concept maps (cmaps) consist of concepts connected by propositions; both can include linked resources, and the resultant cmap can be collaboratively edited and shared online. We evaluate concept mapping in the context of a sophomore-level environmental methods course taught annually at Lewis & Clark College. The course includes adaptations of concept mapping drawing on Novak's work and actor-network theory, designed for students to reflect on their environmental perspectives, synthesize course material, and explore a proposed topic for environmental research. These exercises were evaluated in fall 2010 using self-reports, assessment rubrics, and open-ended student responses. Results showed that higher achieving students generally found concept mapping more demanding and attained more sophisticated understandings of connections. This suggests that concept mapping helps facilitate the intellectual struggle that characterizes engaged learning, yet also that not all students embrace this struggle to fully grasp environment-as-connection. In a larger sense, the study illustrates challenges in cultivating new approaches to environment in the ESS community.

Keywords Environment · Connection · Actor-network theory · Concept mapping · Learning technologies · Education

J. D. Proctor (✉)
Environmental Studies Program, Lewis & Clark College,
0615 SW Palatine Hill Road,
Portland, OR 97219, USA
e-mail: jproctor@lclark.edu

J. Bernstein
Department of Geography, University of Hawaii at Manoa,
445 Saunders Hall, 2424 Maile Way,
Honolulu, HI 96822, USA
e-mail: jbern@hawaii.edu

Environment as connection

The environment of ESS

As an interdiscipline, environmental studies and sciences (ESS) gathers a tremendous diversity of contributing fields, ranging from history and philosophy to economics and chemistry to sociology and ecology. What is shared across this broad spectrum is the term "environment." But what is environment, and how shall practitioners of ESS develop approaches to learning so that their students effectively grasp and communicate this common thread?

To many, environment is, well, environment! In English-language discourse over the last 50 years, the term environment appears settled: no news story on the state of the environment, no poem on environmental beauty, no scientific article on environmental pollution requires a terminological preamble as to what environment means. But this very notion of environment—in large part, a category comprising certain nonhuman stuff in our world, otherwise known as nature—has for the last several decades been challenged by scholars (e.g., Wilson 1992; Bennett and Chaloupka 1993; Evernden 1993; Cronon 1995; Soper 1995; Braun and Castree 1998; Castree and Braun 2001; Latour 2004a) who worry about what this category of nature includes and excludes. As viewed from the work of these scholars, nature can become a dividing line separating the ontological realities, epistemological ways of knowing, and ethical concerns and political movements that define the larger vision of environmentalism. Though this critical literature on concepts of environment qua nature has devoted considerable attention to philosophical and theoretical implications, less attention has been paid to pedagogical implications for ESS; this will be our focus here.

In this paper, we approach ESS from the premise of environment as connection, not a category. This approach is more etymologically true to the root of environment as, roughly, that which surrounds (Proctor 2009) and potentially affords fuller and more novel explorations of environmental issues by our students without importing too much baggage associated with concepts of nature. To us, the connections that comprise environment are not so much between some overgeneralized "human" and "nonhuman" or "natural" realms as between all the specific actors—lizards, laws, ocean currents, spiritual movements, structural adjustments—that come into relation in the context of what we have received as environmental issues, whether relatively longstanding (e.g., water pollution, wilderness) or more recent (e.g., endocrine disruption, environmental justice). There is no clear line separating environmental issues from other issues, which our definition of environment affirms; but there is plenty of good work to be done by practitioners of ESS to shed greater scholarly light on the issues we have inherited, primarily by elucidating the connections that matter in tracing issue-related problems and solutions.

Reframing environmental research

Approaching environment as connection demands new analytical methodologies, as it generally approaches environmental problems and solutions more with a fine-tipped felt pen than a foot-wide paint roller. Gone—if the above critiques of environment are at all valid—are the easy truths of listening to nature, going green, or caring for the earth. There are no a priori problems and villains and no a priori solutions and heroes. What replaces these shortcuts is educationally rich: a more open-ended focus on connecting the details that matter in a given environmental issue; a valorization of curiosity and careful research; and a sense that there is still much of value to be contributed by the current and future ESS community.

Approaching environment as connection and not just a category of nonhuman stuff also challenges notions of cause and effect fundamental to our understanding of environmental issues. Far too often, the nonhuman realm has been understood as a passive recipient of human injury, thus leading to the curious conclusion (sometimes celebrated in "green" product advertisements) that the ideal human impact is to have none at all.[1] If, however, environmental reality is understood as fundamentally entangled, notions of cause and effect become more complex and interesting, and environmental solutions encompass change—or resistance to change—in a host of related human and nonhuman actors. Ultimately, ESS research can remind us that though—as Barry Commoner reminded us (1971)—everything is indeed connected to everything else, some connections are more significant, some are better understood, and some are more tractable to change… in short, certain connections matter more than others. Discovering, explaining, and elucidating these special connections become the value added to contemporary discourse on environmental issues via ESS scholarship.

Connecting via concept mapping

Concept mapping and related approaches

A wide range of existing learning tools and approaches could help ESS students explore connections. For example, role plays in which students adopt the position of different actors in an environmental controversy can help them appreciate a decision's multiple perspectives and impacts: in the Pacific Northwest, the classic case of controversy over salmon management could include roles covering commercial and recreational fishing and hydroelectric power generation, and actors such as native Americans, salmon, pinniped predators, and others—an approach quite resonant with actor-network theory, summarized below. Or, the use of systems modeling to quantitatively explore connections has been important in ESS ever since the classic, and contested, Limits to Growth study of the early 1970s (Meadows 1972). One approachable systems modeling tool, STELLA[2] (used in updates to the Limits to Growth study—see, e.g., Meadows et al. 2004), offers a means to input quantitative relations (in equation or graph format) between visually linked components in an environmental system then models resultant interactions over time via numerically solving the resultant set of differential equations. One important limitation of quantitative modeling software like STELLA is that not all significant connections can readily be numerically specified, suggesting that systems modeling can benefit from contextualization by more qualitative approaches.

With the advent of web2.0 interactive tools, a new host of possibilities arises for ESS instructors interested in helping their students explore environmental connections. Some of these offer web-based simulation in a manner reminiscent of

[1] See, e.g., noimpactproject.org.
[2] See www.iseesystems.com.

STELLA: one example is climateinteractive.org, an online climate simulation community serving users ranging from high school to government. Another class of web2.0 social bookmarking tools (e.g., Digg, StumbleUpon, Delicious, Diigo) provides for readily connecting online resources by allowing users to store, aggregate, share, rate, and comment on anything they find online.

A final class of web-based interactive tools deserves greater attention, as it very closely resembles concept mapping: this is what is generally known as mind mapping. Mind maps are hierarchical in structure, generally starting with a core idea in the center of the map, then branching in tree-like fashion out to subcategories. In this regard, mind maps reproduce a typical text outline given their tree structure, and associations between topics are implicitly defined by this hierarchy (i.e., "is a child of" or "is a parent of"). Though mind mapping has long been done in analog fashion, a variety of recent desktop and online mind mapping tools has provoked renewed interest.[3] Some mind mapping tools allow for nonhierarchical connections to be drawn between components, yet their basic functionality still assumes hierarchical relations.

Mind mapping is generally attributed to the work of educational consultant Tony Buzan dating from the 1970s,[4] though visual tree diagrams stretch back much further in history.[5] Concept mapping is attributed to Joseph Novak dating from the same period (Novak and Cañas 2008), but for somewhat different ends. Novak originally designed concept mapping as a means of evaluating student achievement in the sciences. He was strongly influenced by the work of psychologist David Ausubel, whose theory of cognitive learning proposes that students do not simply assimilate new information, but rather connect and integrate it into their preexisting mental structure (Ausubel 1963). In addition to applications in science education, concept mapping (via Cmap Tools) has also been widely deployed to develop "knowledge models," summary diagrams of relationships in a body of theoretical or applied knowledge (Cañas et al. 2003), and in general has been featured in a number of publications in educational theory, cognitive psychology, and other areas of research,[6] though with relatively fewer comparative and/or critical assessments (e.g., Kinchin 2001; Davies 2010; Karpicke and Blunt 2011). One interesting ancillary publication connected to concept mapping introduces a "macrocognitive model" linking data (specific bits of information) and frames (organizing schema) in a dialectical approach to knowledge acquisition (Klein et al. 2006); this resonates with thinking of ESS education as providing both content and context, ultimately organized around understanding of environmental connections.

Given its roots in Ausubel's theory as interpreted by Novak, concept mapping grew to support a particular approach to learning in which education is not a cognitive, one-directional model of information assimilation, but rather one in which the significance of the student's individual learning experience is critical. Says Novak, "The central purpose of education is to empower learners to take charge of their own meaning making… involving thinking, feeling, and acting, and all three of these aspects must be integrated for significant new learning" (Novak 2010, p. 13). From an assessment perspective, this necessitated scoring concept maps for more than just "correctness," attending to each map's individual morphology (Kinchin 2001)—though others have attempted to create more generalized normative rubrics for "good" concept maps (Moon et al. 2011a; cf. Strautmane 2012).

The literature cited above suggests that concept mapping has been intensively studied in educational settings. Indeed, as elaborated by Novak and others, concept mapping has strong roots in educational theory and is regularly deployed in classrooms worldwide.[7] Since its inception, however, concept mapping has been employed and investigated primarily at the K-12 level (e.g., Novak and Gowin 1984; Pankratius 1990; Schmid and Telaro 1990; Mason 1992; Wolff-Michael and Roychoudhury 1992; Ruiz-Primo and Shalveson 1996; Mintzes et al. 1999, 2000; cf. Cordeiro et al. 2012; Kandiko and Kinchin 2012). Overall, post-secondary implementation and research remain relatively sparse, though it has been the focus of several higher education initiatives. For example, at Carnegie Mellon University, a web-based textbook was developed to facilitate environmental literacy among students, which includes concept mapping as a means of depicting systems and as a process of knowledge refinement (Nair et al. 2002); and the Field Tested Learning Assessment Guide, created by a team of science, technology, education, and physics educators at the University of Wisconsin, includes a module on best practices for concept mapping use (Schau et al. 2001). An interdisciplinary team at Michigan State University attributed the lack of widespread adoption at the post-secondary level to the challenges inherent in grading concept maps. To this end, they developed C-Tools, a Java-based applet designed to provide automated scoring (Luckie et al. 2003). Anecdotal evidence from a well-attended session on concept mapping held at the 2011 annual meeting of the Association

[3] See for instance www.mindmeister.com, www.mindnode.com, www.mindomo.com, and www.thinkbuzan.com.

[4] See www.thinkbuzan.com.

[5] See www.mind-mapping.org/blog/mapping-history/roots-of-visual-mapping for one informative history.

[6] For a listing of publications related to concept mapping, see cmap.ihmc.us/Publications/ReferenceList.php.

[7] As one estimate, the Cmap Tools server network includes over 150 servers distributed across the globe; see cmapdp.ihmc.us/servlet/HtmlViewServlet?viewhtml.

for Environmental Studies and Sciences suggests that the tool is much more widely deployed than documented in the context of ESS. Concept mapping has also been applied in professional natural resource-based contexts such grassland management (White 2011) and ecosystem services (Yee et al. 2011).

One crucial feature of concept mapping supporting our uses at Lewis & Clark is the structure of concept maps, which include concepts (boxes or "nouns") linked by propositions (lines or "verbs" defining associations). The requirement that all concepts be explicitly linked by phrases differs from the implicit hierarchical associations found in mind maps and supports a wider variety of connections than just hierarchical ones. It is true that much concept mapping documentation recommends a loose hierarchical structure, with "the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below,"[8] though "cross-links" or connections outside of this loose hierarchy are also encouraged as they "represent creative leaps on the part of the knowledge producer" (Novak and Cañas 2008, pp. 1–2). Indeed, Cmap Tools,[9] the concept mapping application Novak helped develop and the one we have utilized at Lewis & Clark College, can be deployed to build any sort of diagrammatic structure involving concepts and linking propositions, and more recent concept mapping papers have discussed multiple possible structures (Kandiko and Kinchin 2012).

The difference between strictly hierarchical and other diagrammatic structures proves fundamental when one wishes to use these tools to help students explore connections. If ESS were approached as a *multi*discipline, hierarchical mapping may in many ways be sufficient, as each contributing field (and related system, e.g., hydrology or politics or culture) could be viewed as offering its relatively distinct perspective on an environmental issue. Approached as a mind map, an environmental issue would be the core idea then each contributing field would define a first-level subcategory, with its attendant details under that subcategory. All contributing fields would be related in the context of this environmental issue, but only contingently, so there would be no significant connections outside of this root-level connection to the issue.

In approaching environment as connection, however, hybrids and heterogeneity tend to be the norm, where surprising and persistent entanglements of politics and climate, or culture and charismatic species, or economics and energy, challenge any hope of separating constituent processes. This, to the *inter*disciplinary ESS practitioner, is the reality to be analyzed, with connections that are often more necessary than contingent: the current climate system, or state of charismatic megafauna, or rate of alternative energy development is necessarily entangled with issues of politics, culture, and economics. These relations are, for the most part, nonhierarchical as the overall set of interactions is more of a diffuse network than a hierarchy. This is why, no matter what sort of tool or pedagogical approach is employed, care must be taken to allow for nonhierarchical as well as hierarchical relations in mapping out connections in ESS. In a similar vein, Kinchin (2001) argues that appreciation of nonhierarchical connections—what he calls a "net" concept map—generally suggests a more complex student understanding of biological processes than simple hierarchies, which he calls a "spoke" concept map (cf. Kandiko and Kinchin 2012).

Concept mapping and environmental studies at Lewis & Clark

Given the flexibility of the concept mapping approach and its potential relevance to environmental analysis, the Environmental Studies (ENVS) Program at Lewis & Clark College introduced modified forms of concept mapping into its curriculum as visual tools to more clearly specify connections in environmental concepts and processes. Students use the Cmap Tools application to develop their concept maps (cmaps). We selected this application as it is freely available for a variety of platforms, well maintained, and easy for our students to learn. Cmap Tools-based concept maps are designed not only as visualizations, but as structured textual descriptions of processes. One special Cmap Tools feature our students utilize involves its ability to associate concepts or propositions with resources such as documents, references, or websites, which are simply dragged onto the cmap; these resources, for instance, can be used to justify, or summarize the state of knowledge on, a connection. Another feature that students use involves a Cmap Tools server, whereby they readily save and edit their cmaps in a cloud environment, providing opportunities for live collaboration. In addition, all cmaps saved on the server are immediately rendered into viewable images for web visualization. Cmap Tools thus affords a means of reinforcing an approach to environment as connection and offers a social learning approach for students to work together and compare their efforts.

Our approach follows many of the general recommendations made by the concept mapping community (e.g., start with a focus question, develop a list of concepts, organize them via linking propositions; see Novak and Cañas 2008, pp. 11–14), but our students identify and link concepts in a variety of ways. When we originally introduced concept

[8] The hierarchical nature of Novak-inspired concept maps also seems to be interpreted differently by those who have applied this approach in a variety of practical settings (see Moon et al. 2011b).

[9] See cmap.ihmc.us.

mapping into our ENVS Program, we gave students a great deal of latitude in coming up with concepts and linking propositions. Their early forays proved useful toward refining our pedagogical approach, as in many ways this laissez-faire attitude promoted as much frustration and muddled thinking as clarity in analysis among students. Two challenges arose in particular: first, students tended toward overly broad concepts, such as identifying "population growth," "climate change," or "capitalism" as key drivers of environmental processes. Concepts at this level of generality may be helpful for preliminary work, but typically do not afford the more nuanced understandings we seek among our students. Second, students would generally include a large number of concepts linked by relatively simple propositions, such that their resultant concept maps failed to offer much clarification of environmental processes.

We eventually realized that overly broad concept map elements, and overly complex concept maps, are understandable and useful in early stages of student thinking about an environmental process, yet devised a multiple-stage process to encourage students to focus their cmaps. We also introduced notions such as actor-network theory (ANT) to enhance their understanding of concepts and linking propositions. ANT has been well documented elsewhere (e.g., Law and Hassard 1999; Latour 2007): as applied to environmental processes (e.g., Castree 2002), it reinforces a more hybrid and fluid notion of environment as unfolding connections. In a recent address (2011), Bruno Latour, one of the originators of actor-network theory, asks "Is not ecology anything but the deployment of all the attributes necessary for any self-contained entity to subsist? To be self-contained—that is to be an actor—and to be thoroughly dependent—that is to be a network—is to say twice the same thing" (p. 801). The world of ANT is thus a world of connections, in which objects are defined by their associations.

Though few methodological treatises exist, ANT has been applied to analysis of a variety of controversies (many of relevance to ESS) in a useful primer by Tommaso Venturini (2010). Venturini similarly asserts that, in order to understand controversies, "It is not enough to observe the actors alone nor is it enough to observe… networks once they are stabilized. What should be observed are the actors-networks—that is to say, the fleeting configurations where actors are renegotiating the ties of old networks and the emergence of new networks is redefining the identity of actors" (p. 264). Venturini's liquid/solid "magma" metaphor of actor-networks can remind students that the connections they explore in environmental analysis arose for particular reasons and are not fixed forever; in other words, ANT emphasizes the specifics of how these connections arise and are reproduced or transformed, suggesting possibilities for change—always a keen interest on the part of many ESS scholars.

Actor-networks map readily onto our use of concept maps, and ANT theory addresses the two student challenges noted above, in that actors-networks are ideally specific and concrete, and given the implicit notion underlying actor-networks that some connections matter more than others. These ANT principles have led students to work toward concept maps—and thus understanding and communication of connections in environmental processes—that are clearer and more forceful. Our resultant approach to student concept mapping thus progresses in multiple phases, from relatively rough, general, and complicated initial concept maps to relatively refined, specific, and elegant concept maps including related resources. To aid this approach, we have developed online documentation to guide students in use of the Cmap Tools technology and application of ANT.[10]

We call ANT-based concept maps "process" cmaps, as they represent processes at work in the world. We also teach our students what we call "perspectives" concept maps to organize conceptual material itself: students create perspectives cmaps, for instance, to clarify ideas presented in a reading or to draw together material learned in a class. Similar to process cmaps, our students produced perspectives cmaps in multiple steps, starting with a more general and inclusive set of concepts/propositions, then focusing on selected elements for more in-depth development. These modifications of the standard concept mapping approach, including process and perspectives cmaps and multiple-phase production, were all implemented in the course we will analyze below.

Learning concept mapping at Lewis & Clark College

What we did

We conducted an evaluation of concept mapping during a semester-long sophomore-level environmental analysis course in fall 2010. The objectives of this course are to equip students with a wide array of methodological approaches for empirical and conceptual analysis of environmental issues and to apply these tools to the process of doing environmental research, from formulating initial questions to communicating final results. Though students had previously been introduced to concept mapping in our freshman introductory course, this sophomore-level course explores it in much greater detail and offers feedback to enable improvement in student use of the tool for environmental analysis.

In line with our general approach to teaching concept mapping introduced above, we developed three different types of concept mapping assignments in this course (Table 1).[11]

[10] See sge.lclark.edu/social-learning-tools/#Concept_Mapping.

[11] For sample concept maps produced during this fall 2010 course, see bit.ly/cmc2012talk.

The first builds on Novak's theory of learning summarized above via what we called a MyTFA assignment. In this assignment, students identified and connected their major thinking, feeling, and acting elements in the context of a chosen environmental issue then compared their resultant concept maps in terms of areas of emphasis and overall coherence. This MyTFA assignment was repeated at the end of the course, and students compared their two MyTFA concept maps to see how their key thinking, feeling, and/or acting elements had evolved over the semester. The second type of assignment was a unit synthesis concept map, designed to help students review, analyze, and make visual connections between topics, terminology, skills, or other material covered in main instructional unit in the course. Students began with an overview unit synthesis map incorporating a wide variety of brainstormed elements then selected a small subset of elements to relate in a more detailed way. These two assignments illustrate the perspectives concept mapping approach introduced above, as the main objective was to relate ideas.

The third type of concept mapping assignment in our sophomore-level environmental analysis course gets to much of the theory about environment and connection introduced above: we called it an ANT cmap, following actor-network theory. Students produced these (process) ANT cmaps in teams assembled around a proposed research topic located in one of six international sites our ENVS Program focuses on as part of its situated research approach.[12] They developed these ANT cmaps in two stages. First, after collecting and perusing resources (publications, organizational websites, data sources, etc.) for their research topics, they developed an initial ANT cmap and added these resources to the concept map. The objectives at this stage were for student teams to begin to visually identify connections as elaborated in the resources they had compiled and to document these connections via the resources they added to their concept maps. In the second stage, following several weeks of additional focus on their research topics, they revised these initial ANT cmaps with the goal of preserving only the most important concepts, propositions, and related resources. As suggested above, the idea here was for students to use concept mapping to help them focus their research goals relative to the vast array of potentially relevant connections as elaborated in their initial ANT cmaps: as one possibility, they were recommended to focus their proposed research on connections that are potentially significant but not yet well documented.

We conducted this study within the general framework of action research, which aims to improve student learning and educational performance through teacher inquiry (Carr and Kemmis 1986; Altrichter et al. 1993; McLean 1995; Hendricks 2006). Action research uses interpretive tools to examine the practice of education to improve teaching and comprehension (Carr and Kemmis 1986; McKernan 1996; Mills 2010). Out of a class of 35 in total, 23 students elected to participate in an extended evaluation of concept mapping; the rest did the above assignments as well, but did not participate in evaluation activities. Given our small sample, we refrained from deploying analytical techniques (e.g., *t* tests, ANOVA, factor analysis) that would have been appropriate had the sample been larger. The action research approach dictates that improving student learning on a case-specific basis should be the priority, and that the research approach should be adapted to fit the context of the classroom in question.

For these participating students, we conducted a pre-assessment including an entry quiz, a background interview, and compilation of past grades in environmental studies courses. From these data, we created an individual and collective baseline by which to evaluate student achievement in the course overall and in their concept mapping skills.

A wide variety of assessment mechanisms has been developed for evaluating concept maps (Strautmane 2012). In our evaluation, all concept maps created by participants were assessed using a rubric examining concept map qualities as suggested above (e.g., level of specificity in named concepts and propositions), and feedback was given through online discussion forums and in class. After each concept mapping exercise, participants completed a self-assessment questionnaire which measured their impression of the mapping assignment, including its perceived technical and intellectual difficulty and learning value. At the completion of the course, concept map scores and self-assessments were analyzed longitudinally to determine whether there was overall improvement, whether changes occurred in attitudes toward the concept mapping process, and whether certain exercises proved more beneficial than others. The concept mapping exercises as well were evaluated via the rubric and self-assessment questionnaires. Self-assessment questionnaires were analyzed using descriptive statistics. Students were also assessed as to their overall achievement in the course, as measured through success on their final project (which included an ANT cmap), and their final grade.

What we learned

At the conclusion of the project, we analyzed our data, both qualitative and quantitative, to better understand the degree to which concept mapping facilitated student understanding of environment-as-connection. First, we assessed whether confounding variables were impacting the ability of students to engage with concept mapping as a learning tool. Students generally reported being comfortable with technical aspects

[12] See sge.lclark.edu/sites-overview.

Table 1 Cmapping assignments in ENVS 220

Type of Cmap	Cmap assignment	When conducted	Repetitions
Perspectives	MyTFA	At beginning and conclusion of course	2
Perspectives	Unit synthesis	At the end of each unit	4
Process	ANT	Initial and refined during situated research unit	2

of the concept mapping process, had sufficient time to complete assignments, and felt that assignment instructions were sufficiently clear (see Table 2); thus, these issues did not appear to skew our analysis.

Based on student self-reports, some positive effects of concept mapping emerged: the results summarized in Table 3 below suggest that concept mapping helped students "better understand actor network theory" and "better understand actor-network theory" (text in quotes from evaluation instrument), both critical in ameliorating broad, unwieldy cmaps and fuzzy articulation of environmental connections. Said one student, "This [ANT] cmap was very helpful in organizing all the different actors that were a part of this issue and what connections we need to focus on to address the influence of safaris in the Serengeti." Students reflected on the increased sophistication with which they grappled with environmental problems when revising their MyTFA cmaps. Said another student, "In my new cmap, I do not explicitly say that complete removal of oneself from the conventional agricultural system is an option. It may be possible, but in this class I have learned that there are many complex interactions going on at many different scales, and that elements of a system are so strongly interconnected that completely changing the system could be impossible." In general, most students reported that concept mapping improved their nonhierarchical thinking skills and increased their appreciation of environmentally significant actors as enmeshed in networks of relationships.

Student reports summarized in Table 3 also indicated that concept mapping proved useful as a project design and research planning tool. As part of their collaboration process, it helped "clarify areas that need[ed] further research," "organize [my] ideas," "recognize gaps in [my] understanding," and "pare down or expand" their topic into one with an appropriately focused scope. Said one student, "Overall, this type of concept mapping is a good idea and has helped my group layout the specifics of our research question, along with determining what areas of research need more information and what areas we could focus on for collecting data." Interestingly, however, students did not report that the process helped much with explaining the environmental issue to others or clarifying possible solutions, pointing to a perceived limit to the usefulness of concept mapping in communication or policy contexts.

Table 2 Student assessment of concept mapping challenges. To what extent did you find this exercise easy or hard to do, in terms of:

	n[a]		%	Mean
Having sufficient mastery of concept mapping to complete the task?	103	(4) Significant challenge	6	1.8
		(3) Somewhat of a challenge	13	
		(2) Minor challenge	37	
		(1) Not at all a challenge	45	
Having sufficient time to complete the task?	103	(4) Significant challenge	6	1.9
		(3) Somewhat of a challenge	25	
		(2) Minor challenge	19	
		(1) Not at all a challenge	50	
Having clear instructions to guide you?	103	(4) Significant challenge	2	1.7
		(3) Somewhat of a challenge	13	
		(2) Minor challenge	37	
		(1) Not at all a challenge	49	
The intellectual material you addressed?	103	(4) Significant challenge	15	2.7
		(3) Somewhat of a challenge	46	
		(2) Minor challenge	31	
		(1) Not at all a challenge	9	
Assembling the material into a concept map?	103	(4) Significant challenge	31	3.0
		(3) Somewhat of a challenge	42	
		(2) Minor challenge	22	
		(1) Not at all a challenge	5	

[a] After each of the concept mapping exercises, students were assigned a self-assessment questionnaire (not all students completed all questionnaires). Many of the question items were repeated on each questionnaire, including the questions shown in the table. Therefore, this table is based on the aggregate scores of all six questionnaires

Table 3 Student assessment of concept mapping helpfulness. How much did this (see footnote 10 above) concept map help you with the following?

	n^{a}		%	Mean
Better understand the significance of actors and relationships	31	(4) Helped a great deal	39	3.1
		(3)Helped somewhat	39	
		(2) Helped a little	13	
		(1) Didn't help at all	10	
Better understand actor-network theory	31	(4) Helped a great deal	19	2.7
		(3)Helped somewhat	39	
		(2) Helped a little	39	
		(1) Didn't help at all	3	
Clarify areas where I/we need further research	31	(4) Helped a great deal	48	3.4
		(3)Helped somewhat	39	
		(2) Helped a little	13	
		(1) Didn't help at all	0	
Organize my ideas	66	(4) Helped a great deal	25	2.8
		(3)Helped somewhat	39	
		(2) Helped a little	31	
		(1) Didn't help at all	5	
Recognize gaps in my understanding	66	(4) Helped a great deal	31	2.9
		(3)Helped somewhat	36	
		(2) Helped a little	24	
		(1) Didn't help at all	10	
Pare down or expand my/our topic	31	(4) Helped a great deal	45	3.3
		(3)Helped somewhat	39	
		(2) Helped a little	16	
		(1) Didn't help at all	0	
Explain the environmental issue to others	31	(4) Helped a great deal	10	2.6
		(3)Helped somewhat	50	
		(2) Helped a little	33	
		(1) Didn't help at all	7	
Clarify possible solutions	31	(4) Helped a great deal	10	2.4
		(3)Helped somewhat	39	
		(2) Helped a little	32	
		(1) Didn't help at all	19	

[a] Certain items have a smaller *N* because they were only asked in conjunction with certain assignments. For instance, ANT-specific questions items were only asked of the ANT cmapping assignments, therefore reducing the sample size

The above results suggest that concept mapping was not overly challenging technically and proved helpful in attaining certain key learning objectives. Yet additional results at the bottom of Table 2 indicate that some students struggled with reducing the scope and increasing the clarity of their cmaps. Despite the relative ease with which they took to the mechanics of concept mapping, they reported that the "intellectual material addressed" and "assembling the material into a concept map" were the most challenging parts of the concept mapping process. Said one student, "It was difficult to connect the frameworks [broad philosophical positions related to environment] to the theories [more specific explanatory notions for environmental problems] since the frameworks tend to deal with two ways of looking at one issue. While I was able to find connections, it was difficult to find the words to explain how they connected with arrows." However, not all students perceived this as negative: as one student stated, "I found it challenging to link class concepts and theories/frameworks with this particular set of tools. This was a good challenge, though, as it made me put statistics into context and think about how we use them." To the students, the challenges posed by the mechanics of concept mapping paled in comparison to the challenge of specifying, clarifying, and elucidating the relationships being mapped.

Most educational interventions aim to improve student comprehension and achievement. In this context, the sequence might go as such: students who create better concept maps would have a higher level of mastery over the material and subsequently achieve a higher course grade. However, based on the relationship between concept map quality (as scored via our rubric) and students' final grades, we surprisingly did not find evidence for this progression. While we did not find across-the-board grade improvement, we found that level of engagement moderated the benefit of using of cmaps. We deduced this via two proxies. First, certain students found the concept mapping process significantly more challenging than others, but these were not the low-achieving students. Rather, the students whose final course grades were *highest* reported being the most challenged by "the intellectual material [they] addressed" and "assembling that material into a concept map" ($r(21)=0.44$, $p<0.05$ and $r(21)=0.61$, $p<0.01$). Second, students who completed more required assessments than others found the concept mapping process more useful in general ($r(21)=0.45$, $p<0.05$). Apparently, those who were more invested in the course were more likely to follow instructions, thereby achieving more by reflecting on the cmapping process more systematically.

We thus found that concept mapping did not engender individual student improvement universally but rather benefitted the students who were engaged in the learning process. Our research showed that the end product—the actual *concept map*—was not the critical outcome, but instead the struggle that generated that map. This is consistent with the constructivist philosophy from which concept mapping emerged (Kinchin 2001). The degree to which students took the concept mapping process seriously may have differentiated them into high- and low-achieving groups. This indicates that students with an increased level of buy-in and are willing to engage with the nuance and hybridity of connections reap the rewards. It appears that intellectual struggle, and the subsequent reflection on that struggle, is what increased student achievement.

One possible alternative explanation for this differing level of engagement in concept mapping could invoke the literature on learning styles, based on the intuitive assumption that so-called visual learners may preferentially engage in visually based activities such as concept mapping. One of the most widely used instruments is the VARK (visual, auditory, reading/writing, kinesthetic) learning styles survey (Fleming and Mills 1992). Despite critique (e.g., Cain and Dweck 1989; Dunn 1993; Hargreaves 2004), it has penetrated mainstream consciousness. A background survey we did using Fleming's 2010 VARK 7.0 instrument,[13] however, does not corroborate this intuition. In fact, we found that visual learners found concept mapping less useful overall ($r(21)=-0.434$, $p<0.05$) and were more challenged by the procedural aspects of concept mapping assignments, finding the instructions unclear ($r(21)=0.434$, $p<0.05$) and feeling they lacked the time to complete the assignments ($r(21)=0.455$, $p<0.05$). Visual learners were also less successful in the course overall: of the 25 % of students who had the worst grades in the course, 33 % identified as visual learners. Conversely, none of the students who achieved the highest course grades identified as visual learners. We thus do not believe that learning style, at least as theorized in this manner, was the reason underlying differing levels of engagement with concept mapping.

Given the lack of across-the-board longitudinal student improvement in our assessment, it's worth contextualizing concept mapping within educational innovation generally. If adding an e-tool or teaching technique to a course unfailingly improved individual student grades, educational improvement would be simple. We must be cautious not to make technological innovations our beasts of burden, saddled with rectifying the messy complexity of learning and problem solving with, quite literally, the click of a button. Given the complexity of variables potentially influencing student achievement, it is not surprising that our rising tide of concept mapping did not lift all boats. Additionally, there are inherently confounding variables in a classroom research setting, not all of which we addressed: for instance, we lacked a control group and the final cmap assignment was done as a team. Further research could isolate and rectify these relatively simple issues.

Even in terms of our significant findings, correlation is not causation. Are higher achieving students more likely a priori to go beyond the deceptive simplicity of concept mapping and recognize the delicate hand needed to treat environment as connection? Are higher achieving students more likely to complete all class assignments, bear the fruit of those assignments, and gain the means to do better in the course? It may simply be that students who are high achieving engaged more fully with what the course asked of them and were subsequently rewarded by their engagement. Should this be the case, a valid concern could be that educational innovations such as concept mapping may further stratify high achievers from low achievers, widening the gap between students who thrive with increasingly challenging demands and those who do not.

Next steps, better practices

Better concept mapping, better connecting

Concept mapping is not a straightforward activity; indeed, its founders have openly discussed challenges in successful implementation (Cañas and Novak 2006; Cañas et al. 2012). Our implementation of concept mapping at Lewis & Clark College likewise suggests possibilities and guidelines for use in ESS instruction. For instance, both perspectives (e.g., MyTFA or unit synthesis) and process (e.g., ANT) cmaps can readily be applied to a wide range of existing ESS courses and topics. Additionally, having students do concept map exercises in stages (e.g., by comparing a MyTFA map at the beginning and end of the semester or by incrementally reducing the number of key actors in an

[13] Taken from www.vark-learn.com/documents/TheVARKQuestionnaire.pdf.

ANT cmap) helps students better appreciate the tool. Finally, given the flexibility of the Cmap Tools application, ESS instructors could apply it to a wide range of desired learning outcomes, as we have by using actor-network theory to inform a more specific representation of environmental connections.

In our experience, certain principles have worked better than others. We have found that committing fully to the approach has allowed us to integrate the exercises into our curriculum more authentically. By differentiating concept mapping into lesson-specific exercises, we avoided tacking concept mapping exercises on to preexisting lessons, thereby diminishing their impact. Yet, our efforts to encourage relatively simple, elegant cmaps have clashed with the desire among (mainly high achieving) students to comprehensively map connections. This tension may be a good one, given the need in environmental studies to identify answers in a messy, interconnected world.

Ultimately, no matter how much effort is devoted to designing high-quality concept mapping exercises for students to discover and communicate environmental connections, more fundamental issues may hamper even the best efforts, as the effectiveness of concept mapping seems contingent on student motivation. While there is no simple recipe for increasing student engagement, awareness of the fundamental importance of student interest can assist instructors in designing appropriate classroom activities.

Challenges inherent in reframing environment

Our empirical results speak as well to a larger challenge found in and outside of the classroom. Approaching environment as connection requires new ways of thinking and analyzing in ESS, and some ESS scholars—including our students—will be more willing to do the novel work following from this approach than others. We found that concept mapping may serve, unintentionally, as a differentiator between more and less motivated students, between those who worked hard to appreciate, analyze, and communicate environmental connections via concept mapping and those who were less convinced of the purpose of concept mapping. For all the scholarly justification behind this approach, many students come to ESS expecting the more familiar approach of environment-as-nature.

Building on the origins of concept mapping in assessing student cognition, certain recurrent features of our students' cmaps suggest the extent to which an ANT-based, relational notion of environment remains a cognitive challenge to them. One telltale indicator was the use of color coding of concepts and/or propositions by students to differentiate elements of their cmaps, which we urged them to do in some novel fashion. Our online help page suggested that one relevant differentiator may be those concepts/propositions that prove to be more or less significant or powerful in the overall network; it also discourages students from following more common modes of differentiation, for instance that between "natural" and "cultural" or "local" and "global" actors, given the ANT precept that all actors are nature/-culture hybrids, and local and global scales interpenetrate in the actor/network dialectic. Nonetheless, by far, the most common means of color-coding cmaps distinguished between, say, "biological" and "economic" actors or "community" and "national" actors. Ultimately, even the better students struggled with appreciating how ANT "naturalizes" cultural actors, and "culturalizes" natural actors, to the extent that these differences prove less significant than others.

The challenges we faced among certain students in grasping an ANT-informed notion of environment-as-connection via concept mapping may suggest that recent theories such as ANT are not useful notions to be used in undergraduate ESS education. Some may, in fact, dismiss actor-network theory as "postmodern" or "anti-science." It is worth observing that Latour has frequently cited environmental concerns in rejecting these charges (e.g., Latour 2004b, 2010), which tend to be based on notions of reality, truth, and objectivity arguably unsuited for the complex world that greets practitioners of ESS. We must ask: should we teach our students an approach to environment that they readily understand and embrace, but which has been roundly critiqued in the theoretical literature and may have run its course when applied to practical concerns? Or should we follow the lead of promising new ideas such as actor-network theory in reframing the "environment" of ESS, knowing full well that this paradigm shift will not come readily to our students? As Venturini stated at the opening of his methodological guide on actor-network theory, this approach "will not make your life easier" and "is no piece of cake" (Venturini 2009, pp. 258–9). Maybe, then, the ultimate question becomes not *whether* but *how* new approaches to environment could best be introduced in ESS education, and what role new tools such as concept mapping could play alongside other strategies, such that ESS students wholeheartedly and successfully embrace the related challenges inherent in moving beyond the truisms of the past.

The challenges we face in reframing the environment of ESS are, of course, not limited to the classroom. The larger challenge may fall on the ESS community of scholars to offer compelling models to our students of appreciating, and analyzing, the heterogeneous web of connections that matter. We may best serve our students by taking to heart the insights revealed by approaches such as environment-as-connection, theories such as ANT, and tools such as concept mapping, even if they lead our ESS field in new and uncharted directions.

Acknowledgments We acknowledge support from The Andrew Mellon Foundation to Lewis & Clark College (2006–) for development of new interdisciplinary learning approaches and tools in environmental studies. We also acknowledge the Masters of Science in Science Education program at Montana State University, Bozeman, for which the assessment and evaluation component of this research was integrated into Jennifer Bernstein's capstone project. A draft of this paper was presented at the Fifth International Conference on Concept Mapping, Malta, September 2012.

References

Altrichter H, Posch P, Somekh B (1993) Teachers investigate their own work: an introduction to the methods of action research. Routledge, New York

Ausubel DP (1963) The psychology of meaningful verbal learning. Grune & Stratton, New York

Bennett J, Chaloupka W (eds) (1993) In the nature of things: language, politics, and the environment. University of Minnesota Press, Minneapolis

Braun B, Castree N (eds) (1998) Remaking reality: nature at the millennium. Routledge, London

Cain KM, Dweck CS (eds) (1989) The development of children's conception of intelligence. Advances in the psychology of human intelligence, ed. R.J. Sternberg. Lawrence Erlbaum, Mahwah, New Jersey

Cañas AJ, Hill G, Lott J (2003) Support for constructing knowledge models in CmapTools (Technical Report IHMC CmapTools 2003–02). Institute for Human and Machine Cognition, Pensacola, FL

Cañas AJ, Novak JD (2006) Re-examining the foundations for effective use of concept maps. Concept maps: theory, methodology, technology. Proceedings of the second international conference on concept mapping. pp. 494–502

Cañas AJ, Novak JD, Reiska P (2012) Freedom vs. restriction of content and structure during concept mapping: possibilities and limitations for construction and assessment. Concept maps: theory, methodology, technology. Proceedings of the fifth international conference on concept mapping. pp 247–257

Carr W, Kemmis S (1986) Becoming critical: education, knowledge and action research. Deakin University Press, Geelong

Castree N (2002) False antitheses? Marxism, nature and actor-networks. Antipode 34(1):111

Castree N, Braun B (eds) (2001) Social nature: theory, practice, and politics. Blackwell, Malden

Commoner B (1971) The closing circle: nature, man, and technology, 1st edn. Knopf, New York

Cordeiro GB, Aguiar PL, Cicuto CAT, Correia PRM (2012) Making interdisciplinarity visible during concept mapping. Concept maps: theory, methodology, technology. Proceedings of the fifth international conference on concept mapping. pp 330–337

Cronon W (ed) (1995) Uncommon ground: toward reinventing nature. Norton, New York

Davies M (2010) Concept mapping, mind mapping and argument mapping: what are the differences and do they matter? High Educ 62:279–301. doi:10.1007/s10734-010-9387-6

Dunn R (1993) Teaching gifted adolescents through their learning style strengths. In: Dunn R (ed) Teaching and counseling gifted and talented adolescents. Praeger, Westport

Evernden N (1993) The social creation of nature. The Johns Hopkins Press, Baltimore

Fleming ND, Mills C (1992) Not another inventory, rather a catalyst for reflection. Improve Acad 11:137–149

Hargreaves D (2004) About learning: report of the learning working group. Demos, London

Hendricks C (2006) Improving schools through action research: a comprehensive guide for educators. Pearson, Boston

Kandiko C, Kinchin I (2012) Follow the arrows: tracing the underlying structure of a doctorate. Concept maps: theory, methodology, technology. Proceedings of the fifth international conference on concept mapping. pp 236–243

Karpicke JD, Blunt JR (2011) Retrieval practice produces more learning than elaborative studying with concept mapping. Science 331:772–775. doi:10.1126/science.1199327

Kinchin IM (2001) If concept mapping is so helpful to learning biology, why aren't we all doing it? Int J Sci Educ 23(12):1257–1269

Klein G, Moon B, Hoffman RR (2006) Making sense of sensemaking 2: a macrocognitive model. Intell Syst IEEE 21:88–92

Latour B (2004a) Politics of nature: how to bring the sciences into democracy. Harvard University Press, Cambridge

Latour B (2004b) Why has critique run out of steam? From matters of fact to matters of concern. Crit Inq 30:225–248

Latour B (2007) Reassembling the social: an introduction to actor-network-theory. Clarendon lectures in management studies. Oxford University Press, Oxford

Latour B (2010) A plea for earthly sciences. In: Burnett J, Jeffers S, Thomas G (eds) New social connections: sociology's subjects and objects. Palgrave Macmillan, London, pp 72–84

Latour B (2011) Networks, societies, spheres: reflections of an actor-network theorist. Int J Comm 5:796–810

Law J, Hassard J (eds) (1999) Actor network theory and after. Blackwell, Oxford

Luckie D, McCray Batzli J, Harrison S, Ebert-May D (2003) Concept-connector tools for online learning in science. Int J Learn Tech 10:1051–1068

Mason C (1992) Concept mapping: a tool to develop reflective science instruction. Sci Educ 76(1):51–63

McKernan J (1996) Curriculum action research. A handbook of methods and resources for the reflective practitioner, Second Editionth edn. Kogan, London

McLean J (1995) Improving education through action research: a guide for administrators and teachers. The practicing administrator's leadership series. Roadmaps to success. Corwin, Thousand Oaks

Meadows DH (1972) The limits to growth: a report for the club of Rome's project on the predicament of mankind. Potomac associates books. Universe Books, New York

Meadows DH, Randers J, Meadows DL (2004) The limits to growth: the 30-year update. Chelsea Green, White River Junction

Mills GE (2010) Action research: a guide for the teacher researcher, 4th edn. Prentice Hall, Upper Saddle River

Mintzes JJ, Wandersee JH, Novak JD (1999) Teaching for science understanding: a human constructivist view. Academic, San Diego

Mintzes JJ, Wandersee JH, Novak JD (2000) Assessing science understanding: a human constructivist view. Academic, San Diego

Moon BM, Hoffman RR, Eskridge TC, Coffey JW (2011a) Skills in applied concept mapping. In: Moon BM, Hoffman RR, Novak JD, Cañas AJ (eds) Applied concept mapping: capturing, analyzing, and organizing knowledge. CRC Press, Boca Raton, pp 23–46

Moon BM, Hoffman RR, Novak JD, Cañas AJ (2011b) Introduction and overview of the book. In: Moon BM, Hoffman RR, Novak JD, Cañas AJ (eds) Applied concept mapping: capturing, analyzing, and organizing knowledge. CRC Press, Boca Raton, pp xxi–xl

Nair I, Jones S, White J (2002) A curriculum to enhance environmental literacy. J Eng Educ 91(1):57–67

Novak JD (2010) Learning, creating, and using knowledge: concept maps as facilitative tools in schools and corporations, 2nd edn. Routledge, New York
Novak JD, Gowin DD (1984) Learning how to learn. Cambridge University Press, Cambridge
Novak JD, Cañas AJ (2008) The theory underlying concept maps and how to construct and use them (Technical Report IHMC CmapTools 2006–01 Rev 01–2008). Florida Institute for Human and Machine Cognition, Pensacola, Florida
Pankratius WJ (1990) Building an organized knowledge base: concept mapping and achievement in secondary school physics. J Res Sci Teach 27(4):315–333
Proctor JD (2009) Environment after nature: time for a new vision. In: Proctor JD (ed) Envisioning nature, science, and religion. Templeton Foundation Press, West Conshohocken, pp 293–311
Ruiz-Primo M, Shalveson R (1996) Problems and issues in the use of concept maps in science assessment. J Res Sci Teach 33:569–600
Schau C, Mattern N, Zeilik M, Teague KW (2001) Select-and-fill-in Concept Map Scores as a measure of students' connected understanding of science. Educ Psychol Meas 61(1):136–158
Schmid RF, Telaro G (1990) Concept mapping as an instructional strategy for high school biology. J Educ Res 84(2)
Soper K (1995) What is nature? Culture, politics and the non-human. Blackwell, Oxford
Strautmane M (2012) Concept map-based knowledge assessment tasks and their scoring criteria: an overview. Concept maps: theory, methodology, technology. Proceedings of the fifth international conference on concept mapping. pp 80–88
Venturini T (2009) Diving in magma: how to explore controversies with actor-network theory. Public Underst Sci 19:258–273. doi:10.1177/0963662509102694
White A (2011) The use of concept mapping in ecological management: a case study involving grassland ecosystems in Victoria, Australia. In: Moon BM, Hoffman RR, Novak JD, Cañas AJ (eds) Applied concept mapping: capturing, analyzing, and organizing knowledge. CRC Press, Boca Raton, pp 151–167
Wilson A (1992) The culture of nature. Blackwell, Cambridge
Wolff-Michael R, Roychoudhury A (1992) The social construction of scientific concepts or the concept map as a conscription device and tool for social thinking in high school science. Sci Educ 76(5):531–557
Yee SH, Rogers JE, Harvey J, Fisher W, Russell M, Bradley P (2011) Concept mapping ecosystem goods and services. In: Moon BM, Hoffman RR, Novak JD, Cañas AJ (eds) Applied concept mapping: capturing, analyzing, and organizing knowledge. CRC Press, Boca Raton, pp 193–213