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Conceptual change in natural resource management students' ecological literacy*

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ABSTRACT
Conceptual change in undergraduate capstone courses provides unique opportunities to examine how students draw from multiple courses and experiences to resolve conceptual confusion. We examined how senior-level natural resource management students revised their conceptions of 'ecosystem' throughout their capstone course. The concept of ecosystem is complicated by a lack of shared meaning across disciplines. Our grounded theory study analyzed student coursework and pre/post interviews. It was informed by socio-cultural and conceptual change theories and used an ecological literacy metric to examine how students' conceptualizations of the relationships between natural, ecosystem, human, and human artifact influenced their conceptions of ecosystems. Students who did not describe ecosystems as natural struggled less with integrating human society into ecosystems than their peers that did. We conclude that it is important to explicitly create shared meaning of key conceptions at the start of a capstone course to facilitate shared meaning-making and desired conceptual change during the course.

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Introduction

Capstone courses are becoming more common, since they provide a means to help undergraduate students synthesize content across disciplines while engaging in authentic practices for their major (Berkson and Harrison 2002). These courses focus on integrating and applying disciplinary content knowledge while using inquiry and problem-based teaching strategies (Arthur and Thompson 1999; Gifford et al. 2011). Capstone courses are particularly relevant for disciplines and professions in which graduates need to draw equally on theoretical and practical skills and knowledge to solve problems. For example, natural resource management (NRM) graduates need to be well-versed in ecology, policy, and management practices, as well as communication, problem-solving, and leadership skills, to work collaboratively with stakeholders from private and public sectors to resolve natural resources issues (Bosch et al. 2007; Lachapelle, McCool, and Patterson 2003; Sandri 2013). Because of the focus on interdisciplinary synthesis and career preparation, NRM capstone courses are ideal settings to assess students' conceptual shifts and analyze influencing factors. Within the field of NRM, a current philosophical shift emphasizes conceptualizing and managing ecosystems as an integrated whole, instead of focusing on components as separate (Benson and Garmestani 2011; Folke et al. 2004). This shift most

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likely promotes conceptual change of students within this discipline. While there have been several studies that describe teaching strategies for NRM capstone courses (Habron, Goralnik, and Thorp 2012; Hiller Connell, Remington, and Armstrong 2012; Jacobson et al. 2011; Remington-Doucette et al. 2013), there is a lack of in-depth research on how capstone classes influence student learning. The current study addresses this gap in the literature. Moreover, studies on conceptual shifts that can impact both knowledge and skills are essential and can add to the body of research on conceptual change in primarily theoretical fields (Balgopal 2014; Clough 2006; Gifford et al. 2011; Tanner and Allen 2005).

Conceptual change is the process an individual experiences when they change an existing conception, or explanation of a phenomenon, to a new one (Posner et al. 1982). Even though conceptual change has been described in different ways, the Conceptual Change Model (CCM) described by Posner et al. (1982) has extensively influenced the way science education researchers study learning. The CCM describes that an individual first must be dissatisfied with his/her existing conception. Then, the new conception must be intelligible (make sense), plausible (be consistent with prior knowledge), and fruitful (useful in explaining future phenomena) before a prior conception is replaced with a new one. Posner et al. (1982) described two types of conceptual change, accommodation and assimilation. In assimilation individuals incorporate new phenomena into their existing conceptions, whereas in accomodation an individual reorganizes or replaces their existing conceptions. While conceptual change may sound linear in the CCM, researchers do not agree on the speed of conceptual change (e.g. slow and gradual or rapid), and the process may not be linear, but may be more of a meandering restructuring of ideas (Hallden, Scheja, and Haglund 2013). Taber (2013) discusses the challenges in measuring learning, since we cannot directly observe things such as thinking, learning, and knowledge. Additionally, there is evidence that new conceptions suppress, rather than fully replace, prior conceptions (Shtulman and Valcarcel 2012). For social cultural theorists, who argue that learning is a social practice embedded in a cultural and historical context, conceptual change must be studied within social contexts (Ivarsson, Schoultz, and Saljo 2002; Lemke 2001), such as interactive classrooms. These personal contextual influences are also discussed as 'warming' cold conceptual change (Sinatra 2005). Because of the way individuals must be able to make meaning of new conceptions within their existing knowledge, it is important to look at the potential an alternative conception has, and help individuals extend their existing conception into a scientifically accepted conception (Hallden, Scheja, and Haglund 2013).

Ecosystem conceptions and ecological literacy

Because beliefs influence behaviors, the way NRM students conceptualize the human-environment relationship will influence their decision-making in their careers. A challenge in the field of NRM is that, according to disciplinary experts, NRM students need to conceptualize humans as integrated within the environment, even though it is easy to see ourselves as separate from the systems we inhabit (Bosch et al. 2007; Cachelin, Norvell, and Darling 2010; Lachapelle, McCool, and Patterson 2003; Senge 2006). Alberti et al. (2003) claimed that 'the greatest challenge for ecology in the coming decades is to fully and productively integrate the complexity and global scale of human activity into ecological research' (1172). Additionally, Cachelin, Norvell, and Darling (2010) analyzed the language used in several common ecological textbooks, and criticize textbook authors for using language and metaphors that promote the idea that humans exist outside of ecosystem.

In response to Alberti et al. (2003), new NRM curricula provide great opportunities to study students' conceptual change (Stern 2000). Because *ecosystem* is an underlying concept for the many terms that are now used to describe the integrated human-environment relationship, including social-ecological system (SES), coupled human-natural system, and human ecology (Liu et al. 2007; Stanger 2011), we focus on the term *ecosystem* in our study. Additionally, humans and our impact cannot be separated from ecosystems (Rockstrom et al. 2009). Moreover, human integration within ecosystems is a component of ecological literacy, a concept developed by ecologists to describe the knowledge necessary for ecologically-informed decision-making (Risser 1986).

Ecological literacy is part of a larger set of terms, including environmental literacy and eco-literacy (McBride et al. 2013). All these concepts focus on the knowledge necessary to make environmental and/or ecologically informed decisions, but they focus on different aspects. This suite of concepts began when Roth (1968) defined environmental literacy as the use of knowledge about environmental issues to perform environmentally responsible behaviors. Eco-literacy is a term that emerged from humanities research and focuses on sustainability; it can also include spiritual and other holistic components of addressing an individual's connection to the environment (Orr 1992). Ecological literacy was a term first published by Risser (1986), a past-president of the Ecological Society of America, and is the concept in this suite most rooted in formal ecological sciences.

Risser (1986) included social systems, humans, and human impact as components in his concept of ecological literacy. However, ecological literacy has been developed in multiple ways over the past 30 years (McBride et al. 2013). We used Balgopal and Wallace's (2009) definition of ecological literacy to inform our research, 'an ecologically literate person can recognize the relevance and application of ecological concepts to understanding human impacts on ecosystems,' which they developed from their empirical studies and an in-depth review of the literature (14–15). Balgopal and Wallace's (2009) conceptualization of ecological literacy specifically focuses on the human-ecosystem relationship, which informed out research study focus.

Social-ecological systems

While our study focused on students' conceptions of ecosystem, not SES, the concept of SES was used in the course we studied. SES is a term commonly used in the field of NRM (Adams 2016); however, it has been criticized by those in social science fields (Stone-Jovicich 2015). SESs are defined as 'ecological systems intricately linked with and affected by one or more social systems' (Anderies, Janssen, and Ostrom 2004; p.5). Therefore, SES is used in NRM to explicitly include components beyond biophysical characteristics in management, such as human society, and to address the integrated relationship between society and ecosystems (Adams 2016; Anderies, Janssen, and Ostrom 2004). Social scientists argue that the concept of SES does not appropriately address: (1) epistemological and ontological differences between the types of questions that can be addressed in social and biophysical systems, (2) issues of power dynamics and cultural structures, (3) problems with decontextualizing knowledge, and (4) the influence of human agency (Brown 2014; Cote and Nightingale 2012; Davidson 2010). These critiques have led to dialogue amongst those in NRM and the social sciences (e.g. Davidson 2010, 2013; Ross and Berkes 2013). Stedman (2016) discussed issues of subjectivity and SES in detail and suggested sense of place theory as a way to help address subjectivity within SES. Sense of place theory focuses on how meaning-making occurs in societies (Stedman 2016). This dialogue has not resolved conflict surrounding the SES concept, but it indicates that researchers from different backgrounds are working to address critiques of the SES conception. Because of the importance of SES within the field of NRM (e.g. Adams 2016), and because there is currently no widely-used better alternative, the concept of SES was used in the course we studied and, therefore, in our analyses. As this is a naturalistic study, we examined how students reacted to the way SES and ecosystem were defined in the classroom. A critique of the way SES was presented in the course is beyond the scope of this study.

Ecological literacy assessment

Several researchers have developed metrics to assess ecological literacy, but they tend to be closed-ended and do not assess conceptions of the human-ecosystem relationship (Davidson 2010; Keynan, Assaraf, and Goldman 2014; Morrone 2001; Pe'er, Goldman, and Yavetz 2009).

To address the gap in the literature, we described an ecological literacy continuum metric that specifically targets this human-ecosystem relationship (Table 1; Casper, Fernandez-Gimenez, and Balgopal, In review). This metric describes the range of conceptions held by the different students who participated in that study (Casper et al., In review). Our metric is presented as a continuum because we recognize that

Table 1. The ecological continuum describes different conceptions of the human-ecosystem relationships (Casper et al., In review).

Category	Description
1. Exclusion	Humans are not a component of ecosystems
2. Uncertain-Exclusion	Unsure at first, but final decision is that humans are not, or are probably not components of ecosystems
3. Uncertain	Uncertain, no final conclusion
4. Uncertain-Inclusion	Unsure at first, but final decision is that humans are, or probably are components of ecosystems. Also includes those who include humans, but are unsure of or exclude human artifacts (things people make)
5. Inclusion	Humans are a component of ecosystems

conceptions are not fixed and do not necessarily exist as discrete categories. Because the continuum describes a range of possible conceptions, it can be used to compare different students' conceptions at a given time or identify how a student's conception has changed over time. Although we primarily used pre- and post-course assessments of student conceptions, we argue that the proposed continuum that we developed acknowledges a range of possible conceptions. Moreover, this continuum allows researchers to study conceptual change by placing students along different parts of the continuum before, during, and after an intervention.

Studies of system thinking at the undergraduate level that focus on developing new conceptions are important (Habron, Goralnik, and Thorp 2012; Hiller Connell, Remington, and Armstrong 2012; Jacobson et al. 2011; Remington-Doucette et al. 2013), because existing conceptions influence how students are already thinking. Furthermore, for conceptual change to occur, individuals must determine that new conceptions are more useful than their previous conceptions (Posner et al. 1982). While there are studies documenting K-12 students' misconceptions about systems (Jordan et al. 2014), addressing existing conceptions before trying to develop new conceptions may be important at the undergraduate level as well. Understanding what helps students shift their conceptions is vital in designing curricula that effectively promote learning (Georghiades 2000).

Theoretical framework

This study is informed by the intersection of conceptual change and socio-cultural theories (Charmaz 2014; Georghiades 2000; Ivarsson, Schoultz, and Saljo 2002; Lemke 2001; Posner et al. 1982). Broadly, socio-cultural theory states that our social experiences provide a context that allows us to learn through social interactions (Lemke 2001), and conceptual change theory describes the shift necessary for an individual to change his/her preexisting conception to a new one (Posner et al. 1982; Tanner and Allen 2005). People understand academic science from their cultural lens because language is culturally bound (Balgopal et al. 2017; Gee 2014; Nisbett 2003). Our analyses goes beyond analyzing changes from every day to scientific language because conceptual change can happen without change in language as individuals have opportunities to make meaning (Wallace et al. 2003). Therefore, the intersection of these theories allows us to explore how conceptual change is embedded in cultural and social contexts.

Socio-cultural theory

Socio-cultural theory explains that each individual's background, including their knowledge, culture, and experiences, influences how he/she interacts with others to make meaning (Lemke 2001). In socio-cultural theory, science is an activity created and practiced by humans, which is embedded in historical and cultural contexts. Socio-cultural theorists do not believe that people learn in isolation; instead, conceptions are developed through communication with others, observations of natural phenomena, and opportunities to make meaning of and use new information. Even when conceptions are challenged, socio-cultural theorists would argue that individuals' motivation to change conceptions is influenced by external motivating factors (e.g. desire to impress peers, the goal of becoming part

of a professional community; Linnenbrink and Pintrich 2002). Sometimes learning involves acquiring new conceptions, but it may also involve the changing of an existing conception. This latter process is described as conceptual change.

Conceptual change theory

As discussed earlier, Posner et al.'s (1982) CCM was a foundational framework for describing conceptual change. Conceptual change research since 1982 has diverged in many directions; however, many scholars generally agree that conceptual change is not a straightforward process that can be promoted (and is often not happening) in the science classroom (Coley et al. 2017; Hallden, Scheja, and Haglund 2013; Tanner and Allen 2005). In addition, some researchers posit that what appears to be conceptual change is simply the suppression, not replacement, of prior conceptions (Shtulman and Valcarcel 2012).

The CCM has also been criticized for being purely cognitivist, leaving out the social and extra-rational components of learning (Ivarsson, Schoultz, and Saljo 2002; Sinatra 2005). Dole and Sinatra (1998) expanded upon the CCM to create the cognitive reconstruction of knowledge model (CRKM). The CRKM includes other possible motivational factors beyond discontentment, such as personal relevance, social context, or a need for cognition. The CRKM parallels the CCM's steps of conceptual change (intelligible, plausible, and fruitful) with the steps described as 'comprehensible, coherent, plausible, and rhetorically compelling.' In line with earlier criticisms that extra-rational components are important in conceptual change (Sinatra 2005), Taasoobshirazi et al. (2016) suggested expansion of the CRKM model, after they found that enjoyment and type of motivation (e.g. intrinsic, extrinsic) also influenced conceptual change.

The shift towards embedding conceptual change within social and cultural contexts is the reason why conceptual change theory overlaps with socio-cultural theory, although there are still pure cognitivists. In contrast to those who see conceptual change as part of a social and cultural context, pure cognitivists analyze conceptual change only as an individual's cognitive processes, such as described by Posner et al.'s (1982) CCM. Posner et al.'s (1982) CCM did not account for each individual's social and cultural context, but, because of the socially-embedded nature of learning, one cannot simply change one's conceptions through isolated, rational decision-making (Lemke 2001); instead, conceptual change must occur in a way that is consistent with one's socio-cultural context. Isolated conceptual change is short-lived if it is not supported by change in a larger conception which students have transferred to new examples (Dole and Sinatra 1998).

Research questions

We explored how students in a NRM capstone course developed their conceptions of ecosystems and how they situated humans in relationship to the ecosystem. We asked: (a) how do students' conceptions of ecosystem change during the capstone course? and (b) what factors, such as existing conceptions or instructional strategies, characterize the way students' conceptions shift within the ecological literacy continuum?

Methods

Study context

We conducted this study in the NRM capstone class at a large land-grant university in the western United States, in the spring of 2015. The course was taught by a natural resources professor for the ninth time, and one graduate teaching assistant (GTA) for the third time. The GTA attended all lecture and lab sections, developed course material, taught, and evaluated student work. The professor taught the lecture, and, with the GTA, taught the labs. The course met weekly for two 75-min lectures, and once weekly for a 100-min laboratory class. All students attended lectures together, but the students were split into two sections for lab. The curriculum of the course had recently been revised by the course professor,

a science education professor, and the GTA, an ecology education graduate student [Appendix 1]. The revised curriculum included a semester-long group project for which the students designed a management plan for a local ecosystem, guest speakers that included NRM professionals as well as local residents and stakeholders within the system, small group work in the lecture, conflict simulation scenarios based on local issues, and reading and synthesizing information from the primary literature.

Data

All enrolled students ($n = 45$) were invited to participate, and nearly half the class ($n = 20$) consented to have their coursework analyzed and participate in pre- and post-interviews. Interview questions were informed by the research literature on students' lack of preparedness for jobs in NRM, as well as our preliminary study, which included participants who took the class during the spring 2014 semester (Appendix 2; Casper et al. 2016).

Semi-structured interviews were conducted the first week (20–30 min each) and last week (45–70 min each) of the semester and were transcribed (approximately 1600 min). Course artifacts included informal in-class written work, reading responses students wrote outside of class, and their final essay. All lectures were audio recorded and all laboratory sections were video recorded and were analyzed as triangulating data (e.g. several students mention a specific lecture influencing their ideas).

Data analysis followed Charmaz's (2014) constructivist grounded theory approach and data were analyzed for conceptual change regarding ecological literacy (Balgopal and Wallace 2009). We included the participants' perceptions of how their conceptions of ecosystems changed between the beginning and end of the semester, and the factors that they thought influenced this change, specifically focusing on how they situated humans within ecosystems. Because students had well developed general definitions of ecosystems and because we were interested in their conceptions of the human-ecosystem relationship, we used an ecological literacy continuum, described elsewhere (Table 1, Casper et al., in review). The continuum focuses on the different ways people situate humans within ecosystems: (1) Exclusion – humans are definitely not part of an ecosystem; (2) Uncertain-Exclusion – unsure, but final conclusion is that humans are not; (3) Uncertain – unsure, no final conclusion; (4) Uncertain-Inclusion – unsure, but final conclusion is that humans are, but may leave out some components; (5) Inclusion – humans are definitely part of an ecosystem. Using these categories, we described participants' changes in conceptions between the beginning and end of the semester and how they perceived conceptual change.

Trustworthiness was established through prolonged engagement, peer debriefing, and triangulation of data sources (Merriam 2002). The first author was involved in prolonged engagement through attending all the lab and lecture sections, interviewing the students, and performing all of the initial data analyses. During analysis, the first author participated in peer debriefing with both the second author as well as other NRM and education researchers. Triangulation was accomplished through transcribed interview data, student written work, participant observation notes, transcribed audio recordings of lecture, and PowerPoint presentations given in lecture.

Findings

Students had well-developed conceptions of ecosystems at the beginning of the course, which fell into categories Uncertain-Inclusion to Inclusion (Table 2). Some students who were already at Inclusion in the pre-interview described their conceptions as changing and becoming more nuanced during the post-interview, indicating that even students with well-developed conceptions continued to develop them. Students' conceptions of ecosystems generally moved up along the scale, but a few students moved backwards. While existing conceptions can be robust, and students described themselves as familiar with the concept of ecosystems, half of the students ($n = 10$) still underwent conceptual change, as measured by the continuum (Table 2).

We found that students' existing conceptions seemed to have a strong influence on their conceptual change. Students who defined ecosystems as *natural* usually excluded human society and/or the built

Table 2. Shifts in student conceptions of ecosystems from pre to post interviews.

	Post-interview				
Pre-interview	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	1	0	2	6
5	0	1	0	1	8
Other	0	0	0	1	0

Notes: Categories are: (1) Exclusion, (2) Uncertain-Exclusion, (3) Uncertain, (4) Uncertain-Inclusion, and (5) Inclusion. The one student who started as other explicitly excluded all abiotic factors from ecosystems in her pre-interview and was difficult to place along the continuum. Shading indicates individuals who were in the same category for both the pre- and post-interviews.

environment from ecosystems. Students described different aspects of the capstone class as influencing this change; however, we did not find any specific relationships between students' conceptions of ecosystems or conceptual change and the factors they described as influential (Table 3). Therefore, our findings and discussion focus on the influence of students' underlying conceptions.

Natural

Students' conceptions of ecosystems were directly influenced by their conceptions of the term *natural*. Many students initially described ecosystems as *natural* but then struggled to explain exactly what they meant by the term. All the students who either stayed at Uncertain-Inclusion or shifted between Uncertain-Inclusion and Inclusion struggled with defining ecosystems as *natural*, and determining what was *natural*. Students also used similar terms/phrases including 'disturbance', 'man-made', 'altered', 'detrimental', or 'placed there by humans'. Students who stayed at Uncertain-Inclusion did not change their conceptual framing, whereas students who moved to Inclusion, either reframed, or were in the process of reframing, how they thought about *natural* and other related ideas.

The way students defined the two relationships of ecosystem-natural and human-natural provided underpinnings for their conceptual change regarding ecosystems. Students navigated these components in different ways, which was influenced by their initial conception at the beginning of class (Figure 1). Although the term, *natural*, was not part of the interview protocol, if students used the term, we probed their interpretation of it.

The eight students who stayed in the Inclusion category throughout the class did not claim that ecosystems had to be *natural*; therefore, they did not have to navigate the relationship between humans and natural (Figure 1). Some of these students mentioned the term *natural* but then dismissed it as not important for their personal conceptions: 'well it [an ecosystem] wouldn't even have to be natural, but we kind of look it that way, it always seems to be our goal to keep things that way' (Dave). All the other students equated ecosystems with *natural,* or a similar idea, such as 'not man-made,' and therefore struggled with how they defined *natural* in terms of humans and human artifacts. Many of the students in the class were new to the term SES, and several of the students navigated their perceived conflict between *natural* and *human* by putting whatever components they perceived as *not natural* into a SES, rather than an ecosystem.

Uncertain-Exclusion

Two students, Jim and Jade, navigated their perceived conflict of *natural* and *human* by deciding that humans were only in SES and not ecosystems, because only *natural* things were part of ecosystems. Jim shifted from Inclusion and Jade shifted from Uncertain-Inclusion to Uncertain-Exclusion. Both navigated the perceived conflict between *human* and *natural* by classifying humans into SES and outside of ecosystems. The term SES was new to both students at the beginning of the semester.

Table 3. Fourteen of the 20 students in the class reported that specific instructional strategies influenced their conceptions of ecosystems. The number of different types of strategies an individual reported as influential ranged from one to six (similar categories are grouped for the table).

Instructional Strategy	Group work	Lecture and readings	Guest lectures and stakeholders	Conflict simulation	Field trip	No specific
Number of students	10	6	6	2	1	6

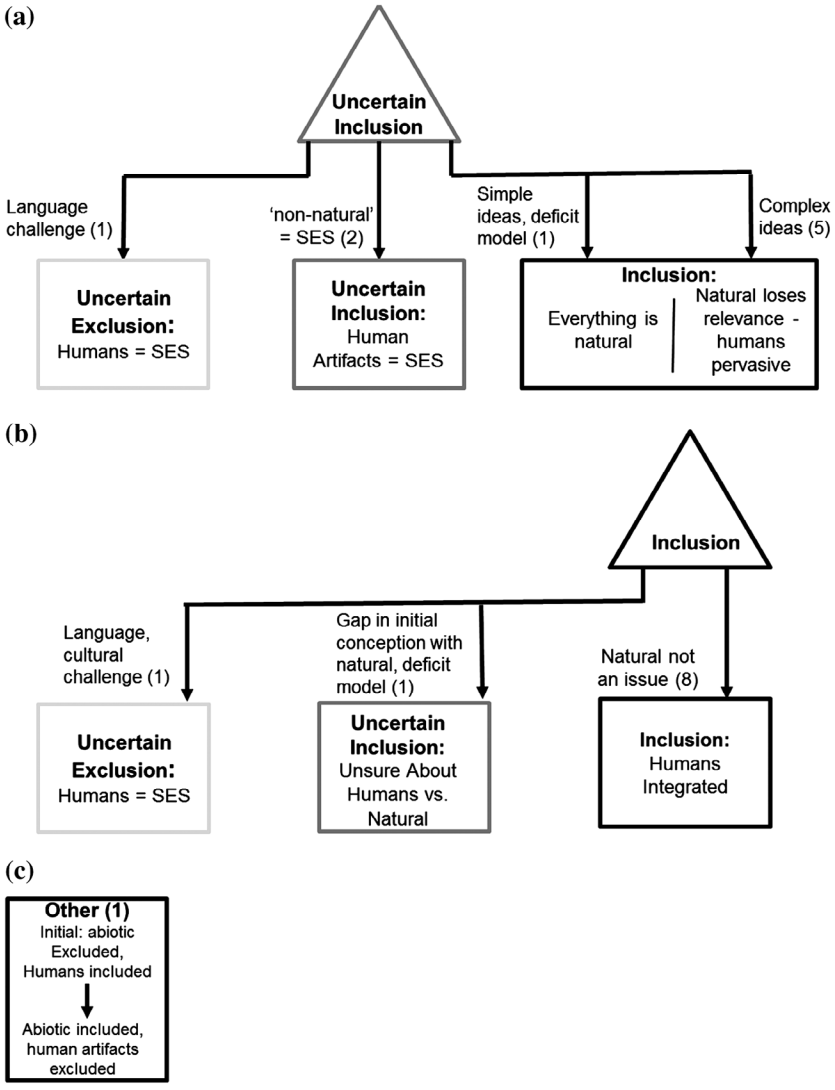

Figure 1. Student conceptual shifts in their ecological literacy were mediated by the way they constructed the relationships between (1) the term natural, (2) ecosystem and natural, (3) human and natural. The way conceptions shifted was influenced by an individuals' initial conception: uncertain-inclusion (a), inclusion (b), or a conception that didn't fit in the continuum (c).

Language was a struggle for both Jim and Jade. Jim was the only international student in the class, and English was not his first language. Jim is East Asian, and he spent his first two years of college at an East Asian institution before transferring to the institution where this study was performed. He struggled with English and differences between how human-environment relationships were framed differently the two institutions he attended. He described the differences between his two majors:

> resource science [at his East Asian institution] includes the natural resources, but we also have the study of people and other things … human resources and natural resources, and there is not a barrier between them … all of them together.

Jade was one of two non-traditionally aged students in the class and was changing careers. While she had always been interested in the NR field, Jade had worked in the public school systems for many years and talked about struggling with the specialized language used in NRM.

In her pre-interview, Jade initially defined an ecosystem as similar to a system, 'an interaction between things, it either could be detrimental or not,' but added, 'with a system it would be, anything man made or not, an ecosystem would be strictly natural.' However, upon further questioning about the meaning of the term 'natural' Jade concluded that it was difficult to find anything that hadn't been influenced by people, 'I guess, since our population has gotten so big, we now influence more ecosystems. But like when it was smaller there were different individual ecosystems that I would consider natural.' Therefore, while Jade eventually determined that human influenced things were components of ecosystems, she struggled with classification. When Jade was asked to define an ecosystem in her post-interview she stated, '*I* guess, humans are in it too, I'm thinking agriculture. … you know it's more social ecological system where humans influence nature … no, ecosystems are just natural.' Jade sometimes conveyed confusion during class sections, and her written responses often focused on recalling material directly presented in the readings, rather than synthesizing and evaluating the material. These examples provide some insight into Jade's meaning-making process. The changes in the way she made meaning during the interviews and her repeated use of 'I guess' when responding to questions, in combination with expressing that she felt that defining the concepts was difficult and her repeated discussion of struggling with language during class, all provide evidence that her meaning-making was influenced by language challenges.

Both Jim and Jade talked about and demonstrated how they struggled with the language in the class and were new to the term SES. As they developed their ideas and struggled with language, they both determined that SES involved all things human, and ecosystem did not involve humans.

Uncertain-Inclusion

Allen and Sam, who stayed at the Uncertain-Inclusion category throughout the study, both included humans in ecosystems, but struggled with how human disturbance or human artifacts fit with their ideas of ecosystems as *natural*. By the post-interview, both students had resolved this conceptual conflict by determining that human artifacts are components of SES, whereas humans are natural, and therefore part of an ecosystem:

> And humans can help the ecosystem too by their development but I wouldn't consider pipelines and buildings and stuff part of a natural ecosystem … that's a good word for it … social-ecological system. It's how it's going to be until we're not here anymore – Allen.

Neither student had essays that could clearly be classified on the continuum. However, Sam did write about the importance of the holistic nature of ecosystems, '*[it is important to] recognize the holistic nature of the ecosystem even when dealing with just one variable.*' But, because Sam did not explain what he meant by holistic, we cannot know how broadly he was thinking.

Shifting to Inclusion

Six of the students in the class – the largest group of students to change conceptions – shifted up the continuum by integrating humans and human artifacts more clearly into their conceptions of

ecosystems in their post-interview. The students in this group resolved their cognitive dissonance about the concept of *natural* regarding how humans are integrated in ecosystems in two ways. One of the students, Eve, determined that everything is natural, and therefore everything is part of an ecosystem, 'really, everything's natural. It's a weird thing to think about. Like that [tv monitor] came from nature, somehow, it was derived from earth.' The other five students stopped using *natural* as a requisite descriptor for ecosystem, and therefore no longer had to negotiate what was *natural*, 'No, I don't think [anything is excluded], I think like everything is part of it. I think if can have an effect, then it is part of it, I'm pretty sure' (Evelyn). Four of these the five students who stopped describing ecosystems as *natural* in their post-interviews also had evidence of their conceptual changes in their written work.

Despite moving to Inclusion, some of the students still had conceptions that were in flux, and were uncertain of how to relate social constructs, like governance, to ecosystems. Nathan stated:

> I guess I'd define it [an ecosystem] like I'd define a system …. I'm still kind of confused on those, now that I look at system and ecosystem … I guess I don't know what I would exclude that's in system from an ecosystem. I'm not sure, like governance and all that stuff. I don't know if I'd include that …. they help make an ecosystem, but I wouldn't define an ecosystem with those.

In addition to his uncertainty about socially constructed components, Nathan described his unclear conception of system; it was embedded within his concrete example of an ecosystem.

In contrast to the other students who shifted to Inclusion, Eve discussed how she avoids complexity, and demonstrated that she did not have a well-developed concept of social system dynamics, or interactions that occur within social systems. She repeatedly discussed how she did not want to persue a career in NRM because of the complexity.

> I've always kind of looked at NRM as kind of an impossible goal … and that has been reinforced after looking at the 100s of things that make up the [local watershed] system …. I really hope I don't do anything in management …. being part of that process just seems terrible.

Eve's desire to deal with 'black and white' situations, instead of 'grey' ones, was woven throughout her interview. One of her criticisms of NRM was that it did not address issues she perceived as much more pressing and doable:

> I feel like there are more important things that are more black and white that could use attention that aren't NR related … something simple like getting clean water to the world. We could do that … if you're just going in and digging a well I don't know if it would be nearly as involved as, I don't know.

As part of her criticism of NRM, Eve revealed that she had a simplistic, deficit view of other cultures. She perceived providing clean water to the world as simple. She did not think that the complexity she wanted to avoid in NRM existed within the challenges of bringing water to the world. Therefore, even though she developed a more integrated view of ecosystems during the class, she shifted her ideas in a way that supported her simplistic world-view to avoid grappling with complex issues.

Inclusion to Uncertain-Inclusion

The one student, Jesse, who moved from Inclusion to Uncertain-Inclusion became uncertain of how humans fit into ecosystems. When he initially described an ecosystem in his pre-interview he used *natural*, but then dropped the term *natural* without discussing it. None of his essays could clearly be classified on the continuum. In the post-interview he expressed confusion how humans fit into the idea of *natural*, having exposed unexplored dissonance in his initial description. Additionally, he was the only other student in the study besides Eve who expressed a deficit view of other cultures:

> I guess more first world man-made things as opposed to huts in a jungle for a tribe or something like that, I think of that as more like natural. I guess first world where there's concrete and motor vehicles, I think that's kind of where I draw the line from a natural ecosystem …. I guess I'm having a tough time …. I think natural ecosystems like being environmental portions of it, and then ones like the man-made, like I keep on saying concrete and cars and cities.

Because Jesse continually expressed confusion in his post-interview, he was struggling to address previously-unexplored complexity, while still maintaining simplistic views of the world and other cultures.

Discussion

Students' conceptions of the technical conception 'ecosystem' were often tied to their conceptions of the common word, *natural*. According to the Oxford English Dictionary ('natural' 2016), *natural* has three main definitions, although one exclusively relates to bullfighting. Of the other two, natural as a noun has 21 different uses, and natural as an adjective has 18 uses, plus an additional 50 special uses, including 'natural resources' ('natural' 2016). Specific definitions given by the OED ('natural' 2016) include 'without human interference,' 'innate,' 'not spiritual,' 'consistent with nature; normal, expected,' and 'not artificial.' Clearly the students have likely encountered the term *natural* before enrolling in their NRM courses, which explains why students held multiple conceptions of natural. When students tied the conception of ecosystem to *natural*, they may have struggled to navigate the relationship between the multiple meanings of *natural* used in every-day language, and the more disciplinary-specific term *ecosystem*. None of the students used the related term *nature* in their descriptions of ecosystems. However, it is possible that they thought of *nature* and *natural* as synonymous. For the students who shifted their conceptions or struggled with defining *natural*, such as Jade, the course appears to have given students opportunities to explore differing interpretations of natural and nature. Therefore, it appears that students' colloquial language influenced their likelihood of undergoing conceptual change.

Despite the fact that many of the students equated ecosystem with *natural,* Tansley (1935) did not describe the term *ecosystem* as *natural*. In fact, Tansley (1935) explicitly included human disturbance in his conception, 'an exceptionally powerful biotic factor which increasingly upsets the equilibrium of pre-existing ecosystems and eventually destroys them, at the same time forming new ones of very different nature, human activity finds its proper place in ecology' (303). The students' textbook also does not use *natural* to describe an ecosystem but rather as:

> a dynamic complex of plant, animal, fungal, and microorganism communities and their associated nonliving environment interacting as an ecological unit (Noss and Cooperrider, 1994). …, an ecosystem certainly includes humans as part of the system if they are present at the particular place and time (Meffe 2002, 70).

Even though the student data indicate that ecosystem is equated with *natural* in every-day language, their textbook does not include the idea of *natural* in its definition. While the textbook does provide a description that includes humans, the idea that humans are only included if they are present at a given time and place is problematic, due to the global nature of human impacts (Rockstrom et al. 2009). Therefore, even though the message from the text is somewhat in alignment with an integrated human-ecosystem conception, it provides evidence that students may be trying to navigate mixed messages about how humans interact with and influence ecosystems.

Discussions in the literature provide some insight into the roots of students' confusion about 'natural,' as well as disagreements about how human influence should dictate future research and management (Miller, Minteer, and Malan 2011). Arguments range from the extremes of explicitly excluding all humans from ideas of *natural* (Hunter 1996), to the idea that *natural*, is gone, and therefore management should come from an anthropocentric utilitarian stance (Nordhaus and Shellenberger 2007). Because of the potential to dichotomize humans and ecosystems when making management decisions (Miller, Minteer, and Malan 2011), and in light of the confusion students had in our study, it is important that NRM curriculum addresses these challenges.

Some of the struggles students had in navigating their conceptions of ecosystem have been previously described in the literature, particularly that the term SES can cause people to think that social and ecological systems are separate (Binder et al. 2013). Even though the four students in the study who determined that *non-natural* things fell into SES defined *natural* differently, they used the concept of SES to address anything in the system they deemed *non-natural*, and therefore excluded from the ecosystem. Similar to Cachelin, Norvell, and Darling's (2010) argument that language used in ecology classes can limit students' development of ecological literacy, we argue that our data demonstrate that Jade and Jim struggled with the language of the course, making them more likely to develop this misconception. While neither Sam nor Allen directly discussed struggling with the language of the class, they did discuss struggles with the concept of *natural* in their interviews. Even if the students

were not aware of it, the way they resolved their cognitive dissonance with SES indicates that they struggled to make both conceptual meaning – determining the human-ecosystem relationship – as well as understand the specialized language – ecosystem, SES – that is used to describe these conceptions. In terms of conceptual change, these students assimilated the new knowledge into their existing knowledge, by using a new term to explain challenges to their existing knowledge (Posner et al. 1982). While conceptually, their integrated idea of SES is like that of their peers who used ecosystem to label the integrated conception, the seemingly nuanced difference could lead to differences in how different individuals approach management and stakeholder interactions.

Jim faced additional language and conceptual challenges as an international student and English language learner. Jim's confusion may have been due to cultural differences, including the different conceptualizations he grew up with and learned in his first two years of his undergraduate program (Nisbett 2003). The differences in Jim's two institutions exemplify general differences in how East Asians and Westerners conceptualize the world, including conceptualization of ecosystems (Nisbett 2003). The separation of humans from the environment is a Western construct, according to Nisbett (2003), and East Asians generally include humans with other animals, and avoid creating a dichotomy between humans and the rest of the world. Jim may have also struggled with synthesis because of linguacultural (the intersection between language and culture) challenges (Luykx et al. 2007). It is possible that he was unable to accurately interpret the questions and/or convey the full complexity of his thoughts clearly in English (Luykx et al. 2007).

Some students struggled with the complexity of ecosystems but addressed it in different ways than those who used SES to resolve their cognitive dissonance. For example, Eve and Sam demonstrated simplistic systems thinking overall through their deficit views of other cultures. Because an integrated view of ecosystems' complex interactions requires complex systems thinking (Meadows and Wright 2008), it is possible that these students will need to confront their limited conceptions of social systems to develop complex ecosystem conceptions. Sam's discussion of his confusion indicates that he was probably dissatisfied with his existing conception and therefore in the anomaly stage of conceptual change, where he had not yet addressed his cognitive dissonance (Posner et al. 1982). In contrast, Eve's clear desire for a 'black and white' world indicated that she was unmotivated to address the limitations caused by her simplistic thinking and had simply assimilated new ideas into her conceptions – if everything is natural, she avoided addressing her questions about if humans are natural (Posner et al. 1982). While several authors have suggested ways to promote systems thinking in undergraduate NRM courses (Bosch et al. 2007; Connell et al. 2012; Habron, Goralnik, and Thorp 2012; Monroe, Plate, and Colley 2015), Eve's strong dislike of complex issues will likely limit her receptiveness to pedagogical strategies that promote complex systems thinking.

The five students who developed more integrated, complex conceptions of ecosystems dropped their attachment of 'natural' to *ecosystems*. Based on Posner et al.'s (1982) description of the conceptual change process, these students have likely used accommodation to resolve their cognitive dissonance; they have shifted their base assumptions about the conception. Even though the written assignments were not designed to target conceptual change regarding ecosystems, the student written work provides evidence that at least some of the students started shifting their conceptions about the human-ecosystem relationship early in the semester. While the instructional strategies that students reported as helpful ranged greatly (Table 3), the diversity of instructional strategies students had experienced (reading, lecture – audio and visual, class discussion, and writing) by the time they were writing their essays may have helped target different ways of learning (Pritchard 2014).

Because our analysis was limited by what students told us about their conceptual change, we cannot make any conclusions about how permanent their conceptual change is, nor how fully they replaced their prior conceptions through accommodation or assimilation (Posner et al. 1982). Many of the students, though, were aware that their conceptions had changed over the course of the semester (Casper 2016).

Implications and future research

Because of the socially-embedded nature of learning and meaning making, it is important to remember that students' prior experiences and backgrounds influence the way they make meaning in the classroom (Lemke 2001), and, therefore, how they accommodate or assimilate new conceptions (Posner et al. 1982). Even when students share a degree program, as most of our students did in this study, differences in university coursework, pre-university experiences, and extra-curricular experiences determine participants' prior exposure to conceptions and language. The wide variety of instructional strategies students discussed as influential (Table 3) and the lack of relationship between instructional strategy and conceptual change is important for curriculum design because different students found different strategies influential.

Our students struggled to create shared meanings of the term '*ecosystem*,' a technical term, because many of them depended on their ideas of *natural*, a common word, to help make meaning. It is possible that this common-technical term link limits students' conceptual change because they simply assimilate a new technical term instead of accommodating the new conceptions represented by the new term. It is possible that this common-technical link exists for other conceptions that students struggle with in the classroom as well. It is important that instructors work to create shared meaning in their classrooms, including upper-division classes where it may be easy to assume that shared meaning already exists.

We argue that our study contributes to the growing literature on ecological literacy and conceptual change in spite of a couple of limitations. Our research on language and conceptual development responds to Cachelin, Norvell, and Darling's (2010) call to address language that promotes the idea that humans are separate from ecosystems. Additionally, we found few studies on conceptual change of ecological literacy. The few studies we found focused on pre-service teachers, not future content experts (Balgopal and Wallace 2009; Puk and Stibbards 2010; Wyner 2013). Therefore, our study builds knowledge regarding conceptual change and ecological literacy by analyzing future content experts. However, our results are reported from a single class of NRM students at one university. Because of the complex nature of the 'ecosystem' conception, there was no one path to studying student conceptions. Additionally, the lead author on the study was also the graduate teaching assistant for the course. While students did not seem to alter their responses during the interviews, also performed by the lead author, it is possible that their responses may have been influenced by their relationship with the interviewer. As other researchers have pointed out, further research is needed to identify the instructional strategies that are effective in promoting conceptual change.

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No potential conflict of interest was reported by the authors.

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Appendix 1

Course Structure Information

The revised curriculum focused on a central theme – guiding the students to develop a complete management plan for a local watershed. The lecture section was designed to provide students with information to scaffold their process of developing a management plan, and the lab sections provided specific guidance on developing a component of the management plan, as well as time for students to work on their project in groups with the instructor and GTA present.

The lecture section of the class was broken into four sections: (1) an overview of management practices and tools pertinent to the class, ecosystem management, adaptive cycles, state and transition models, system models; (2) water, energy, and land governance structures and management practices pertinent to the local watershed; (3) an overview of the four types of management plans covered in the class (adaptive management, payment for ecosystem services, scenario planning, and education and outreach), including examples of how each type of plan can be implemented; and (4) real-world examples of natural resource management cases presented by people involved in the actual management situations. The lecture section was presented by the lead instructor and many guest speakers. The instructor used teaching strategies including interrupted lectures with small-group think-pair-share activities, other informal small group work, and role-playing activities. The guest speakers were free to use whatever teaching strategies they wished, and they usually taught using either a traditional lecture format or interrupted lecture with informal small group work.

The lab section of the class focused more specifically on the management plan, and each lab day focused on a specific component of the management plan. Students in each lab section were broken into four groups, and each group was assigned one of the four management plan types. One of the labs focused on water management and the other lab focused on energy management. The students filled out a survey about their academic background, their preferred management plan type, and any concerns they had about working in the group project or working with specific members of their lab. The GTA used these surveys to create groups that included students with a variety of academic backgrounds within NRM

(e.g. wildlife, plant ecology, water law), took into account students' preferences for management type and any other concerns they had, and were sensitive to demographic characteristics of the individuals in each group. Specifically, we made sure that none of the groups only had one woman in them, because of the literature that shows that a lone woman in a group is often not listened to by her male group-mates, and may not be able to participate and contribute fully (CITE).
The management plan itself was broken into smaller components that the students turned in for feedback and to revise before turning them in as part of the final management plan at the end of the semester. Students turned in different components at four times throughout the semester: (1) system model; (2) resilience assessment (geographic description, revised system model, disturbances within the system and their historical range of variation, adaptive cycles and cross-scale interactions, state and transition models, and overall assessment of the resilience of the SES); (3) stakeholder involvement assessment and plan, and (4) final management plan (includes all above components as well as a management plan informed by the other components.) Students also gave 15-minute group presentations on their resilience assessment (mid-semester) and final management plan (end of the semester). The iterative nature of this work allowed students to improve their revision skills and more thoroughly learn how to develop a management plan. In the even that a group received a grade lower than a B on any of the project components, the group was given the option to revise the section to improve their proficiency and grade.

Appendix 2

Pre-semester interview questions

(1) Please briefly describe your background in NR, including coursework, occupational and volunteer work, and any other related experiences.
(2) What types of coursework assignments or activities do you think help you learn most effectively? What are some examples from previous courses?
(3) What types of assignments or activities do you think are least effective in helping you learn? What are some examples from previous courses?
(4) (a) Please define 'system.'
(b) What has helped you to develop this definition?
(5) (a) Please define 'resilient system.'
(b) What has helped you to develop this definition?
(6) (a) Please define an 'ecosystem.'
(b) What has helped you to develop this definition?
(7) (a) Please describe the most extensive group work project you have ever worked on and your experience with it.
(b) How do you think your prior experience might help you to work effectively with your group in NR420?
(8) If you have experience working in the field of NRM, what do you think has most effectively prepared you for that work?
(9) Is there anything else you would like to add that did not come up from these questions?

Post-semester interview questions

(1) Please briefly describe your NR capstone course
(2) (a) How would you define a 'system'?
(b) How were your thoughts challenged, reinforced, and/or extended throughout the semester?
(c) How do you think this will influence your approach a career in NRM?
(3) (a) How would you define a 'resilient system'?
(b) How were your thoughts challenged, reinforced, and/or extended throughout the semester?
(c) How do you think this will influence your approach a career in NRM?
(4) (a) How would you define an 'ecosystem'?
(b) How were your thoughts challenged, reinforced, and/or extended throughout the semester?
(c) How do you think this will influence your approach a career in NRM?
(5) (a) How would you define a 'social-ecological system'?
(b) Describe what you remember about your thoughts were about a social- ecological system at the beginning of the semester.
(c) How were your thoughts challenged, reinforced, and/or extended throughout the semester?
(d) How do you think this will influence your approach a career in NRM?
(6) For your large group project, describe:
(a) What helped you develop your ideas for the project?
(b) How your group's ideas and interactions shaped your ideas

(c) How you shaped your group's ideas.
(d) How did your group divide up the work for the project?
(e) How did your previous group work experiences influence your work this semester?

(7) Describe which assignments or readings in the capstone course particularly helped influence your understanding of systems, resilience, ecosystems, and social-ecological systems.
(8) Describe if there were any aspects of NR 420 that you think were particularly beneficial in preparing you for working in the field of NRM.
(9) What would have helped you be more prepared, that were not:
(a) Part of your capstone course?
(b) Part of your NR program altogether?
(10) Are there any details you would like to add that did not come up from these questions?