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Natural Resource Management Students' Perceptions of Conceptual Change in a Capstone Course

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ABSTRACT

Currently, there is a concern that natural resource management (NRM) students are not graduating with well-developed systems thinking, communication, and group work skills. Through our phenomenological exploratory study, we used conceptual change and discourse theories to frame our questions: How do students describe their conceptions of social-ecological systems and resilience as changing over the course of an NRM capstone course, and what do they think helped change them? Using semi-structured interviews ($n = 3$) we found that students' conceptions of social and biophysical systems became more integrated, and their ideas about systems thinking and resilience broadened to encompass greater complexity. These conceptual shifts were influenced by interactions with other students, natural resource professionals, and stakeholders during class, as well as their engagement with one another in a semester-long group project. The conceptual change these students demonstrated indicates that large conceptual shifts can occur in a capstone class.

Core Ideas

- Students' conceptual change of systems thinking was facilitated by a capstone class.
- Conceptual change was influenced by stakeholders, peers, and a large group project.
- Students' conceptions of biophysical and social systems became more integrated.

Natural Resource Management (NRM) graduates need well-developed systems thinking skills, as well as strong communication and collaboration skills to articulate their ideas and effectively manage social–ecological systems (SESs) (Sample et al., 1999; Bosch et al., 2007; Sandri, 2013). Graduates who consider a SES as a whole, rather than as separate social and ecological components, are better able to address the "wicked" and "messy" problems that challenge natural resource managers (LaChapelle et al., 2003). The SESs are "ecological systems intricately linked with and affected by one or more social systems," and as such, it is necessary to include resource users, physical infrastructure, biophysical characteristics, and non-human organisms in analysis of these systems (Anderies et al., 2004, p. 5).

Systems thinking is a framework that shifts the conceptualization of inter-related components from a reductionist focus on the parts to a broader focus on identifying the interactions and dynamics within a system (Senge, 2006). Systems are made up of interacting components that are interconnected in ways that cause them to have complex responses that cannot be predicted from the constituent elements (Meadows and Wright, 2008). However, undergraduate students sometimes struggle to understand what a system is and how components of systems interact because if students have not had a chance to explore systems thinking in their undergraduate courses, they may be perceived as abstract and difficult to conceptualize (Habron et al., 2012; Remington-Doucette et al., 2013). Even if undergraduate students have been taught about ecosystems—systems made up of abiotic and biotic elements that interact with one another within defined boundaries from micro to global scales (Chapin et al., 2011)—they may not have been taught about systems at a conceptual level.

The NRM professionals use the term SESs, rather than ecosystems, because SESs also include non-biophysical components, such as actors, organizations, and institutions (i.e., social norms, laws, and policies) (Anderies et al., 2004). The SESs have multiple stable states, meaning there are different ways that the systems can function (Meadows and Wright, 2008), and therefore functions differently when thresholds are passed, (i.e., a point when the components and/or the interactions between the components change). For example, in a clear, healthy lake, the levels

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Abbreviations: F&RS, forest and rangeland stewardship; GTA, graduate teaching assistant; NRM, Natural Resource Management; SESs, social–ecological systems.

of phosphorous can increase without changing the function of the lake; however, once the nutrients reach a certain point, the lake will shift to a cloudy state with frequent algal blooms (Walker et al., 2004). Subsequently, passing this threshold for phosphorous levels influences several other interactions within the lake ecosystem (Walker et al., 2004).

The complex interaction of systems results in emergent properties, which Meadows and Wright (2008) argued are generally difficult to understand, and may be nearly impossible to predict. Emergent properties are the larger-scale manifestations of smaller-scale interactions of components within a system. For example, diffusion, or the movement of a substance from areas of high concentration to areas of low concentration, is a larger-scale pattern that occurs through the smaller-scale random movement of molecules that students often explain as a cause-and-effect process instead of an emergent process (Chi, 2005). Hence, helping students identify properties of systems on both small and large scales is important.

Current NRM practices strive to understand and account for complex relationships within SESs to enact effective management. When SESs or ecosystems are viewed as collections of parts, rather than complex systems, NRM professionals often miss the underlying factors driving a system's existing state, which prevents them from effectively managing a system in a way that incorporates continued human impacts (Meffe, 2002; Walker and Salt, 2006). Because we, as humans, are inherently part of any system we analyze, it is difficult to examine the system in which we live more broadly and to see ourselves as part of the system (Orr, 1992; Senge, 2006). Even when social components are considered in SESs, if stakeholders are not included in research, systems components may be left out, and research conclusions may be removed from the experiences of the stakeholders, leading to conclusions that are limited in scope and implementation value (Reid et al., 2009). It is possible that major "ecological surprises" that have occurred throughout the last several centuries—including pandemics, population collapses and explosions, ecosystem state shifts, and losses of ecosystem services—are due to a narrow, "command and control" reductionist management focus, driven by societal desires and norms, which did not account for the complex interactions within an ecosystem (Holling and Meffe, 1996; Estes et al., 2011).

Resilience theory predicts the way the components of ecological and SESs interact and respond to disturbance (Gunderson, 2000). Within resilience theory, characteristics of systems include resistance, transformability, and resilience (Walker et al., 2009; DeRose and Long, 2014). The resistance of a system is its ability to be unchanged by a disturbance, and transformability and resilience describe how a system changes in response to disturbance (Walker et al., 2009; DeRose and Long, 2014). Transformability deals with managing the system when disturbance causes changes in the fundamental way the system functions, whereas resilience is the capacity for the system to respond to disturbance while maintaining its fundamental functional state (Walker et al., 2009). Therefore, resilience theory addresses how system function changes over time, and addresses characteristics beyond the ecological resilience of a system (Gunderson and Holling, 2002).

The NRM literature usually focuses on a type of resilience termed ecological resilience, first defined by Holling (1973) as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (p. 14). In contrast, engineering, or equilibrium resilience, is simply the ability of something to "bounce back" to its original state (Benson and Garmestani, 2011a). Although the difference between equilibrium and ecological resilience may seem semantic at first, they represent different philosophical underpinnings: equilibrium resilience focuses on predictability, efficiency, and consistency, whereas ecological resilience focuses on persistence, change, and unpredictability (Holling and Meffe, 1996).

Resilience theory emerged in the NRM literature in the 1990s (Berkes and Folke, 1994), and became more prevalent moving into the 2000s (Walker et al., 2004). The move toward reliance on resilience management is an important shift in NRM, as it approaches management from a social-ecological, systems thinking stance. However, teaching resilience theory to undergraduates is challenging because it relies on systems thinking, already a challenging concept, and requires higher order thinking (Meadows and Wright, 2008; Fazey, 2010). Despite these challenges, a broad perspective that integrates SESs and resilience theory is vital for effective NRM (LaChapelle et al., 2003; Chapin et al., 2009; Krasny et al., 2010).

Traditionally, students were taught NRM from command-and-control or steady-state frameworks, which treated individual components of a system separately, managed for a single historical condition and a single species or resource, and considered humans to be separate from an ecological system (Holling and Meffe, 1996; Chapin et al., 2009). Since the 1990s, there has been a shift toward managing ecosystems for multiple ecological benefits, rather than commodity production alone. More recently this shift has been accompanied by a move toward managing systems as interconnected wholes using systems thinking and resilience management (Holling and Meffe, 1996; Walker and Salt, 2006; Chapin et al., 2009).

In light of these philosophical shifts in management paradigms, some experts argue that content-focused NRM coursework may not adequately teach critical thinking skills (Quinn et al., 2009), nor sufficiently integrate social systems as a part of ecological systems (Bosch et al., 2007). Additionally, traditionally taught NRM classes often do not help students to develop strong communication and group work skills (Derting and Ebert-May, 2010) because time is not allotted for problem-solving or small group interactions.

As in many natural science disciplines, some NRM educators are grappling with identifying "best practices" in this field. The NRM professionals tout the value of authentic experiences and assessment of student learning in class; however, there is little well-supported research on the impacts of student-centered instructional strategies in NRM, such as long-term problem-based learning, on student outcomes. As NRM capstone courses are becoming more common, it is timely to examine what identifying characteristics may define best practices in NRM education. These best practices are those that, in particular, help students bridge social and bio-physical systems needed to adopt an inclusive system-thinking framework.

A capstone class that allows students to synthesize content across disciplines in an interdisciplinary way while actively engaging them in authentic NRM practices can help NRM students develop professional competencies (Berkson and Harrison, 2002). Existing literature on NRM capstone courses focuses on reporting pedagogical strategies, but these strategies are not rigorously evaluated (Arthur and Thompson, 1999; Berkson and Harrison, 2002; Yeon-Su et al., 2007; Prokopy, 2009; Pile et al., 2012; Habron et al., 2012). For example, weakly supported evidence from several curriculum-focused studies suggests that when instructors use readings from the primary literature, engage students with extensive group projects that apply current professional management models, integrate stakeholders into the classroom, and have students present their work to stakeholders involved in their system, students may be better prepared to participate in NRM practices (Arthur and Thompson, 1999; Berkson and Harrison, 2002; Yeon-Su et al., 2007; Prokopy, 2009; Pile et al., 2012; Habron et al., 2012). Although the aforementioned studies focused on reporting their implementation of new pedagogical practices and not evaluating the practices, the techniques used are consistent with educational reform efforts of moving away from teacher-centered instruction towards student-centered problem-solving activities (Lemke, 2001; Hmelo-Silver, 2004; Costa and Rangachari, 2009). Therefore, more rigorous studies evaluating the impact of innovative instructional practices in NRM capstone classes are needed.

One of the challenges of studying conceptual change is assessment, which may be dependent on students' awareness, or perceptions, of their own conceptual change. It has been well-established that when learners think about how they learn, they are more likely to take ownership of their learning (Bransford et al., 2000). Georghiades (2000) advocated the use of "metacognitive instruction" to promote conceptual change because he purported that helping students to reflect on what they know and what they do not understand enables them to increase their confidence in their learning and retain what they have learned. Furthermore, the ability to be reflective of one's learning has been linked to conceptual change (Dole and Sinatra, 1998). Instructional strategies that facilitate metacognition, such as reflective writing, drawing, diagramming, and speaking activities, have been associated with conceptual change (Georghiades, 2000; Balgopal, 2014). Based on our literature review, however, there is a lack of literature on student perceptions of their learning in NRM.

The implementation of a multidisciplinary synthesis capstone class for NRM majors has been identified as a solution to help transition students from their "student" role to a "professional" role (Yeon-Su et al., 2007). Although several studies describe assessment of systems thinking skills, there is a lack of research on how content influences students' conceptual change regarding systems thinking. In our research, we sought to explain how classroom interactions help students shape their conceptions about scientific issues that have social implications. Through an examination of how people speak and write about a conception we can articulate the role that learning environments play in influencing conceptions. We used a phenomenological approach to study student learning in an NRM capstone class. Our study was informed by the questions:

- How do students describe their conceptions of SESs and resilience as changing over the course of an NRM capstone course?
- What do they think helped create this change?

METHODS

Study Context

We conducted our exploratory, qualitative study in an NRM capstone class at a large, western land-grant university in the United States. The students enrolled in the class were primarily final year NRM students. In spring 2014, the course was taught by a forest and rangeland stewardship (F&RS) professor for the eighth time, and one graduate teaching assistant (GTA) who taught the course once before. The GTA developed course material, taught, evaluated student work, and attended all lecture and most lab sections. The professor taught the lectures and, with the GTA, co-taught the labs. The course curriculum was revised recently by the professor, GTA, and a science education researcher, all authors of this study. The class met twice weekly for a 75-minute lecture, and once weekly for a 100-minute lab. Students (n = 37) were primarily NRM majors, but a few other majors were represented. The lecture included group work, guest speakers, and panel discussions with local stakeholders. In the lab section, students were assigned groups in the second week of class and worked together on their extensive, multi-phase, semester-long project.

The semester-long project was a central component of the class. For this project students developed a management plan for a local watershed. The learning objectives for the project were: (1) search for, synthesize, and apply new and existing knowledge of natural resource ecology, management, law and policy, and human dimensions to describe and analyze a complex SES; (2) develop a management or scenario plan to address a key issue in your system, including identification of realistic and measurable goals and objectives, description and evaluation of alternative management strategies or scenarios, development of a detailed monitoring and adaptation plan, and feasibility assessment; (3) communicate your results and work products effectively and professionally in written and oral form, while adhering to the standards of academic integrity and professional ethics; and (4) work effectively as a team to accomplish these objectives, by practicing clear communication, mutual accountability, and respect for diverse viewpoints, knowledge, and skill sets.

To guide the students in the semester-long project, the instructor divided the requirements into four large assignments: (1) system model, (2) resilience assessment, (3) stakeholder analysis, and (4) management plan and recommendations. These assignments were further broken down into constituent components. One laboratory section was dedicated to each component, during which students received help to develop outlines, matrices, or drafts of the focus component. During labs, students explored examples and handouts with guiding prompts. Each of the four sections was evaluated before the final project was graded. Hence, students were expected to revise their plan as they developed it.

This study was grounded in a phenomenological research approach, which draws on participants' descriptions of their own experiences to develop descriptions of that experience (Merriam, 2002). Data from interviews are grouped together into meaning units, which are used to develop an overall description of the experience, or "essence" (Creswell, 1998). The role of the researchers, therefore, is to interpret participants' views of their phenomena using the participants' narratives (Merriam, 2002). Regular member checking is an inherent part of phenomenological studies in order to decrease the biased views of the researchers as they attempt to find themes across participant voices (Creswell, 1998). The primary data sources for this study were in-depth, semi-structured interviews, as well as artifacts developed for the course (such as assignments). Interviews were performed at the end of the semester-long course, after grades had been submitted. All participants gave consent for participation in the study (IRB #047-15) and all names reported are pseudonyms.

All three participants were still in contact with the professor and represented a convenience sample in our exploratory study, which we anticipated would allow us to identify methodological considerations for a full study the following academic year. We recruited two male participants (Hamadah and Tyler) and one female participant (Rachel). Hamadah was working in the NRM field at the time of interview, Tyler had just completed his last semester of college, and Rachel was working in a non-academic staff role with NRM students and faculty. The interviews were semi-structured, and questions were informed by not only the participants' course work in the capstone course, but by the research literature on learning related to understanding of resilience and systems thinking (Appendix).

The interview transcriptions were analyzed using discourse analysis, following the framework of Gee (2014). Gee (2014) examines both "what" individuals say and the broader "cultural context" in which words are spoken or written. Gee (2014) distinguishes between "little d discourse" as simply the language content and text being disseminated, and "Big D discourse" as the discourse embedded within the context of interactions, including the specific way individuals think, speak, act, interact, and use pertinent symbols. Individuals can switch between using the discourse of a novice and that of a professional or expert (Gee, 2014). In this manner, Gee's ideas are nested within sociocultural theory, which explains that people learn through interactions with other people and that cultural contexts are relevant as they learn (Charmaz, 2005).

The data were analyzed for demonstration of conceptual change regarding resilience and systems thinking. Because the primary data sources for our study were interviews following the intervention, we were inherently analyzing students' perceptions of their conceptual changes. A conception describes an individual's understanding of a concept, such as the process of diffusion; conceptions that are inconsistent with generally accepted scientific explanation are often labeled misconceptions. Posner et al. (1982), drawing on Piaget's cognitive studies, described the process of replacing prior conceptions with new ones in the Conceptual Change Model. First, an individual must be dissatisfied with his/her existing conception. The new conception must be intelligible (make sense), plausible (be consistent with prior knowledge), and fruitful (useful in explaining future phenomena). However, for social cultural theorists, whose research is grounded in the premise that learning is a social practice embedded in a cultural and historical context, the process of conceptual change must be studied within social contexts (Lemke, 2001; Ivarsson et al., 2002).

Conceptual change research often involves gathering pre- and post-semester data (see Posner et al., 1982); however, in a phenomenological study we were interested in students' descriptions of their own conceptual change. In other words, we focused on the participants' awareness of their own conceptual change, and their perceptions of how peer interaction influenced their learning. Particular attention was given to how each participant described the biophysical and social components of SESs, and how these components interacted with one another (either while discussing content, their job at the time of interview, or the course), as well as how the participants described these concepts changing.

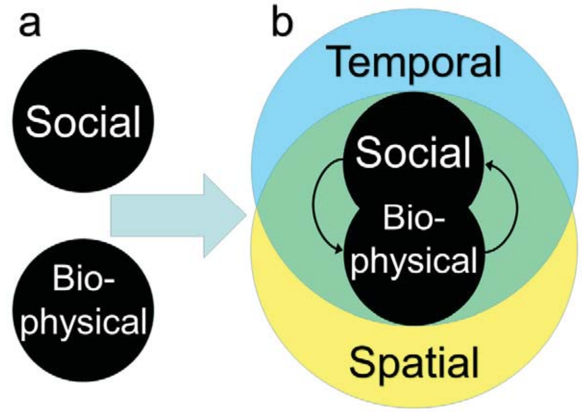

Fig. 1. Participants' conceptions of biophysical and social systems shifted during the capstone course. Participants initially saw biophysical and social systems as separate (a). However, the participants described their conceptions of biophysical and social systems as becoming more integrated and imbedded within temporal and spatial scales during the NRM capstone course (b).

The transcripts were initially open coded by the first author, while being sensitive to issues related to systems or resilience (Charmaz, 2014). These initial codes were grouped into meaning units (systems thinking and resilience conceptual change, real-life experiences, and group work). A second author then coded this first transcript and collectively we collapsed the codes to reflect an overall description of the "essence" of the experience. These themes were discussed by our entire research team. Subsequently, we developed propositions about NRM student learning in their capstone course (Creswell, 1998). The first two authors then collaboratively coded the second transcript. The third transcript was then coded by the first author using the established coding protocol.

The trustworthiness of the findings was established through prolonged engagement with the participants by two of the authors (first and third), member checking at the time of the interviews, peer debriefing among our research team, and triangulation of data sources to support propositions (Merriam, 2002). Charmaz (2005) advocates that qualitative researchers conduct an iterative review of data, allowing us to read between the lines and ensure that inferences were supported by evidence in the transcripts. As a team, we reviewed interview questions before data collection, and then we discussed initial themes after we reviewed raw transcripts. In doing so, some propositions were clarified and/or collapsed.

RESULTS AND DISCUSSION

Two major concepts that students described as changing in the capstone class were (1) the overlap of social and biophysical systems, and (2) the dynamic and cross-scale nature of resilience in SESs. Participants initially described conceptualizing social and biophysical systems as separate (Fig. 1a); however, the NRM capstone course helped them to see social and biophysical systems as integrated, and to situate these integrated systems within temporal and spatial scales (Fig. 1b). The two instructional interventions that the participants repeatedly referenced were (1) prolonged engagement working on a semester-long group project, and (2) interacting with the stakeholders and NRM professionals. Both of these experiences helped shape how the participants developed and refined their conceptions about SESs and resilience.

Overlap of Social and Biophysical Systems

In describing their conceptual change of systems throughout the class, the participants discussed the importance of addressing the interconnectedness of factors within a SES, demonstrating a shift from their earlier conceptions (Fig. 1). Hamadah specifically discussed the relationships within a system:

> We need to think of the system as a whole. You need to include as many factors of the system as a whole.

Rachel, even with her strong social science background and interest in the social aspects of NRM, saw these components as separate rather than integrated, before the class. However, the class shifted her perspective.

> …there's policy, there's the social aspect, and there's the physical aspect…maybe they're not so separate, they're more blended.

In his written work for the class, Tyler discussed the importance of looking at the components of systems as interconnected.

> Instead of looking at natural resource issues as separate linear problems with one solution, one must look at natural resource problems as a system that is interconnected with multiple solutions and we are a part of this system.

Hamadah also demonstrated understanding of the challenges of managing a complex ecological system.

> You need to address so many issues at once. You might benefit some part of the issue while really impacting a different part of the issue; it's finding the balance in between. That was one of the challenges for me in the class.

He and his group had to directly find this balance in their group project. In other words, the participants shifted from a more localized to a more integrated understanding of SESs, with overlap between social and ecological systems.

Along with generally discussing the integrated nature of social ecological systems, Hamadah went further and discussed the importance of both social and ecological data:

> I think you can't really focus specifically on ecological data, for example, as opposed to social data. You can't put more weight on one form of data than the other, because they all have their unique values. The interviews [with ranchers] show things that are drastically different than what we are seeing on the [grazing] field...That's one of the things from class too. Just not looking at one as opposed to the other, just looking at both, because they're equally important.

Hamadah's discussion of the importance of multiple types of data demonstrates the value he places on both social and ecological components of a SES.

Factors that Influenced the Shift

Participants explained that activities within the class that immersed them in real-world problems and problem-solving influenced how they thought about social and biophysical systems. They also emphasized the importance of the local relevance of the project. Rachel highlighted the real-world, problem-solving, role-playing scenario in which students participated: "It was a real world thing, and we had to figure out what the problem was," as well as the semester-long group project on which she worked: "It's right now, this is what they're doing here," as important in helping her see the interconnectedness between social and biophysical components of SESs. Tyler discussed the self-guided field trip, which required students to drive around the SES they were researching for their semester-long group project. Students traveled in small groups outside of class time, and responded to discussion questions both during and after they traveled:

> [the field trip] specifically helped me look at systems because I've traveled a lot, and I've driven a lot, but I've never really thought about how things work. I remember specifically we went to [nearby town], and there were a bunch of really nice houses there that were going up. It was sort of like, you know, why are these houses here, and how does that, how is that influenced by other things?

Through physically inspecting the landscape, while looking at it with a new lens, Tyler was able to observe interactions within the SES he was studying. Both of these participants described activities that engaged them with real situations—problems and landscapes—that helped them engage with the SES and understand how it is interconnected. They also discussed how locally situated work made their class experiences relevant to their lives.

In his interview, Hamadah described his conceptual shift more generally. He pointed out that his previous classes had primarily focused on non-anthropogenic ecological factors. From his new-found perspective following the capstone class, he criticized his previous classes for not integrating anthropogenic factors into ecological systems and not addressing political issues. Hamadah also indicated that he learned that the way different viewpoints and goals of different stakeholders can influence management. By criticizing previous classes through the perspective he developed in the capstone class, Hamadah went beyond describing his own conceptual change by applying his new perspective. Additionally, Hamadah's criticism of previous classes helps explain the more limited conceptions students had as they entered the capstone class.

Dynamic and Cross-Scale Nature of Resilience in Social–Ecological Systems

The participants described a shift in their conceptual understanding of resilience during the capstone class. Hamadah described his initial definition of resilience as "very direct," or "localized, dealing with 'one aspect' of a system":

> …[resilience] really had to do with an ecosystem and a disturbance, and it related to succession, but, with this class, resilience really took on a broad, broad definition. And it looked at a wide range of factors, not just ecological.

Tyler discussed how the class shifted him toward "just sort of seeing the greater picture of any decision that you're going to make," and Rachel described a similar shift, moving from a narrow and possibly unformed definition of resilience to a much broader definition.

The participants also discussed how their ideas changed about how the different components of SESs interact. Hamadah spoke more explicitly about how the dynamic nature of systems led to his conceptual change surrounding resilience. State changes, or shifts in the way a SES fundamentally functions, are a key component of resilience thinking (Gunderson and Holling, 2002). Although Hamadah had been exposed to the ideas of thresholds, which are the points of transition between states, he did not understand them until after grappling with them for a while in the capstone class. Once he began to understand thresholds and state changes, he realized that

> …we have the power to do something to the system to change it drastically enough so that it would never go back to how it was in the past. That's an idea that really shook me.

This kind of conceptual shift is key for effective implementation of resilience management (Gunderson and Holling, 2002), and to address the global thresholds we are starting to cross that lead to climate change (Rockstrom et al., 2009). Similarly, Tyler discussed how he began to think about systems differently in the capstone class: "I think I was challenged to start thinking about systems in terms of their resilience." Rachel discussed how her ideas about how the different components of the system interact to influence the system changed: "…the interaction between the social system, or maybe it's one system, but the parts of the system that are social and physical…" However, her hesitation may indicate that she still struggled with conceptualizing SESs as an integrated, interacting whole, rather than separate components.

The participants' written work produced during class supports the claims they made in their interviews (Fig. 1). During the first lecture on resilience, students were asked to write out their definitions of systems and resilience at the beginning of class, then asked to revise the definitions after class. In their revisions, the participants explicitly added issues of scale (Fig. 1). Tyler directly stated, "scale is important," whereas Rachel specifically discussed time: "I would add that time frame is a key factor here."

Participants also addressed the importance of cross-scale interactions, adding additional complexity to their conceptions. In a writing response synthesizing lecture and reading material, Hamadah addressed the issue of cross-scale interactions across time and space, when he discussed the need to manage holistically for natural variation [in space] and processes within a system over time. Hamadah also explained the importance of scale and cross-scale interactions, and identified this as an often forgotten component in NRM:

> It is important to consider scales because what happens at one scale can influence or even drive what's happening on another scale. Ignoring the cross-scale effects is actually a common mistake in natural resource management.

Tyler also addressed the importance of cross-scale interactions, which further supports his description of his conceptual shift in the interview:

> Linkages across scales are extremely important. The processes and variables in one scale can influence or even drive the processes in another scale. If you can understand the linkages that go on in these different scales, then when an issue arises you can go to the different links in order to find a solution that may be implicit. Resilience is a holistic approach that looks at all scales of a system. For example, if soil degradation is an issue within a system, then in order to solve the problem you might have to consider a larger scale approach and focus on issues of nomadic ranchers or even a global impact such as climate change. Soil degradation is caused by overgrazing of a particular system but it might also result from larger problems as well.

After thresholds had been addressed in class, the participants' work demonstrated their developing knowledge of an important concept in resilience thinking. Hamadah wrote, "Thresholds are levels in controlling variables where feedbacks to the rest of the system change, crossing a point with the potential to alter the system in its entirety," clearly explaining a concept that he discussed as challenging him initially in the course, during his interview. In the same assignment, Hamadah used examples of anthropogenic influences on biophysical systems to demonstrate his knowledge of thresholds, which parallels the surprise he expressed in his interview when he realized how powerful human influence can be on ecosystems. After the class addressed resilience and thresholds, Tyler framed systems in terms of their resilience, whereas in his initial writing for the class he defined a system as "a broad term that describes many parts working together in a sustainable way."

Factors that Influenced the Shift

The shift from a narrow to a broader definition of resilience that participants described occurred through the guidance they received building the components of the large group project, including interactions with stakeholders in the local system the participant analyzed. It was also during class that the participants were able to interact with peers, the instructor, and with a myriad of stakeholders. Hamadah explained, "...there were definitely things that we did in class that were more effective than the readings…the class interactions…all of those brought real life ideas."

In their interviews, all the participants mentioned the scenario planning lab, which guided them through a specific process to develop possible futures for the watershed for which they were writing management plans, as a component of the class that particularly helped shift their learning. Rachel specifically discussed how the activity helped her group refine their focus for their project. One of the participants on the stakeholder panel was a farmer who spoke as if climate change did not exist. His statement, which shocked Rachel, made her group decide to focus on educating farmers and ranchers. Therefore, the group identified the target group for their management plan through their interactions with stakeholders in the systems.

All of the participants noted that change was facilitated by their interactions with peers during group work while grappling with real problems. Hamadah explained that his changed perception did not happen overnight; it was through prolonged engagement with his group mates as they constructed their plan that he began to reconsider the importance of dynamics within systems:

> I wouldn't have been able to do it [the project] on my own…that whole group interaction, especially for that long term [was vital].

Tyler discussed how he was impressed with what his group was able to produce:

> It's like wow, I can't believe me and four other guys wrote all of that, which is really exciting. I'd never written anything of that depth before.

He discussed the growth he experienced due to the diversity of his group:

> I think it really helped me grow because I was able to work with different people…I mean if I had a perfect group we'd probably had a great grade in the class, but I don't think I really would have learned anything…learning how to balance different personalities…I've worked on group projects before, but nothing of this magnitude.

The participants' ideas of what they were capable of shifted, as they learned through peer-to-peer interactions, instead of receiving direct instruction from a professor. The structure of the group project required the participants to consider others' perspectives and rely on peer and self-guided learning. The importance of prolonged engagement with material agrees with Hiller Connell et al. (2012), who found that prolonged engagement with holistic systems thinking interventions were more effective in fostering systems thinking than one-time interventions.

The capstone course provided a holistic perspective to what interaction means for the participants. The participants repeatedly described the importance of group interactions as they made sense of resilience and systems thinking. All of the participants mentioned being affected by observing and listening to stakeholders (NRM professionals and community members) and communicating with one another in the class. Hamadah described how the stakeholder panel influenced him:

> The stakeholder panel really helped show me that there are so many different points of view for the same exact issue.

He was also surprised at how people with such differing views could work together, and made personal observations of the tact necessary for NRM professionals when working with controversial topics:

> Even if you might believe these things [global warming], you can't really mention them, because you want to put yourself in their shoes. That's definitely something that I think was helpful from NR420, because it taught me not to get, not to put emotions and ego in arguments and discussions…sometimes it's ok to discuss and argue for hours on end and not change someone's mindset. You don't need to change everyone's opinions, but you need to listen to all the different opinions just to shape your own.

Rachel discussed the influence of a particular event that occurred in the stakeholder panel, when a rancher, who otherwise seemed progressive, discussed climate change.

> And, I remember this, they were saying something about global warming doesn't exist (laughs). I think that's what they were saying…he was like super progressive…was saying global warming doesn't exist and stuff, and I think that kind of made us feel like, we need to talk to these people! …I feel like that helped us to really solidify who we wanted to talk to…that was very helpful in like changing, helping us see what we wanted to do.

This event not only broadened the participants' views of the stakeholders' views, but also helped her entire group determine the angle of their group management plan. Because of the interaction with the stakeholders in the panel, they were able to identify a population they thought was important to target through their education and outreach management plan. On a broader scale, through opportunities such as these, the participants described how they understood social and biophysical systems interactions.

Human–Ecosystem Relationships

Despite the described integration of all parts of the system, the participants still struggled with the integration of anthropogenic and ecological factors at the time of the interview. The course emphasized the importance of addressing NRM from an integrated social-ecological perspective. However, the participants had different conceptions of how humans related to ecosystems, and these pre-existing conceptions may have influenced how they perceived the course material (Lemke, 2001; Chi, 2005). Hamadah described ecological components as exclusive of anthropogenic components:

> Studying the ecosystem in detail, by first excluding the anthropogenic side of it, just so you can understand that system…[then] you start getting the other ideas of humans, resource use, populations, passive, active use, stuff like that.

Tyler saw more complexity in the human–ecosystem relationship. His description reveals the tensions he feels in trying to resolve the relationship between humans and ecosystems.

> I think a lot of people try and separate human systems from ecosystems. I still don't know where I stand on that, whether or not you know there's this big, like, we're all interconnected sort of thing, or like we're separate…I think it depends on how far you're willing to extend an ecosystem…You can say a tropical ecosystem, but people live in the tropics…I guess it depends on the scale, I suppose.

Rachel's ideas fell between the other two participants. She described humans as separate from ecosystems, similarly to Hamadah, but acknowledged that some people include humans as part of an ecosystem, acknowledging some of the tension with the term ecosystem that Tyler discussed.

The differences in the participants' perspectives of the relationship between humans and ecosystems following the capstone course indicate that this important issue may need to be addressed more directly in the class. The participants clearly discussed a shift toward more integrated conceptions of social and biophysical systems, but they still struggled with how to situate humans in relationship to ecosystems. Even though it can be beneficial to focus on certain scales or components of a SES for detailed analysis, without considering the larger picture, it is possible to fall into the problems of reductionist management practices (Holling and Meffe, 1996). Therefore, following the capstone course, the participants' conceptions still existed somewhere between Fig. 1a and 1b. The SES framework itself has been criticized by those in social science fields as being biased toward addressing social systems only from an ecological standpoint (Cote and Nightingale, 2012; Brown, 2014). Thus, it is possible that some of the conceptual challenges participants described grow out of the philosophical bias of SES and resilience theory. Explicit interventions that target students' pre-existing misconceptions and discuss criticisms of the SES and resilience theory may help further facilitate conceptual change in the capstone course (Posner et al., 1982).

Further research that analyzes how students conceptualize the human–ecosystem relationship throughout the capstone class is necessary to help identify existing student conceptions at the beginning of the class, and follow factors that influence these conceptions more closely throughout the class. Because we only conducted post-semester interviews in this study, we are limited in our ability to explore this result further. However, the results of this study have informed the study design and interview questions for a larger subsequent study for which we are analyzing conceptual change of the human–ecosystem relationship in more depth.

CONCLUSIONS

Participants' conceptions of (1) the overlap of social and biophysical systems and (2) the dynamic and cross-scale nature of resilience SESs changed during the semester-long capstone course. It was through opportunities for both dialogic (sharing of ideas) and dialectical (convincing one another of ideas) conversation, with both practitioners who visited the class and with classmates, that our participants revised these conceptions. It was through long-term assignments, bringing various voices into the classroom space, watching different stakeholders interact with one another that the participants became aware of the limitations of their own conceptions.

Both major concepts that shifted for students, (1) the overlap of social and biophysical systems and (2) the dynamic and cross-scale nature of resilience SESs, are key components of systems thinking and resilience management. Systems thinking cannot happen without each of these components facilitating an individual to change from linear thought to looking at the inter-relatedness of the components within a system. Therefore, these conceptions are vital to systems thinking (Meadows and Wright, 2008). Additionally, managing SESs as integrated overlapping social and biophysical scales is a key component of resilience thinking (Gunderson, 2000; Benson and Garmestani, 2011b). All of the participants described how interactions with stakeholders influenced their conceptions of the way biophysical and social systems overlap. Because the integration of stakeholders and different viewpoints is key to resilience management (Chapin et al., 2009), this conceptual shift helped participants build necessary skills for resilience management.

The NRM instructors can support student learning through meaningful classroom experiences that make explicit connections between theory and practice. Previously, Hiller Connell et al. (2012) found that prolonged engagement has been more effective in teaching undergraduates systems thinking, which is consistent with our findings. In our study, the participants' descriptions of their interactions with stakeholders and/or other NRM experts, clearly had an impact on their understanding of systems and resilience. Unscripted perspectives of guests reinforced both (1) the personal relevance of NRM issues for communities and (2) potential conflicting views that arise during NRM decision making. Even the simulation activities in which the class participated had a strong impact on some of the participants' learning, as the scenarios were rooted in real life situations. Through these opportunities the participants were able to develop more inclusive definitions of systems and resilience plausible and fruitful (Posner et al., 1982). Through their descriptions of their conceptions, students demonstrated socially embedded conceptual change (Posner et al., 1982; Lemke, 2001; Ivarsson et al., 2002).

A well-developed NRM capstone class is a key component in providing NRM students with the experiences that will help them thrive in jobs after graduation. Capstone classes can play an important role in facilitating student development of systems thinking skills. Previous studies that quantitatively assessed one time systems thinking interventions with undergraduates found that grappling with systems thinking problems in general, not intervention type, influenced learning outcomes (Jacobson et al., 2011; Monroe et al., 2015). Therefore, because college instructors' practices are not always aligned with their perceptions of their practices (Gess-Newsome et al., 2003), and qualitative analyses of undergraduate systems thinking have been limited in their conclusions (Jacobson et al., 2011; Hiller Connell et al., 2012; Remington-Doucette et al., 2013; Monroe et al., 2015) studies, such as ours, that qualitatively analyze student outcomes from a class implementing active and authentic learning strategies are particularly important to demonstrate the importance and effectiveness of moving beyond traditional teaching methods.

As with any study, there were some limitations that should be acknowledged. Remington-Doucette et al. (2013) found that student major was a larger predictor of systems thinking learning outcomes than pedagogical intervention. Because all of the participants in our study were NRM majors, we cannot comment on the influence of major on learning outcome. Due to convenience sampling, this study explored the conceptions of only three participants. Further studies are being conducted with up to 44 individuals who participated at varying levels. The current study enabled us to identify themes that informed our interview protocol for the larger, subsequent study.

We found that large conceptual shifts can occur in a NRM capstone class. One important finding is that the participants' conceptions of the relationship between humans and ecosystems were still limited at the end of the course, despite clearly struggling with this complex relationship during the course. The integration of humans in ecosystems is particularly important as those in NRM grapple with the effects of climate and human population change, and differing stakeholder views (LaChapelle et al., 2003). The NMR instructors should integrate instructional strategies that allow students to explore the interaction of anthropogenic and biophysical factors that influence ecosystems. Even though NRM professionals may focus on particular aspects of a system for analysis and management, it is vital that they are aware of the larger system their focus area is embedded within, and the ways in which changes to one part of the system or at one scale may affect other system elements or dynamics at other spatial and temporal scales

(Fig. 1b). Addressing current local issues, involving students in long-term student-directed group work, and inviting stakeholders to share their experiences can be powerful instructional strategies that influence students' conceptions of SESs. However, further research is necessary to identify more specific factors that influence how students conceptualize the relationship between humans and ecosystems.

Appendix: Interview Questions

1. Please describe your capstone course briefly.
2. Please define *system*, as you would define it right now (post-capstone course).
3. Please define *resilience*, as you would define it right now (post-capstone course).
4. Can you recall what your thoughts were about systems at the beginning of the semester (before the class)?
    a. Please describe what you remember.
    b. How were your thoughts challenged, reinforced, and/or extended throughout the semester?
5. Can you recall what your thoughts were about resilience at the beginning of the semester, (before the class)?
    a. Please describe what you remember.
    b. How were your thoughts challenged, reinforced, and/or extended throughout the semester?
6. For your large group project, including all of the components of your final project:
    a. Can you first generally describe your ideas about the project?
    b. How did your group's ideas shape your ideas?
    c. How did you help shape your group's ideas?
7. How did your group divide up the work required for the completion of the project?
8. Can you describe which readings or assignments in the capstone class helped your understanding of systems and resilience, or any other concepts?
9. Please describe how the work you did in NR 420 helped you be prepared for your current job.
10. Please describe if there were any aspects of NR 420 that were particularly beneficial in preparing you for the field of nrm.
11. What would have helped you be more prepared for working in the field of NRM that was not part of NR 420? Not part of your whole degree program?
12. Is there anything else you would like to add?

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