DISSERTATION

EXAMINING STUDENTS' SYSTEMS THINKING IN A NATURAL RESOURCES MANAGEMENT CAPSTONE CLASS

Submitted by

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[1] With the exception of the already published material in Chapter 2, which is presented here by permission of the journal.

ABSTRACT

EXAMINING STUDENTS' SYSTEMS THINKING IN A NATURAL RESOURCES MANAGEMENT CAPSTONE CLASS

Critical Literature Review

Humans undisputedly dominate Earth's ecosystems, therefore we need to move beyond 'human-free' conceptions of ecosystems. However, there is a lack of consensus about how humans, our influence, and our social systems fit within ecosystems, and several different terms, such as social-ecological system, are now used to describe integrated systems. The current proliferation of terms and lack of shared meaning causes problems for interdisciplinary researchers as well as students. I propose that our language needs to catch up with our conceptions, and that 'ecosystem' needs to be explicitly defined to include humans, our impacts, and our social systems.

Research Manuscripts

Natural resource management (NRM) decisions have far reaching implications for global ecological change. Because beliefs influence decisions, it is vital that the NRM curriculum reflects the shift to include humans as integrated components of ecosystems to facilitate effective future NRM, however no appropriate metric exists for assessment. Additionally, there is a concern that NRM students are not graduating with well-developed systems thinking, communication, and group work skills. Social-ecological systems (SES) are linked social and ecological systems, and graduates who are able to consider a SES as a whole are better able to address the complex problems in NRM.

I framed my research through the intersection of socio-cultural and conceptual change theories. Socio-cultural theory states that each individual's knowledge and experiences influence how they learn, and conceptual change theory describes the process individuals go through to replace existing conceptions with new conceptions. The intersection of these lenses imbeds conceptual change within an individuals' experiences and knowledge.

My guiding question was: how do students' conceptions of systems thinking change during a one-semester capstone class? Specifically, How do 1) 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? 2) NRM students situate humans in relation to ecosystems, and more specifically, to the term, ecosystem? 3) NRM students revise their conceptions of 'ecosystem' over the course of their capstone course?

I used phenomenological and grounded theory qualitative research approaches to study the Spring 2014 and 2015 NRM capstone classes at a large research university in the United States. I interviewed students, collected all coursework for analysis, audio recorded lectures, and obtained copies of all lecture presentation materials for analysis.

In my phenomenological study (n=3) I 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 and their semester-long group project. However, some students still held under-developed conceptions of ecosystems, which became the focus of the following two study manuscripts.

From student responses (n=20) and the course context I developed a continuum of human relationships to ecosystems for my metric to address question two: i) exclusion, ii) uncertain-exclusion, iii) uncertain, iv) uncertain-inclusion, and v) inclusion. My continuum provides a useful tool to help unpack the complexity of the human-environment relationship conception, which is a part of the ecological literacy construct.

To address research question three I used my continuum to identify how students' conceptions changed. I found that students' definitions of the relationships between natural and ecosystem, human, and human artifact influenced their conceptions of ecosystems. Students who did not describe ecosystems as natural struggled much less with an integrated human-ecosystem conception than those who described ecosystems as natural.

My overarching findings indicate that students can and do experience conceptual change throughout their capstone course. However, I found that students' conceptions and conceptual shifts were not always consistent with the material presented in the class. Therefore, it is important to teach from a constructivist standpoint (that each individual builds their own meaning of the world, which is influenced by their prior knowledge and experiences), and explicitly co-construct meaning in the classroom.

ACKNOWLEDGEMENTS

I would like to thank all of the people who helped me as I traveled through my winding path of my doctorate degree. Meena Balgopal, my adviser, took me on as a graduate student, even though I had no education research background, and who has guided me through the process of learning to stand with one foot in ecology and the other in education (quite literally as we jumped programs and departments). Maria Fernandez-Gimenez, my co-adviser, gave me a field site, and willingly collaborated through the challenging process of restructuring curriculum as I studied and taught the capstone class with her. The rest of my committee, Courtney Schultz and Rebecca Atadero, have given me guidance through my proposal and preliminary exams, and have been flexible with my slightly unusual degree timeline created by switching into GDPE as I finished my coursework.

I also thank all of the students who participated in my study. Without them, this work would not have been possible. One of the challenges in human-subjects research is participant consent, and I am very grateful to the 23 students who voluntarily gave their time to be interviewed, despite all of their time constraints as they prepared to graduate These students not only participated in the study, but taught me how to be a better teacher as we navigated the revised curriculum together.

Learning is a social process, as I discuss in the text of my dissertation. The other graduate students I have worked with, particularly those in both Dr. Balgopal's and Dr. Fernandez-Gimenez's labs, have helped me learn and grow as a researcher. In particular, Hailey Wilmer helped me develop my ideas through countless discussions as we both tried to navigate our own research and how to convey social science research within worlds were people really just want to know your p-value. Katie Boyd also helped me develop my ideas, and also helped me with inter-rater coding for my dissertation work.

Madeleine Lecocq has helped me in countless ways throughout my doctorate degree. She is an amazing editor, has probably heard more about my dissertation research than even Dr. Balgopal, and is great at reminding me that I still need dirt, water, and sunshine in my life. Maisie and Annie, our two border collies, helped in making sure I maintained some life-work balance, by reminding me that everyone needs to spend time walking on dirt paths amidst vanilla-scented ponderosa pines. I also could not have written this dissertation without the assistance of cat Mocha May's supervision, as well as Tihar, the guinea pig (whom we inherited when his people moved), who has kept me company for endless hours of typing.

PREFACE

This dissertation is written in journal article format. Chapters 1 through 4, as well as appendix IV will be submitted for publication. Chapter 1 is a critical literature review written for the 'concepts and questions' section of Frontiers in Ecology and the Environment (FEE). This section is specifically for short "review-type papers which showcase ideas not yet widely accepted by the scientific community," as per FEE's author guidelines. Chapters 2, 3, 4, and appendix IV are all research papers from my primary research. Chapter 2 is already published in Natural Sciences Education, chapter 3 is in review in Ecosphere, and the rest of the chapters will be submitted in the near future. The target journal and any length restrictions for each chapter are noted in a footnote on the title page of the chapter.

Due to the interdisciplinary nature of my work, I am submitting manuscripts to journals with different audiences. Each chapter was written with the specific target audience and standard manuscript headings in mind. The most notable difference between chapters is how I address my theoretical framework sections. While not all of the chapters have an explicit have a theoretical framework section, chapters without an explicit section have theoretical frameworks embedded in the introduction and/or methods section.

In addition to the standard dissertation chapters, this dissertation also includes appendix IV, with additional data that is in the process of being developed into its own manuscript. While at the Annual Conference of the (inter)National Association of Research in Science Teaching in mid-April, I was inspired by some of the sessions I attended, and realized a better way to structure chapter 4. This shift led to a stronger manuscript, but included re-writing large sections of chapter four. As part of this change, one of the original findings for chapter 4 will now be developed into its own manuscript.

DEDICATION

I dedicate this dissertation to all of the people in my life who encouraged me to always explore the world around me, those who helped me explore ‘why,’ rather than telling me to stop asking. My parents and many others helped me to develop my own conception of myself within the world. Many of my earliest memories include turning over rocks to look for bugs, discovering countless tiny snails in pond algae, saving worms from puddles, trying to wrap my four year old brain around the amazing symbiosis that is a lichen, and other things that usually involved water, dirt, and sunshine. I include in this dedication a large group of influential people who existed in my life almost exclusively pre-memory – all of my nursery school teachers (some of whom were early childhood development researchers). I went to nursery school at Vassar College, and I used to joke that I did my four years of college before first grade. But, my experiences there – between the teachers/researchers, college students, and a peer group who mostly had at least one parent with a Ph.D. - somehow left me with the assumption that obviously I would complete a Ph.D. when I grew up, it was just what people did.

I also dedicate this dissertation to Jane Aileen Richardson Winchester. She provided a sense of ever-present encouragement the summer she spent with us as I studied for my prelims. She was ever-patient watching me work, and could not have been prouder, or my confident in me as I completed my prelims and worked on my dissertation. My life was incredibly enriched by her presence.

TABLE OF CONTENTS

CHAPTER 1: ECOSYSTEM: SHARED LANGUAGE, DISPARATE MEANINGS[2]

Framing the Problem

Human domination of Earth's ecosystems has been undisputed in the ecological literature for over a decade (Rockstrom et al., 2009; Vitousek, Mooney, Lubchenco, & Melillo, 1997). Climate change, biodiversity loss, and changes in the nitrogen cycle have all exceeded proposed 'safe' boundaries of these systems, and ocean acidification, change in land use, global freshwater use, and the phosphorous cycle are all moving towards exceeding these boundaries (Rockstrom et al., 2009). Humans are fundamentally changing ecosystem interactions on a global scale (Alberti et al., 2003; Chapin et al., 2011). Therefore, it is vital to move beyond the 'human-free' conception of ecosystems, where humans are external drivers, and include, as integrated components, humans, human impacts, and human social systems as researchers, managers, and all people interact with, study, and manage the earth (Alberti, 2008; Chapin et al., 2011; Liu et al., 2007).

'Ecosystem' has entered the colloquial American lexicon and is used in broad interdisciplinary contexts. The basic definition is simple – abiotic and biotic factors and their interactions within a given boundary (Ricklefs & Relyea, 2014). Ecosystems exist across many scales, from a drop of water to the entire globe. Yet, there is little consensus on how humans, our influence (including our artifacts, the things we produce), and our social systems relate to the ecosystem concept. We argue that the lack a consistent and shared meaning of the term ecosystem must be resolved because of its negative influence on collaborative research across

[2] In preparation for submission to the 'Concepts and Questions' section of Frontiers in Ecology and the Environment. Maximum length: 3,000 words and 30 references.

the disciplines (Druschke & McGreavy, 2016) and the education of natural science and resource management college graduates (Anne Marie A. Casper, Balgopal, & Fernandez-Gimenez, 2016, Casper et al. unpublished manuscript).

A plethora of related, sometimes synonymous terms, have been developed within different disciplines to try to clarify systems that include humans and/or social systems, such as social-ecological system, socio-ecological system, human ecosystem, urban ecosystem, and coupled human and natural system (Binder, Hinkel, Bots, & Pahl-Wostl, 2013; Druschke & McGreavy, 2016; Liu et al., 2007; Pickett et al., 2001). However, the meaning of these terms can vary (Liu et al., 2007; Scholz & Binder, 2011), creating the potential for confusion (Druschke & McGreavy, 2016). Furthermore, terms that specify ecosystems in addition to social/human systems can lead to the misconception that humans are separate from our environment, rather than integrated (Scholz & Binder, 2011). Terms such as 'human ecosystem' have been suggested to avoid this incorrect interpretation. However, 'human ecosystem' still implies that there are ecosystems free of human influence, which researchers argue, no longer exist (Rockstrom et al., 2009; Vitousek et al., 1997). Even seemingly untouched ecosystems, such as those deep in the oceans, are likely influenced by global changes. Alterations in the global nitrogen, phosphorous, and carbon cycles have far reaching effects on a global scale (Rockstrom et al., 2009). Fossil record evidence from previous abrupt global climate changes shows that even deep see biota are influenced by changing ocean temperatures at decadal to century timescales (Yasuhara, Okahashi, Cronin, Rasmussen, & Hunt, 2014).

Broad interdisciplinary collaboration is vital to address our current global challenges (Alberti et al., 2003; Druschke & McGreavy, 2016; Vitousek et al., 1997), but effective interdisciplinary collaboration requires collaborators to create shared meaning across disciplines (Druschke &

McGreavy, 2016). Shared meaning, though, is dependent on commonly accepted terms, which describe shared conceptions.

Historical Roots

The challenge of conceptualizing and describing the systems ecologists study is as old as the discipline itself (Golley, 1993). Early researchers, such as Forbes, Cowles, and Clements, attempted to define the boundaries of the systems they studied, and to develop terminology to describe those systems and the interactions within them (Clements, 1936; Hagen, 1992; Tansley, 1935). Tansley first published the term ‘ecosystem’ in 1935. At the time, scholars discussed whether animals should be included in designations of biotic communities (Golley, 1993); therefore, Tansley’s assertion that ecologists should frame their research in terms of ecosystems stepped beyond much of the dialogue in which he was immersed (Hagen, 1992). He was unsatisfied with existing terms researchers were using (e.g., quasi-organism, biotic community, complex organism, biome, and biocenosis) because felt he felt that these terms were insufficient, colloquial, or limited in scope. Therefore, he believed it was necessary to develop a new concept, the integration of biotic (organisms, living and dead) and abiotic (non-living) factors within the system, and a new term, ecosystem, to foster the development of the field of ecology.

Although Tansley argued for the importance of the ecosystem concept, he discussed it only theoretically and did not use it for research (Hagen, 1992). Lindeman (1942) was the first researcher to use the term ecosystem as a conceptual basis for a quantitative study, in his classic study of a lake ecosystem (Hagen, 1992). Because Lindeman (1942) studied the movement of energy within a lake system, Tansley’s concept was necessary. Despite Lindeman’s emphasis on the ecosystem as a grounding construct for ecological research, the concept did not become widespread until Odum used it in his text, *Fundamentals of Ecology*, published in 1953 (Odum, 1953). Odum continued to further develop the concept of ecology in his text and its multiple editions (Golley, 1993). He specified that ecosystems exist across many scales and that humans have the power to alter ecosystems, embedding us within the complex biogeochemical (biological, geological, and chemical) cycles that are fundamental to ecology (Golley, 1993). Hence, a new generation of ecology students learned that humans have some role in ecological systems.

Current Challenges

Conceptions shift and grow as scientists generate new knowledge. In the interdisciplinary fields of ecology, biology, and natural resources, which study global change, the scope of studies is continually being described and defined (Figure 1.1). Over time, the initial conception of ecosystem has also evolved (Golley, 1993; Silvey, Kirby, & Smith, 2015). We argue that the conception of ecosystem faces new challenges, and that we should explicitly include humans, human impact, human artifacts, and human social systems within the environment we inhabit (Figure 1.1). As our colleagues in ecological, natural science, and environmental fields use a plethora of synonymous terms that will likely coalesce again, it is time for the ecological science community to articulate and clarify our shared conceptions and associated terminology. Failure to do so will inhibit effective interdisciplinary collaboration (Druschke & McGreavy, 2016), and pose conceptual challenges for students as they try to navigate multiple conceptions of the same term in the classroom (A. M. A. Casper, Fernandez-Gimenez, & Balgopal, in review). Humans and human influence are clearly integrated in the conception of ecosystems in some research (Alberti et al., 2003; Bridgewater, 2016; Pickett et al., 2001; Rockstrom et al., 2009; Sarrazin & Lecomte, 2016; Vitousek et al., 1997), as well as newer editions of ecology textbooks (e.g., Ricklefs & Relyea, 2014). Additionally, some researchers now use the Anthropocene explicitly within their research (Bridgewater, 2016; Sarrazin & Lecomte, 2016; Waters et al., 2016). However, these examples are all focused on physical systems, and do not explicitly address or include human social systems.

If the current concept of ecosystem clearly included humans, and human influence, artifacts, and social systems already, terms such as social-ecological system, human ecosystem, and coupled human and natural systems would not have been developed. It is telling that even though ecological researchers are using ecosystem to include humans and human impacts, the alternative terms to ecosystem, with the exception of urban ecosystem, all came out of fields beyond ecology. This indicates that researchers in fields such as natural resource management and political science found the existing conception of ecosystem deficient. Because the alternative terms came out of non-ecological disciplines, and these terms are used across disciplines, including the social sciences, the unified term needs to effectively frame research in diverse disciplines.

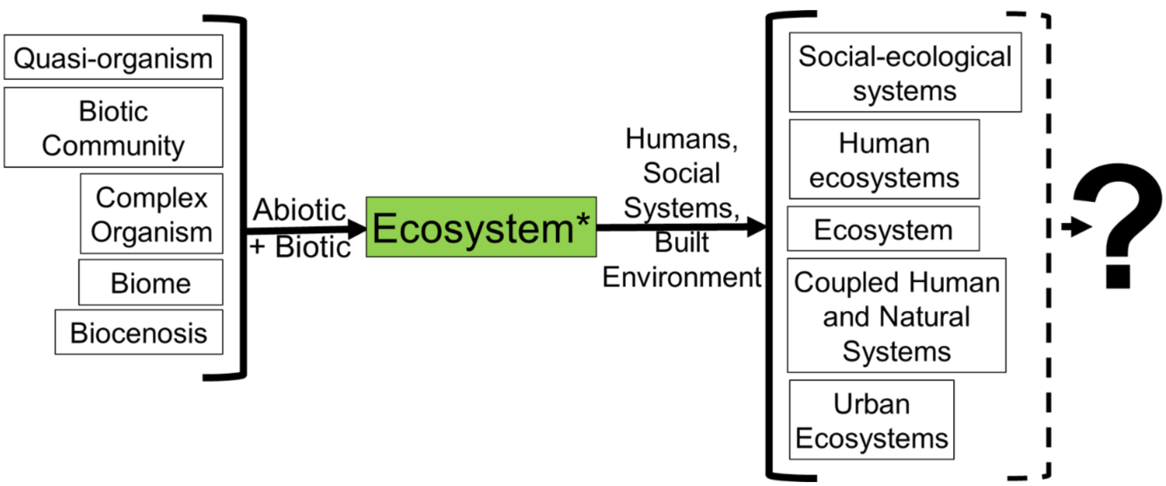

Figure 1.1: Development of the ecosystem concept over time. In the 1920s and 30s there were many different terms developed to describe the systems ecologists study. Tansley identified the importance of including both abiotic and biotic factors within the systems of study, and first published the term ‘ecosystem’ in 1935. Currently, we are in an era where the proliferation of terms to specify areas of study that include ecosystems, humans, social systems, and human artifacts. We, as authors, argue that we need to create a clearly shared conceptions across the

disciplines. *Tansley argued that humans and human impact needed to be included within ecosystems.

A Proposed Resolution

We propose, much like Tansley did for abiotic components in 1935, that humans, human influence, and human artifacts are all components of an ecosystem. We further argue that social systems are also an inextricably integrated component of ecosystems, echoing voices such as Kitcher (2004), who claimed that ecological research cannot be effectively performed without addressing the social and cultural contexts in which it is imbedded. This integrated conception is already being called for by some researchers, particularly those who study urban ecosystems (Alberti, 2008; Alberti et al., 2003; McDonnell & Pickett, 1997; Pickett et al., 2001). Explicitly expanding the ecosystem concept to include humans, our influence, and our social systems, follows the tradition of critically examining how we conceptualize and describe the earth and its systems. We are not stuck with Clements' initially deterministic ideas of succession and climax communities, even though we still use some of his language today (Clements, 1936; Ricklefs & Relyea, 2014); as such, we should be willing to shift and develop our conceptions of ecosystems as well.

On a basic level the existing definition of ecosystem already aligns with our proposed definition. Humans are biotic, and human artifacts are derived from abiotic and biotic factors. We are not the only organisms that manipulate our environment – beavers and other organisms vastly change the landscape too; nor, are we the only social animals (Ricklefs & Relyea, 2014). Therefore, there is nothing inherent in the ecosystem concept that excludes humans, our influence, and our social systems, if we stick with Tansley's (1935) initial conception. Indeed, it is quite the opposite.

Era of Anthropogenic Change

The issue of an integrated conception of ecosystem has become more pressing, since we have reached a point where humans now dominate ecosystems globally (Rockstrom et al., 2009; Vitousek et al., 1997; Waters et al., 2016). While the multiple terms developed to describe integrated social or human and environmental systems may seem to be the answer (Figure 1.1), they leave room for the concept of an ecosystem that exists independent of human influence, or conversely, a human system that exists independent of ecosystems. Additionally, the way these alterative terms (such as social-ecological systems) are often depicted as separate but linked domains in diagrams (Figure 1.2a, simplification of *Ojima et al.*(2005)) needs to change towards an integrated an imbedded depiction as well (Figure 1.2b). With our proposed conception we see existing specialized terms that describe integrated human and ecological systems as being helpful for describing a specific research focuses within an ecosystem, helping to shift ideas and depictions from Figure 1.2a to 1.2b.

Urban ecologists, who study ecosystems in areas heavily inhabited and altered by humans, have long been making strides to analyze the less obvious influences that humans have on ecosystems (Alberti, 2008; Alberti et al., 2003; McDonnell & Pickett, 1997; Pickett et al., 2001). While some effects are obvious, there are many less obvious ways people change their environments, including: *indirectly* (e.g., through influences that mediate other interactions); *historically* (e.g., through past management actions); *lagged effects* (e.g., chlorofluorocarbon release and the ozone hole, when there is a time lag between an action and a result); and *unexpected action at a distance* (e.g., many current global changes that can be particularly pronounced when migratory species are involved) (McDonnell & Pickett, 1997). These subtle factors also describe many of the ways humans influence ecosystems that would otherwise seem ‘pristine’ and ‘untouched.’

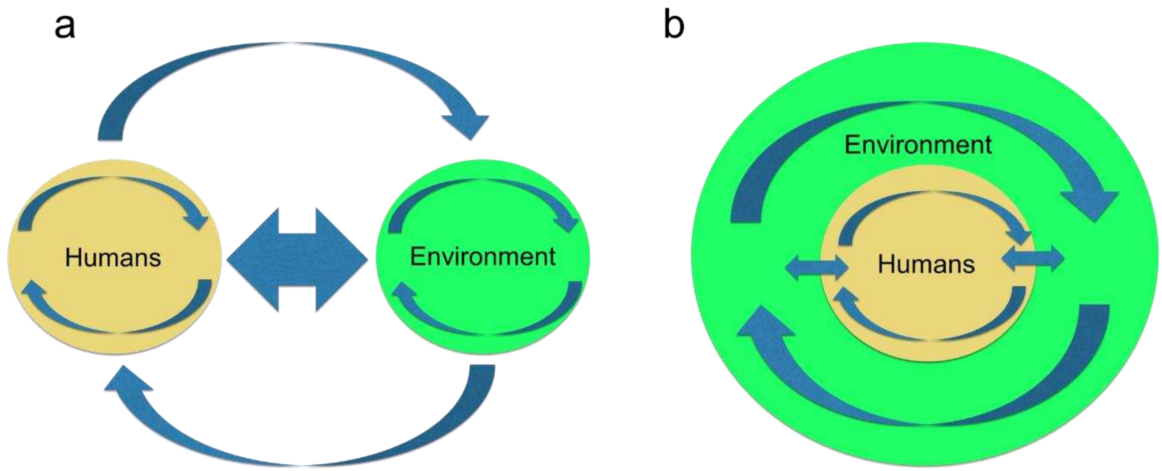

Figure 1.2: It is important to shift our diagram structure of humans within our environment along with our language. Human-environment systems are often currently depicted separately (a, simplification of Ojima et al.(2005)), but need to be presented in integrated pictures, consistent with integrated language (b).

We are now in the Anthropocene, a geologic era characterized by global human influence (Waters et al., 2016). Modern humans have shifted global cycles and geologic formations to the point where there are clear demarcations between the present and pre-industrial ages (Rockstrom et al., 2009; Waters et al., 2016). We are also responsible for unprecedented shifts in the extinction rates of other organisms (Rockstrom et al., 2009). Additionally, unlike any previous known organism, humans have the ability to make intentional decisions about how we interact with our environment based on our knowledge of future global ramifications, either through focusing on short term gain for our own species, or basing our decisions on their effect over a larger physical and temporal scales (Bridgewater, 2016; Sarrazin & Lecomte, 2016). Therefore, it is even more important that we see ourselves and our social systems and choices as embedded within global ecosystems. Ideas of ‘pristine’ and ‘untouched’ must be left in the past – ‘unaltered by humans’ is an ecological state no longer relevant, which has not existed for a very long time

(Pausas & Keeley, 2009) Indigenous peoples have manipulated and managed ecosystems around the globe since as least the Mesolithic period, altering ecosystems on a landscape scale (Pausas & Keeley, 2009). Humans were components of ecosystems thousands of years ago, and we continue to be today.

Framing Research within Ecosystems

We propose that ecosystem should be used as a broad, encompassing term. Yet, we acknowledge that specialized constructs are needed for research *within* ecosystems. Clearly work in ecological and social sciences requires different types of framing. Therefore, we agree with Binder et al. (2013) that different frameworks are needed to appropriately address research questions from different angles. However, as Binder et al. (2013) acknowledge, there is a difference between the overall description of a system and the framework used to analyze it. Additionally, existing frameworks for analyzing social and ecological systems are limited, and fall short in encompassing the entire integrated system (Binder et al., 2013). These frameworks are generally either more ecologically or more human focused; only one of the ten Binder et al. (2013) reviewed had the possibility of being used to address both equally. While different research questions dictate different perspectives, starting with an inclusive system will add clarity to communication and collaboration across disciplines.

We propose that the broad field of ecology is already moving towards an integrated system conception, which can be analyzed through diverse research frameworks. It is necessary for the language we use to catch up with changing conceptions. The current diversity of conceptions surrounding the term ‘ecosystem,’ as well as the number of terms developed to describe integrated systems, does not serve the larger interdisciplinary community well (Figure 1.1) (Druschke & McGreavy, 2016). There are inherent differences between the types of research and research questions one can address in natural and social science research. Specialized terms that have been developed to describe integrated social and ecological systems, such as SES, are already criticized by social science researchers for their limitations and assumptions (Brown, 2014; Cote & Nightingale, 2012; Davidson, 2010). Studying humans through a lens developed for ecosystems is limited for several reasons including: 1) how reality and knowledge are framed, 2) human agency, 3) issues of culture and power, and problems with decontextualized knowledge (Brown, 2014; Cote & Nightingale, 2012; Davidson, 2010).

By explicitly expanding the concept of ecosystem to broadly define a study system, we argue for an inclusive construct of the system that we investigate, which can be studied through diverse lenses. This shared construct will lower barriers to interdisciplinary research, by helping researchers create shared meanings of the overarching system. As researchers with training in both the social and natural sciences, we often work at the intersection of fields and are, therefore, are aware of subtle differences. We call on our colleagues to ensure that our language matches our conceptions, if we hope to 1) foster more interdisciplinary research and 2) prepare new graduates to do so.

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CHAPTER 2: NATURAL RESOURCE MANAGEMENT STUDENTS' PERCEPTIONS OF CONCEPTUAL CHANGE IN A CAPSTONE COURSE[3]

Introduction

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) (Bosch, King, Herbohn, Russell, & Smith, 2007; Sample, Block, Giltmier, & James, 1999; 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, McCool, & Patterson, 2003). 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, Janssen, & Ostrom, 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 of 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 & Wright, 2008). However, undergraduate students sometimes struggle to understand what a system is and how components of systems interact

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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, Goralnik, & Thorp, 2012; Remington-Doucette, Hiller Connell, Armstrong, & Musgrove, 2013). Even if undergraduate students have been taught about ecosystems, systems made up of abiotic and biotic elements that interact with one other within defined boundaries from micro to global scales (Chapin, Matson, & Vitousek, 2011), they may not have been taught about systems at a conceptual level.

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). SESs have multiple stable states, meaning there are different ways that the systems can function (Meadows & Wright, 2008), and therefore function 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 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 (B. Walker, Holling, Carpenter, & Kinzig, 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; B. H. Walker & Salt, 2006). Because we, as humans, are inherently part of any systems 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 (Estes et al., 2011; Holling & 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 (DeRose & Long, 2014; B. Walker, Abel, Anderies, & Ryan, 2009). 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 (DeRose & Long, 2014; B. Walker et al., 2009). 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 (B. 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 & 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 for something to ‘bounce back’ to its original state (Benson & Garmestani, 2011b). While 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 & Meffe, 1996).

Resilience theory emerged in the NRM literature in the 1990s (Berkes & Folke, 1994), and became more prevalent moving into the 2000s (B. Walker et al., 2004). The move towards 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 (Fazey, 2010; Meadows & Wright, 2008). Despite these challenges, a broad perspective that integrates SESs and resilience theory is vital for effective NRM (Chapin, Kofinas, & Folke, 2009; Krasny, Lundholm, & Plummer, 2010; LaChapelle et al., 2003).

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 (Chapin et al., 2009; Holling & Meffe, 1996). Since the 1990s, there has been a shift towards managing ecosystems for multiple ecological benefits, rather than commodity production alone. More recently this shift has been accompanied by a move towards managing systems as interconnected wholes using systems thinking and resilience management (Chapin et al., 2009; Holling & Meffe, 1996; B. H. Walker & Salt, 2006).

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, Burbach, Matkin, & Flores, 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 & 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. 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 & Harrison, 2002). Existing literature on NRM capstone courses focuses on reporting pedagogical strategies, but these strategies are not rigorously evaluated (Arthur & Thompson, 1999; Berkson & Harrison, 2002; Habron et al., 2012; Pile, Watts, & Straka, 2012; Prokopy, 2009; Yeon-Su, Dewhurst, & Hospodarsky, 2007). 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 & Thompson, 1999; Berkson & Harrison, 2002; Habron et al., 2012; Pile et al., 2012; Prokopy, 2009; Yeon-Su et al., 2007). 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 (Costa & Rangachari, 2009; Hmelo-Silver, 2004; Lemke, 2001). 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, National Research Council (U.S.), & National Research Council (U.S.), 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 & Sinatra, 1998). Instructional strategies that facilitate metacognition, such as reflective writing, drawing, diagramming, and speaking activities, have been associated with conceptual change (Balgopal, 2014; Georghiades, 2000). 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). While 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 and 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 natural resources 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; however, 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 hand-outs 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.

Research Methods

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 participant's 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 I).

The interview transcriptions were analyzed using Discourse analysis, following Gee's (2014) framework. 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 student's 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 (Ivarsson, Schoultz, & Saljo, 2002; Lemke, 2001).

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 as well as 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.

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 (1st and 3rd), member checking at the time of the interviews, peer debriefing amongst 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 prior to 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 (Figure 2.1a), 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 (Figure 2.1b). The two instructional interventions which 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 (Figure 2.1). 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.

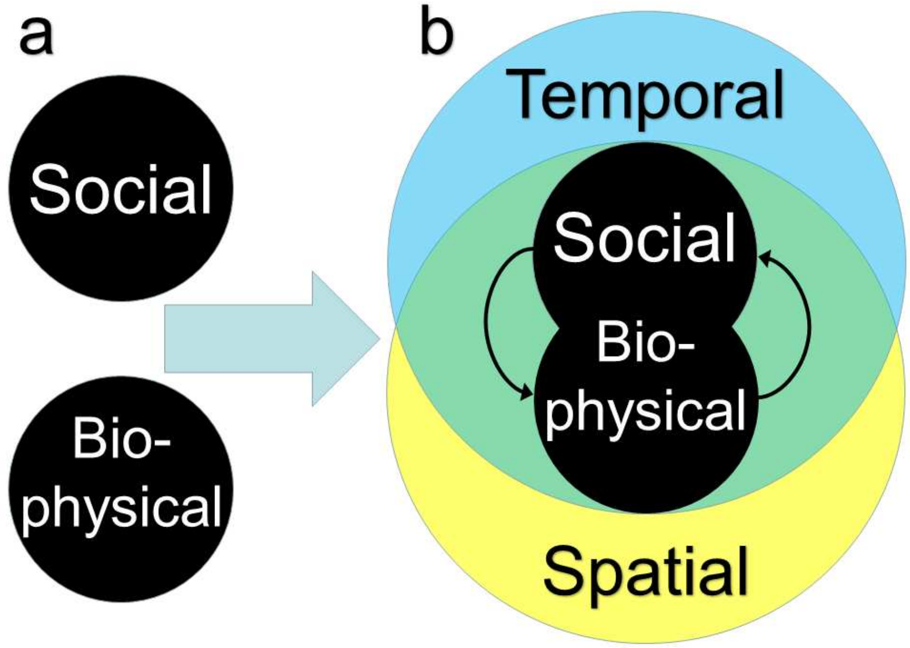

Figure 2.1: Participants' conceptions of biophysical and social systems shifted during the capstone course. Participants initially saw biophysical and social systems as separate (a). However, the participants described their conceptions of biophysical and social systems as becoming more integrated and imbedded within temporal and spatial scales during the NRM capstone course (b).

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 as 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 towards "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 & Holling, 2002). While 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 & 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 (Figure 2.1). 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 (Figure 2.1). 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 maybe 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," and 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 Connel et al.'s (2012) findings 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 (Chi, 2005; Lemke, 2001). 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 discusses.

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. While the participants clearly discussed a shift towards more integrated conceptions of social and biophysical systems, 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 & Meffe, 1996). Therefore, following the capstone course the participants’ conceptions still existed somewhere between Figure 2.1a and 2.1b. The SES framework itself has been criticized by those in social science fields as being biased towards addressing social systems only from an ecological standpoint (Brown, 2014; Cote & Nightingale, 2012). Therefore, 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 & Wright, 2008). Additionally, managing SESs as integrated overlapping social and biophysical scales is a key component of resilience thinking (Benson & Garmestani, 2011a; Gunderson, 2000). 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.

NRM instructors can support student learning through meaningful classroom experiences that make explicit connections between theory and practice. Previously, Hiller Connel 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 (Ivarsson et al., 2002; Lemke, 2001; Posner et al., 1982).

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, Kapur, So, & Lee, 2011; Monroe, Plate, & Colley, 2015). Therefore, because college instructors' practices are not always aligned with their perceptions of their practices (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003), and qualitative analyses of undergraduate systems thinking have been limited in their conclusions (Hiller Connell et al., 2012; Jacobson et al., 2011; Monroe et al., 2015; Remington-Doucette et al., 2013) 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 and colleagues (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). 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 (Figure 2.1b). 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.

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CHAPTER 3: MEASURING ECOLOGICAL LITERACY OF NATURAL RESOURCE MANAGEMENT STUDENTS: HUMANS AS AN INTEGRATED COMPONENT[4]

Introduction

In the midst of current global change, natural resource (NR) managers make management decisions that can have far-reaching ramifications for future environmental change (Rockstrom et al., 2009). Currently there is a shift in NR management (NRM) towards understanding and managing ecosystems as dynamic, interconnected, and inclusive of humans, rather than as static, single-species focused, and without human influence in their "pristine" state (Meffe, 2002; Walker & Salt, 2006). This paradigm shift follows the field of ecology, which has also adopted a conceptualization of humans as an integrated part of ecosystems (Chapin, Matson, & Vitousek, 2011). Further, Kitcher (2004) has called for biologists, and scientists as a whole, to consider the social ramifications of their research, and Alberti et al. (2003) stated 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" (p. 1172). Therefore, tools to measure students' conceptions of complex systems can help NRM and ecosystem educators assess how to best guide learning.

Beliefs influence behaviors (Stern, 2000), and if NRM students believe humans are separate from ecosystems, instead of integrated parts of these systems, their professional decisions will reflect this. This is problematic because when ecosystems are viewed as collections of separate parts, and humans are considered external to the system, NR managers often miss the underlying factors driving a system's existing state, which results in ineffective or destructive management

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strategies (Alberti et al., 2003; Estes et al., 2011; Meffe, 2002). Balgopal et al. (2012) found that biology students frequently framed ecological problems as something that others should solve, indicating that those undergraduates did not see themselves as agents of change capable of influencing ecological issues through their personal or professional decision-making. Furthermore, the communication of complex issues as simple false dichotomies can lead to poor decision making by the public and undermine the credibility of scientists and NR managers when systems do not respond as expected (Kueffer & Larson, 2014). While citizens need sound ecological knowledge to make informed decisions and interpret information from NR managers and scientists (Jordan, Singer, Vaughan, & Berkowitz, 2009), because of the far-reaching impact of NR managers' decisions, it is vital that NR managers base their decisions on solid ecological foundations.

Holistic Conceptions

The way ecologists describe and frame the systems they study has evolved over time (Chapin et al., 2011). The term 'ecosystem' itself arose out of shifting ideas about how to define and delineate natural systems, when Tansley (1935) argued that the term 'ecosystem' was necessary to explicitly include abiotic factors. Even though Tansley's (1935) initial description of an ecosystem included anthropogenic influences, ecologists have largely excluded humans from their studies (Machlis, Force, & Burch, 1997). Therefore, the philosophical shift towards a holistic perspective of ecosystems that explicitly includes humans, including social context, continues an important tradition of questioning and redefining how we delineate our study systems (Chapin, Kofinas, & Folke, 2009; Kitcher, 2004; Machlis et al., 1997)

This philosophical shift towards a more inclusive understanding of ecosystems has begun to shape various, related scientific disciplines, including biology, ecology, and NRM (Alberti et al., 2003; Berkes & Folke, 2002; Chapin et al., 2011; Kitcher, 2004; Machlis et al., 1997). Holism, according to Wilson (1998), is a philosophical approach to understanding natural systems and allows researchers to consider multiple levels of processes that may produce emergent properties. The inclusion of the Anthropocene and discussion of humans as part of ecosystems in recent editions of ecology textbooks (Chapin et al., 2011; Ricklefs, 2008) are further evidence that conceptions of ecosystems in science is becoming more inclusive and holistic in its conception of ecosystems, explicitly recognizing the role of humans. Concurrently, through new management philosophies, academic discussion in NRM is shifting towards the term social-ecological system (SES), which explicitly encompasses both ecosystems inclusive of humans, as well as the social systems that are dependent upon a given ecosystem (Chapin et al., 2009). Creating common language and meaning is a key component of interdisciplinary work. (Druschke & McGreavy, 2016). Because of the way ecosystem and SES are used synonymously in the literature of different fields (Alberti et al., 2003; Berkes & Folke, 2002; Liu et al., 2007; Risser, 1986), we treat an integrated concept of ecosystem and SES as different terms for the same underlying conception—an integrated human-ecological system.

Historically in the United States, NR managers have approached management from a reductionist, single-species, "command and control" stance, which predicts a linear cause-and-effect relationship between management actions and results, and may be economically driven (Holling & Meffe, 1996). However, since the 1980s, NR management philosophy has broadened to include more holistic philosophies including adaptive management, ecosystem management, resilience management (Folke et al., 2002; Grumbine, 1994; Gunderson, 2000; Walters, 2001; Williams, 2011b). Adaptive management uses 'management experiments' to manage dynamic systems, in a structured, deliberate process for adjusting management strategies based on learning from the outcomes of these experiments (Walters, 2001; Walters & Holling, 1990; Williams, 2011a). Ecosystem management is similar to adaptive management, without necessarily using 'management experiments' in as strict a manner (Boyce & Haney, 1997). Resilience management builds upon both adaptive management and ecosystem management (Boyce & Haney, 1997; Chapin et al., 2009; Gunderson, 2000)(Boyce and Haney 1997, Gunderson 2000, Chapin et al. 2009). It emphasizes three core management principles: 1) adaptation and renewal in response to change, 2) social change dynamics, including human-ecosystem relationships, and 3) the role of resource managers as stewards shaping change in social-ecological systems (Boyce & Haney, 1997; Chapin et al., 2009; Gunderson, 2000). Particularly due to the philosophical shifts in how human-ecosystem relationships are conceptualized, some experts argue that traditional, content-focused NRM coursework may not sufficiently integrate social and ecological systems (Bosch, King, Herbohn, Russell, & Smith, 2007).

Ecological Literacy

There are many constructs that describe relationships between knowledge, beliefs, and behaviors relating to human/environment interactions, including ecological literacy, environmental literacy, and ecoliteracy (Long et al., 2014; McBride, Brewer, Berkowitz, & Borrie, 2013). Ecological literacy was first introduced by Risser (1986) while addressing the Ecological Society of America, and unlike environmental literacy and ecoliteracy, it is directly rooted in the ecological sciences. Since its inception, ecological literacy has included the integration and interaction of social and ecological systems (Risser, 1986). In contrast to ecological literacy's initial integrated nature (Risser, 1986), other authors have not always included social systems in discussions of ecological literacy (McBride et al., 2013).

Due to the diverse definitions of ecological literacy, we needed to define ecological literacy explicitly in our research. In this study, we used Balgopal and Wallace's (2009) definition, "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 (p. 14-15).

Despite the importance of ecological literacy in the environmental education literature (Balgopal & Wallace, 2009; Duailibi, 2006; Lewinsohn et al., 2015; McBride et al., 2013), our literature review revealed few metrics for measuring ecological literacy. The metrics we found were generally close-ended, and focused on content knowledge and/or beliefs about human interactions with nature (Bogan & Kromrey, 1996; Davidson, 2010; Keynan, Ben-Zvi Assaraf, & Goldman, 2014; Morrone, 2001; Pe'er, Goldman, & Yavetz, 2009). None of the metrics directly addresses our area of interest: a system-level conception of ecosystems that includes humans.

Jordan et al. (2015) extended the concept of ecological literacy and developed the Ecological Nature of Science (ENOS) framework. Our research is different from Jordan et al.'s (2015) because we are examining undergraduate science majors, not high school students, and we are interested in conceptions of integrated social-ecological systems, not ecological content knowledge.

Our study population, undergraduate NRM majors, had extensive exposure to ecological content through their coursework, thus content metrics would simply measure information retention. Existing metrics are not appropriate for students in NRM because 1) students likely already possess general ecological and environmental knowledge, 2) metrics may not sufficiently include integrated social and ecological systems, and 3) students may see their personal beliefs and behaviors as separate from their professional decision-making processes. Therefore, to assess NRM students' ecological literacy, and specifically conceptions of ecosystems that integrated humans and the environment, we needed to develop a more inclusive ecological literacy metric.

We based our study in "ecological literacy" research for several reasons, even though many NR managers often frame their management in terms of SES. NR managers work with diverse stakeholders, and an ecosystem framework is used more broadly across disciplines. As such, ecological literacy is an established construct, and students have been developing their conceptions of ecosystems throughout their studies (SESs were novel to some of our students).

Studying Student Conceptions

Because we sought to describe the way students describe their conceptions of *ecosystems*, we used the intersection of socio-cultural and conceptual change theories as a lens to explore individuals' conceptions (K. Charmaz, 2005; Chi & Roscoe, 2002; Lemke, 2001; Posner, Strike, Hewson, & Gertzog, 1982). Socio-cultural theory states that social experiences throughout our lives provide a vital context that allows us to learn through social interactions (Lemke, 2001). Socio-cultural theory frames science as a human activity that is embedded in historical and cultural contexts, and as such, each individual's social and cultural background influences the way he/she interacts with others to make meaning (Lemke, 2001). In other words, socio-cultural theorists argue that people do not learn in a vacuum. Rather, conceptions are developed through communication with others, observations of natural phenomena, and opportunities to assimilate and make meaning of new information (Lemke, 2001).

Sometimes learning involves acquiring new conceptions, but it may also involve replacing or extending an existing conception, a process termed conceptual change. To experience conceptual change an individual must be dissatisfied with their existing conception, and find the new conception to be intelligible, plausible, and fruitful (Posner et al., 1982). Due to the socially embedded nature of learning, isolated conceptual change is short-lived, if not supported by a larger context, where students have a chance to transfer ideas to new examples and practice using their new conceptions (Dole & Sinatra, 1998).

Both theories are relevant to our study, because students' conceptions of ecosystems are influenced by their prior experiences and the way they interact with others to make meaning (Lemke, 2001). Because final year NRM undergraduate students have at least worked with the concept of ecosystems throughout their time as undergraduates, they likely have established conceptions of the construct, making it difficult to promote conceptual change if students have misconceptions (Chi & Roscoe, 2002; Posner et al., 1982).

Research Question

In a previous study, we found that the way participants situated humans in relationship to ecosystems varied after students completed a capstone course (Casper, Balgopal, & Fernandez-Gimenez, 2016). The three conceptions identified were: 1) humans are separate from ecosystems, 2) humans are separate from the ecosystems, but some people include humans as part of ecosystems, and 3) uncertain of the relationship (Casper et al., 2016). Based on our previous finding that students were not conceptually committed, we determined that a deeper exploration of how students conceptualize the human-ecosystem relationship was warranted. To develop an ecological literacy assessment metric, we designed our study around the research question: What is the range of conceptions of ecosystems (i.e., their ecological literacy) that students convey in the NRM capstone class?

Methods

Study Context

We conducted our study across two semesters of an NRM capstone class (n=37, 45) at a large land-grant university in the Rocky Mountain region of the U.S. Most of the students enrolled in the course were NRM majors, and the non-NRM majors were all Rangeland Ecology majors. The NRM major requires students to have a minor or a second major; the students' minors in the class varied widely across NRM-related disciplines, giving students diverse coursework backgrounds (Table 3.1). Of the students who participated in the study (n=23), 18 were NRM majors only, four had a second major (Forest Biology, Agricultural and Resource Economics, Journalism and Technical Communication, and Forestry – Forest Management), and two were Range Ecology Majors. While only eight of the NRM majors reported their minor, minors included Forestry, Ecological Restoration, Conservation Biology, Spatial Information Management, Political Sciences, Global Environmental Sustainability and Environmental Affairs.

Table 3.1*: There was high variation in the number of classes in different content areas that students reported having taken prior to the capstone course.*

NRM	GIS	Ecology	Economics	NR Planning	NR Policy	Anthropology or Sociology
1-10	0-5	1-7	1-10	0-2	0-5	0-4

The course met weekly for two 75-minute lectures and one 100-minute lab. The first year the study was conducted was the NR professor's eighth time teaching the lecture part of the course and the graduate teaching assistant's (GTA) second time teaching the laboratory part the of course. The authors of this paper had recently revised the course curriculum: the course professor, a science education professor, and the GTA, an ecology education graduate student. The revised curriculum included a semester-long group project designing a three-part management plan for a local SES (ecosystem assessment, stakeholder analysis, and management strategies), guest speakers (diverse NRM professionals and local stakeholders) and readings from the primary literature.

In the first year of the study a convenience sample of students (n=3) were invited to participate in the study and consented to have all of their coursework analyzed and participate in interviews at the end of the semester. All the students in the class were invited to participate in the second year of the study, and about half (n=20) consented to have all of their coursework analyzed and participated in interviews at the beginning and end of the semester (see Appendix II). Interview questions were informed by the literature describing NRM students being unprepared for jobs, (LaChapelle, McCool, & Patterson, 2003; Sample, Block, Giltmier, & James, 1999).

Data Collection and Analyses

The data for this study included 1) student-produced artifacts (reading response assignments) produced during the course by all students who consented to participate and 2) semi-structured interviews (close to 1,600 minutes were transcribed) during the first and last weeks of the semester. All lecture sections were audio recorded and all lab sections were video recorded to document information provided in lectures and interactions in lab, and to capture the learning environment.

We analyzed data following Charmaz's (2014) constructivist grounded theory approach. A grounded theory approach allowed us to ask inductive and deductive questions, and to use the data to guide research throughout the research process (Balgopal, 2014). Charmaz's (2014) constructivist approach to grounded theory holds that theories that explain social phenomena are not discovered, rather they are constructed from the data based on the researchers' own social and cultural experiences. Charmaz (2014) argued that through triangulation of data, researchers can interpret participants' actions and discourse, while making inferences about their intentions. In grounded theory qualitative research, categories, or codes, are used to describe characteristics of the data.

In our study, analyzed data fell into two large categories, 1) student produced data and 2) course context data. We initially coded written work, interview transcripts, lecture Power Point presentations, and lecture transcripts using initial line-by-line coding. In this process, we labeled sentences, phrases, or paragraphs with main ideas (called "codes"), which allowed for close study of the data, and initial conceptualization of ideas. Some of our codes included 'uncertain-none,' 'uncertain-natural,' and 'uncertain-humans.' We then synthesized these main ideas across data sources (interview transcripts and written work) to develop preliminary categories. We then returned to the interview transcripts and written work for focused coding, when we verified and refined conceptual categories. Through advanced memos, we synthesized the focused coding process, to further develop our categories and themes. We then reviewed all data sources again, to search for evidence that contradicted or further developed our findings and to ensure that our categories captured all of the data. To develop our final analyses we sorted the memos we had written throughout the data analysis process, integrated them into conceptual diagrams, and drafted propositions.

To analyze the student-produced data we examined the data and documented the way students situated humans within ecosystems. We read written artifacts and interview transcripts several times before developing a systematic coding scheme. When analyzing student interviews we focused on the sections of the interviews where we directly asked students about their conceptions of ecosystems. Analysis of written artifacts was limited to work written in response to prompts targeting conceptions of ecosystems, which included the six reading response assignments students completed throughout the semester. After open-coding, we developed focused codes that described 1) how students described the relationship between humans and ecosystems, 2) what students described as components of ecosystems, and 3) words or concepts students struggled with in their descriptions, or that had multiple meanings. We developed our focused codes into our continuum of conceptions.

We analyzed course context data to determine how humans were situated within ecosystems within the class. We specifically focused on analyzing all lectures presented by the professor, as these formed the underlying conceptual structure of the class. For the lectures we analyzed visual material presented during lecture, such as power points, and audio recordings of the lecture. We also included assigned readings that directly related to the human/ecosystem relationship in our analysis. Similar to the student-produced data, we coded the course context data for the way ecosystems were conceptualized in the readings and lectures. Additionally, we also coded for words and concepts we identified as “ambiguous terms” from the student interviews.

We decreased bias in our analysis through prolonged engagement, member checking during interviews, peer debriefing, and triangulation of data sources (Merriam, 2002). For member checking, the interviewer asked clarification questions during the interview. In peer debriefing, the primary coder (the first author) discussed findings with the other authors. During triangulation, multiple data sources were used and compared for a single student to verify their classification. A second coder, also an ecology education graduate student, coded 20% of the sections of the interviews focused on ecosystems. Inter-rater reliability initially was 87.5%, and after discussing codes, we came to 100% consensus. Following initial analysis, all three authors met for peer debriefing.

Findings

The way students situated humans in relationship to ecosystems varied, both between students, as well as across the semester for individual students. Additionally, students' conceptions did not always align with those presented in the capstone course, even after the end of the semester (Tables 3.2 and 3.3; Casper and Balgopal, unpublished manuscript). However, students' simple description of an ecosystem as a bounded system made up of biotic and abiotic factors remained fairly static both between students and across the semester for individual students. Therefore, the nuances of what an ecosystem is what generally varied, not students' foundational concepts of ecosystems (Table 3.3).

In the course, the professor presented the construct of ecosystems through lectures and course readings (Table 3.2). She generally presented ecosystems as inclusive of humans (Table 3.2); however, the construct was never explicitly defined within the lectures, and there was some ambiguity as to how humans fit within the construct of ecosystems (lectures 1-3 audio and Power Points; Verstraete et al., 2009). Within the lecture, the professor presented social-ecological systems as integrated systems encompassing biophysical and social components, embedded within an ecosystem (lectures 1 & 3). When discussing SES she explained,

> [a] *social-ecological system is really just explicitly bringing in and considering the human part of the system as well as the biophysical part, and understanding them as really being a whole, not being two separate spheres. That they really are inseparable, and that we as individuals and as societies are part of that whole* (lecture 3).

Later in the same lecture the professor described the Spanish Pyrenees ecosystem prior to the late 20th century in the following way. "*At the time it was not just the livestock, but it was the* *people working and living and having their daily lives on the landscape. They were doing small scale controlled burns at the time, and collecting firewood for fuel.*" In this manner, the professor described humans and human actions as integrated components of ecosystems, and explicitly described social components integrated into social-ecological systems.

Table 3.2: *Ecosystem as presented in the course context through class readings, lectures, and lecture power points.*

Course Material	**Description**	**Example**
Lecture 3	A system made up of biophysical components, including humans. (Ecosystem is never directly, explicitly defined).	Sources of complexity in ecosystems include: "*Environmental variation, biological variation, non-independence of events & interactions, uncertainties in the human realm.*"
Lectures 4 & 7	Diagrams separating "social" and "environmental" components may give students room for ambiguity and allow them to interpret material through whatever their existing conception is (e.g., Verstraete, Scholes, & Smith, 2009).	N/A
Course reading Lecture 2: Holling and Meffe, (1996)	Does not explicitly define ecosystem. However, it discusses humans & human impacts in discussing NRM of ecosystems. It also occasionally uses the term "natural ecosystem". Discusses the importance of human influence on natural resources & management.	NRM should: "*Proceed from simple monocultures to more complex agroecosystems with integrated pest management and no-till methods." "Promote, through education and economic means, ecological complexity in agriculture…*" "*Relocate communities out of floodplains of the Mississippi River and other large riverine systems*" (p. 335).
Course reading Lecture 2: Meffe et al., 2002, Chapter 2.	Explicitly defines ecosystems as inclusive of humans. However, their initial quote appears to be exclusive of humans, but later in the same paragraph they explicitly include humans.	"*Ecosystem is defined here as "a dynamic complex of plant, animal, fungal, and microorganism communities and their associated nonliving environment interacting as an ecological unit. (italics added) (Noss and Cooperrider, 1994).*" Additionally "*In addition, an ecosystem certainly includes humans as part of the system if they are present at the particular place and time*" (p. 70).

Table 3.3: *Continuum of student conceptions of humans in ecosystems: student conceptions were classified into five categories based on how they situated humans in relationship to ecosystems. The description column describes the criteria for the category, and the example column provides an illustrative quotation from a student interview. All names used are pseudonyms.*

Category	**Description**	**Example**
Exclusion: Humans are definitely not part of an ecosystem	Describes ecosystems as distinct and separate systems from humans and human influences. There may be interactions between the two, but they are different.	" *I guess I'm just thinking of things that people didn't make, you know, like nature. I put people in a separate box ... I think. I think we're set apart*." - Rachel
Uncertain Exclusion: Unsure, but final conclusion is that humans are not, or are probably not part of an ecosystem.	May use terms conveying uncertainty, or they may start out with a different idea and end with a final conclusion in the exclusion category.	"*I guess, humans are in it too, I'm thinking agricultural point, so they plough the fields and everything and they're changing it. … you know it's more social ecological system where humans influence nature. So that's where I'm going to, like ok no, ecosystems are just natural*." – Jade
Uncertain: Unsure, no final conclusion.	Discusses uncertainty, may discuss possibilities of humans either excluded/included, but they have no clear final conclusion.	"*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 if we're separate*." – Tyler
Uncertain Inclusion: Unsure, but final conclusion is that humans are, or probably are part of an ecosystem.	May use terms that convey uncertainty, or they may start out with one conclusion and talk their way to a final conclusion in the inclusion category. May also describe humans as part of an ecosystem, but include exclusionary caveats, such as human artifacts (roads, etc.)	"*I don't want to not include humans as being part of the ecosystem because we are natural, but I wouldn't say a big building like this is necessarily part of an ecosystem*." – Charlie
Inclusion: Humans are definitely part of an ecosystem.	Describes ecosystems as inclusive of humans and human influence. May include terms such as "altered ecosystem," or caveats of a bounded system, such as, if something is not physically present it is excluded.	"*I feel like at this point it wouldn't be wise to not think of something as not part of an ecosystem. But I think that it's important to recognize that those two items [human development and land] can intermingle to become their own ecosystem, and that both of these are not separate. You know, they don't function separately*." –Laura

Student conceptions of human-ecosystem relationships ranged widely (Table 3.3). Only some students' conceptions aligned with the conceptions presented in class. While students whose conceptions were consistent with those presented in class, and clearly situated humans and human impacts as either part of an ecosystem (Inclusion), as well as those who clearly situated humans as not part of an ecosystem (Exclusion), were easy to describe, those that did not clearly include or exclude humans were more difficult to classify. Often, students initially made a distinction between 'human-influenced' and 'natural' environments, but then struggled to determine what a natural environment was. Key words that students used when struggling to situate humans in relation to an ecosystem included *natural*, *man made*, and *infrastructure*. Key ideas included the *type of influence* an action had on an ecosystem, or the *intent* behind a management action. When students struggling with how to situate humans eventually decided that humans were included in some way, they were classified as Uncertain-Inclusion, whereas if they decided that humans were excluded, they were classified as Uncertain-Exclusion. If a student was unable to come to a conclusion, they were classified as Uncertain. Most of the students in the study had conceptions in either the Inclusion or Uncertain-Inclusion categories, therefore we focus on these categories to present our most important findings.

Written work

Students' written work provided triangulating data that supported their classification within the continuum. Much of the students' written work did not directly identify their location on the continuum, therefore our analyses focused on the reading responses that students wrote during class. Often students used the non-specific term "system" in their writing, however the way they wrote about systems varied. Some students frequently wrote about human-environment interactions, whereas others often stuck to examples that focused on either human and social systems or non-human environmental systems. In addition to the supporting examples, such as those discussed below, we also looked for, but did not find, counter-examples that would have challenged our interpretation of interviews as presented in the continuum.

Only students whose essays fell into the Inclusion category included enough explicit information to code their essays on the continuum scale. These students also tended to provide examples that included human-environment interactions. For example, Dale clearly demonstrated his integrated conception of ecosystems when he wrote: "*A holistic way of managing a landscape, ecosystem management attempts to manage in a holistic way, viewing the system as one interactive system (which it is).*" Similarly, Debbie wrote, "*First, humans live within, not apart from, ecosystems, and we depend on them for our continued existence.*"

In the same essay, Dayton's example of thresholds (which can occur in any type of system) included human-environment interactions:

> *We talked about the effects of dams on rivers, and how they make the water temperature rise to a point in which some fish species cannot survive and die off. This changes the behavior of the entire river system, the slow variable in this case is the temperature of the river being caused by the dam.*

Debbie's example of thresholds also included human-environment interactions:

> *One example of a system that crossed a threshold is the Tallgrass Prairie. Today only 4% of the original prairie exists, and the rest has been cultivated into cropland in such a way that even if all cultivation ceased, the prairie may not regenerate to its previous condition due to changes in the soil profile and fire regime. The slow variable in this case was likely the persistent use of cultivation tools over time that altered the natural landscape.*

Both Dale and Debbie's interviews, which occurred shortly before they wrote the aforementioned written assignments, were also classified as Inclusion.

In contrast, students whose interview scores fell into the Uncertain-Inclusion category were often less clear about human/environment relationships in their writing, or they may have provided less integrated examples. Sam, who was classified as Uncertain-Inclusion in his initial interview, was less clear on how humans are situated within ecosystems in his writing:

> *Thresholds are a very important component of natural resource management because we must recognize when human manipulation of a certain variable may alter an ecosystem into something that can no longer supply us with the product that we were dependent upon.*

In his entire essay, Sam never clearly situated humans in relationship to ecosystems or the environment. However, he implicitly places humans as external to ecosystems in his interview. Jade, who was classified as Uncertain-Inclusion in her initial interview, which occurred close to the time of her essay, mostly focused on social and human examples, such as town populations supporting necessary services:

> *It hasn't happened yet but a system that I see that could change if it crosses a threshold and is influenced by outside systems is [a local rural village]. The slow variable would be the population if it continues to decrease the village would continue to decline. With the decline in population services such as the school and/or the post office would close. This would lower the draw to the area and would unravel the community structure. The closing of the school or post office could also bring about a decrease in population.*

Jade's examples that did include human-environment interactions, such as over-fishing, focused on the extractive problems, rather than the specific human/ecological interactions within the example. Similarly, Sam's threshold example includes the human-environment interaction of an introduced species, but his description focuses on the biological processes that occur between the competing species:

> *A current example of a threshold being met could be the case of non-native trout being introduced to basins of Colorado. Non-native trout, such as brook and rainbow trout can cause native trout like greenbacks to be outcompeted for food and be subjected to interbreeding which dilutes the gene pool. Eventually the native trout will no longer be major components of the ecosystem and the non-native and interbred trout will cause differently behaving trout to take over and the ecosystem shifts its dynamics into a new regime. The slow changing variable in this case is the dwindling gene pool of the native trout until it is no longer able to recuperate its species population.*

Some students, such as Kevin and Noah, who were classified as Uncertain-Inclusion in their interviews, described integrated conceptions in their writing, even though they did not describe an integrated conception in their initial interviews. Shortly after his interview, Kevin wrote:

> *In Colorado, there is a problem with overly dense Ponderosa Pine forests. These forests are encroaching on naturally occurring pockets of pine-free grasslands. In nature, these meadows occur because fire kills groups of Ponderosa Pine, allowing room for grasses to move in. Due to human fire suppression, these forests are allowed to grow unchecked, forcing treeless areas to become less common.*

Similarly, Noah wrote,

> *Thinking and working across multiple scales is vitally important when managing ecosystems for resilience. Understanding how the ecosystem functions and what keeps it functioning (stakeholders, volunteers, organizations, land managers, farmers, etc.) requires the knowledge of many different scales and functions."*

Kevin's forming ideas about integrated conceptions also came up in his interview. In response to the question, "*are there any things that you consider not part of an ecosystem*," he stated "*I mean aside from humans, I can't think of anything*." But, upon further questioning about ecosystems he said, "*I feel like [humans are] detrimental to most ecosystems. I can't think of any ecosystem where human activity has actually improved it … I feel like we are definitely a part of [ecosystems], just because we interact with it, and we affect it*." In the span of a few minutes, Kevin shifted the way he described his conception of ecosystems as he was further question about the details of an ecosystem. Therefore, the way he discussed his ideas changed as he talked and clarified his meaning during the interview, and the negative influence of humans he discussed in his interview was also present in his writing.

Unlike Kevin, Noah started out including humans within ecosystems, but specifically excluded built environments, such as buildings, because they "*don't contribute to anything*" to the ecosystem. Similar to Kevin, Noah didn't see human impact on ecosystems as positive, and therefore either initially (Kevin) or continually (Noah) excluded this impact from their concept of an ecosystem during their interviews.

Discussion

A student's location along the continuum was influenced by two major factors: 1) underlying conceptions, and 2) language. Some students struggled with one or both of these categories, possibly due to challenges with language and differing discipline-specific conceptions of ecosystems. Because students differ in pre-college background experience, coursework for their different minors (Table 3.1), and work and volunteer experience, the disciplinary roots of their knowledge prior to the class differed.

Students demonstrated varying levels of integration in the way they conceptualized the human-environment relationship through their interview data and written assignments. Students such as Debbie and Dale had strongly integrated conceptions that came across clearly in their interviews and writing.

The challenges in coding students with less integrated conceptions, such as Kevin, may have been due to students' own challenges as they grappled with trying to address differences between their own conceptions and the conceptions presented in the course, as well as the struggles they had with course-specific language. The examples that Kevin and Nick, who had Uncertain-Inclusion conceptions, used in their essays showed that these students could describe human-environment interactions well when writing. In contrast, in their interviews these students sometimes struggled when asked to clarify their examples.

Because the written assignment prompts were open, and students were not operating under time pressure, students were able to take the time and space necessary to describe system interactions they understood using their own language. This instructional strategy seemed to particularly benefit students with Uncertain-Inclusion conceptions, because the assignments allowed language and underlying conception to be de-coupled to some extent. For example, Kevin did not need to use terms such as ecology, ecosystem, or SES when providing his example of a threshold in his writing about ponderosa pines. But, he demonstrated evidence of an underlying integrated conception. Kevin's shift in how he positioned humans during his interview may indicate that he was struggling with the underlying conception, the language used, or both. Because there are multiple discipline-accepted conceptions for ecosystem (Alberti et al., 2003; Meffe, 2002; Risser, 1986), students may particularly struggle to develop their own conception of an ecosystem, leading to the confusion Kevin demonstrated in his interview.

Creating Shared Meaning

The lack of consensus within and across fields regarding ecological literacy and ecosystems is an overarching challenge in interdisciplinary dialogue (Druschke & McGreavy, 2016) and makes assessment of students challenging. This lack of consensus may tie in to why students struggled with both language and their underlying conceptions when they described ecosystems, since exposure to differing ideas may have caused disconnect between conceptions and terminology.

Because development of new conceptual constructs is informed by our experiences and prior knowledge (Lemke, 2001), conflicting conceptions across fields are particularly problematic when working with individuals with diverse backgrounds since each individual may not have knowledge of the alternate conceptions others are using (Druschke & McGreavy, 2016). Differences in accepted conceptions among disciplines may lead to unintentional cognitive dissonance, as individuals deal with trying to understand material and engage with others who have different, but also accepted conceptions (Posner et al., 1982). The lack of metrics for assessing ecological literacy, particularly in adults with strong ecological content knowledge, compounds this problem. Our continuum provides a tool to fill this assessment gap, and adds to the broader dialogue of developing and defining ecological constructs.

Our work points to the importance of co-constructing shared meanings of terms across disciplines (Druschke & McGreavy, 2016), since the students in our study clearly did not have shared meanings of the foundational term: ecosystem. Similar to our findings, Glaser (2006) and Balgopal et al. (2012) both found that individuals vary in how they describe human-environment relationships and human-environment interactions. Glaser (2006) analyzed varying conceptions of ecosystems, including eco-centric, anthropocentric, interdisciplinary, and Balgopal et al. (2012) discussed differing conceptions that undergraduate students have of human-ecosystem relationships. These varying conceptions provide different foundations for decision-making, possibly leading to unintended differences in outcomes.

Along with lack of clarity surrounding the term ecosystem, the term SES, which is primarily used in NRM and related fields, can also cause confusion about both language and conceptions. From a term-specific perspective, the term social-ecological can cause people to see the two components as separate, even though the intention of the term is integration (Scholz & Binder, 2011). While analysis of factors that caused students' conceptual change is addressed in another manuscript (Casper and Balgopal, unpublished manuscript), it is of note that Jade moved from the Uncertain-Inclusion in her pre-interview to the Uncertain-Exclusion category in her post-interview because of the way she interpreted the term 'social-ecological system,' which was a term new to her (Table 3.3). From an interdisciplinary perspective, SES is commonly used within the field of NRM, as well as institutional economics and environmental governance. However, individuals outside of these fields may not be familiar with the term. Furthermore, depending on how the terms SES and ecosystem are defined, there may or may not be a difference between the two (Alberti et al., 2003; Balgopal et al., 2012; Chapin et al., 2009; Glaser, 2006; Holling & Meffe, 1996; Risser, 1986).

SES is also not the only term used to described linked human-environmental systems, and other terms in other disciplines, such as “human ecology,” “human-environment systems,” and “coupled human-natural systems” may only add further confusion to the discussion (Liu et al., 2007; Machlis et al., 1997; Scholz & Binder, 2011). Liu et al. (2007) define coupled human-natural systems as, “integrated systems in which people interact with natural components,” and use it as a general term synonymous with SES and human-environment systems (p. 1513). While we did not ask students about their knowledge of these other terms, it is possible that some students did not describe humans as integrated components of ecosystems because they thought the integrated conception was described by one of these other terms (i.e., neither ecosystem nor SES). This plethora of terms exemplifies that it is difficult, if not impossible, to predict all of the different alterative conceptions students may have. By explicitly co-constructing knowledge in the classroom, clarity in language will not inherently create integrated human-environment conceptions, but will help decrease confusion (Druschke & McGreavy, 2016).

Implications

The continuum we developed as part of this study describes varying ways individuals conceptualize how students in an NRM class situate humans within ecosystems, helping to unpack the complexity of the ecological literacy construct. Our continuum provides a useful tool to start to understand differing conceptions of human-environment relationships within ecosystems, creating shared meaning and facilitating effective communication. As part of a larger study, this metric will facilitate our analysis of factors that influence how student conceptions of ecosystems change throughout their capstone course. More broadly, the continuum could be used to assess individuals' conceptions of ecosystems in a variety of situations where the way they situate humans within ecosystems is pertinent.

Because of the increasing focus on ecological literacy as a universal skill (Keynan, 2014), our continuum contributes to the ecological literacy literature by providing a metric to assess undergraduate students in ecology-related fields. This metric is valuable for instructors and researchers who want to help students develop necessary foundational conceptions, particularly in light of the current anthropogenic influence on changing global ecosystems (Rockstrom et al., 2009; Vitousek, Mooney, Lubchenco, & Melillo, 1997). We found that students' conceptions were not necessarily consistent with those taught in the capstone class; therefore, educators of NR students and other students in ecology-related fields should be aware of the way they communicate about ecosystems through the curriculum and classroom discourse. Students are exposed to many different concepts throughout their lives, and, in turn, develop their own conceptions (Dole & Sinatra, 1998). The term ecosystem represents differing conceptual constructs, therefore students may continue to rely on prior conceptions, rather than conceptions introduced in class, if instructors do not directly address students' existing conceptions (Alberti et al., 2003; Druschke & McGreavy, 2016; Glaser, 2006; Kitcher, 2004; Kueffer & Larson, 2014; Lemke, 2001; Posner et al., 1982; Risser, 1986). Additionally, if educators do not address students' existing conceptions, they may be unintentionally reinforcing outdated conceptions, or creating confusion due to differences in meaning of terms across disciplines. In the past, NRM decisions have caused social, ecological, and economic collapses (Estes et al., 2011; Holling, 1973), and currently, rapid global ecological shifts may have disastrous consequences for humanity in the near future (Rockstrom et al., 2009). Therefore, it is vital that NRM coursework reflect the current philosophical shift to prepare our future NR managers to manage our natural resources as effectively as possible (Derting & Ebert-May, 2010; Quinn, Burbach, Matkin, & Flores, 2009).

The use of our continuum in academia may help instructors teach more effectively, through identifying their students' existing conceptions, and tracking conceptual change over time. Although there are studies documenting K-12 students' misconceptions about systems (Chi, 2005; Jordan, Brooks, Hmelo-Silver, Eberbach, & Sinha, 2014), studies of systems thinking at the undergraduate level focus on developing new conceptions, without first identifying misconceptions that may exist (Habron, Goralnik, & Thorp, 2012; Hiller Connell, Remington, & Armstrong, 2012; Jacobson, Kapur, So, & Lee, 2011; Remington- Doucette, Hiller Connell, Armstrong, & Musgrove, 2013). Because existing conceptions influence how students are already thinking, and individuals must determine that new conceptions are better than their previous conceptions (Posner et al., 1982), identifying and discussing students' existing conceptions before trying to develop new conceptions may be important at the undergraduate level as well.

As with any research, our study has limitations. We developed this continuum with a small sample of NRM undergraduates while they were involved in their capstone course. Although our results may be applicable to undergraduate students in other related majors, our data are drawn only from students majoring in NRM and Rangeland Ecology. The complex nature of the construct "ecosystem," and the need to select a specific definition also limited our research.

Therefore, further research that includes students in other majors is necessary to further assess and develop our metric.

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CHAPTER 4: CONCEPTUAL CHANGE IN NATURAL RESOURCE MANAGEMENT STUDENTS' ECOLOGICAL LITERACY[5]

Introduction

Capstone courses are becoming more common as a means to help undergraduate students synthesize content across disciplines while engaging in authentic practices for their major (Berkson & Harrison, 2002). These courses focus on integrating and applying disciplinary content knowledge while using inquiry and problem-based teaching strategies (Arthur & Thompson, 1999). 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, King, Herbohn, Russell, & Smith, 2007; LaChapelle, McCool, & Patterson, 2003; Sandri, 2013).

While there have been several studies that describe teaching strategies for NRM capstone courses (Habron, Goralnik, & Thorp, 2012; Hiller Connell, Remington, & Armstrong, 2012; Jacobson, Kapur, So, & Lee, 2011; Remington-Doucette, Hiller Connell, Armstrong, & Musgrove, 2013), there is a lack of in-depth research on how capstone classes influence student learning. Because of the focus on interdisciplinary synthesis and career preparation, an NRM capstone course is an appropriate place to assess students' conceptual shifts, and analyze the

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factors that influence these shifts. Furthermore, 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; Tanner & Allen, 2005).

Theoretical Framework

This study is informed by the intersection of socio-cultural and conceptual change theories (Charmaz, 2005; Chi & Roscoe, 2002; Georghiades, 2000; Ivarsson, Schoultz, & Saljo, 2002; Lemke, 2001; Posner, Strike, Hewson, & Gertzog, 1982). Broadly, socio-cultural theory states that our social experiences throughout our lives provide a vital 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 & Allen, 2005). Therefore, the intersection of these theories allows us to explore how conceptual change is imbedded in cultural and social contexts.

Socio-cultural Theory

Socio-cultural theory frames science as a human activity that is embedded in historical and cultural contexts, and as such, each individual's social and cultural background influences the way he/she interacts with each other to make meaning (Lemke, 2001). In other words, socio-cultural theorists do not believe that people learn in isolation; rather that conceptions are developed through communication with others, observations of natural phenomena, and opportunities to make meaning of and assimilate 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 & 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

Although cognitive psychologists have described the process of conceptual change in different ways, the Conceptual Change Model (CCM) has long influenced how science education researchers study learning. The CCM describes the shift necessary for an individual to change his/her preexisting conception to a new one (Posner et al., 1982). A conception describes how an individual understands a concept, such as the process of diffusion; conceptions that are inconsistent with generally accepted scientific conceptions are often labeled misconceptions or alternative conceptions. At the root of the CCM, Posner et al. (1982), drawing on Piaget's cognitive studies, described the process of conceptual change. First, an individual 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). 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 et al., 2002; Lemke, 2001), such as classrooms.

Dole and Sinatra (1998) expanded upon the conceptual change model 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 conceptual change model's steps of conceptual change (intelligible, plausible, and fruitful) with the steps comprehensible, coherent, plausible, and rhetorically compelling. One of the biggest differences between the two models is that the CRKM includes an engagement continuum, stating that strong conceptual change cannot happen without high levels of engagement with a concept. Social and cultural contexts influence the level of an individual's engagement with a concept and the possibility of strong conceptual change.

The shift towards embedding conceptual change within social and cultural contexts is the reason why conceptual change theory almost completely 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 CCM (1982). 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 & Sinatra, 1998).

We use a combination of Chi and Roscoe's (2002) and Ivarsson et al.'s (2002) framing of the conceptual change model, as they are not mutually exclusive (Mayer, 2002). Ivarsson et al.'s (2002) explicit inclusion of a socio-cultural context strengthens our situation at the intersection of socio-cultural and conceptual change theories. Chi and Roscoe's (2002) focus on the way individuals classify information, particularly their work with misclassification of emergent properties, is particularly relevant to systems thinking.

Conceptions of ecosystems

NRM graduates are often not proficient in the skills necessary to enter management professions (LaChapelle et al., 2003; Sample, Block, Giltmier, & James, 1999). In addition to systems thinking, communication, and group work skills, these students also need to understand 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; LaChapelle et al., 2003; Orr, 1992; 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” (p. 1172). In response to Alberti’s claims, researchers and NRM practitioners need curricula that reflect changing conceptions and perceptions (Stern, 2000).

While there has been a recent proliferation of newer terms to describe a system that integrates human systems and ecosystems, including social-ecological system, socio-ecological system, coupled human-natural system, and human ecology (Anderies, Janssen, & Ostrom, 2004; Liu et al., 2007; Machlis, Force, & Burch, 1997; Scholz & Binder, 2011; Stanger, 2011), these terms tend to be used within specific disciplines, rather than in a broad interdisciplinary context the way ecosystem is used. Additionally, ecosystem is an underlying concept within all of these terms, and humans and our impact cannot be separated from ecosystems (Rockstrom et al., 2009; Vitousek, Mooney, Lubchenco, & Melillo, 1997).

Individuals’ knowledge necessary for ecologically sound decision-making is referred to as their ecological literacy. Risser (1986), a past-president of the Ecological Society of America, first developed the concept to frame key knowledge the general public needed for decision-making. While Risser (1986) included social systems, humans, and human impact in his initial conception, his concept of ecological literacy has been developed in multiple ways by more recent researchers (McBride, Brewer, Berkowitz, & Borrie, 2013).

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 (Bogan & Kromrey, 1996; Davidson, 2010; Keynan, Ben-Zvi Assaraf, & Goldman, 2014; Morrone, 2001;

Pe'er, Goldman, & Yavetz, 2009). We described an ecological literacy continuum that specifically targets this human-ecosystem relationship (Authors, in review). The use of a continuum allows researchers to measure, at different time periods (e.g., beginning and end of a course) how student conceptions of human-ecosystem relationships can be described. The continuum tool, therefore, allows researchers to study conceptual change. Studies of system thinking at the undergraduate level that focus on developing new conceptions are important (Habron et al., 2012; Hiller Connell et al., 2012; Jacobson et al., 2011; Remington-Doucette et al., 2013), because existing conceptions influence how students are already thinking, and 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 (Chi, 2005; Jordan, Brooks, Hmelo-Silver, Eberbach, & Sinha, 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 promotes learning (Georghiades, 2000).

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 instructional strategies or existing conceptions, 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 9th time, and one graduate teaching assistant (GTA) for the 3rd 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-minute lectures, and once weekly for a 100-minute laboratory class. All students attended lectures together, but the students were split into two sections for laboratory class. The curriculum of the course had recently been revised by the F&RS professor, a science education professor, and the GTA, an ecology education graduate student. 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 (See Appendix III; Authors, 2016).

Semi-structured interviews were conducted the first (20-30 minutes each) and last (45 to 70 minutes each) weeks of the semester and were transcribed (approximately 1600 minutes total).

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 were analyzed for conceptual change regarding ecological literacy (Balgopal & Wallace, 2009). We included the participants' perceptions of how their concepts of ecosystems changed throughout 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 we were interested in their conceptions of the human-ecosystem relationship, we used an ecological literacy continuum, described elsewhere (Authors, in review). The continuum focuses on how people situate humans within ecosystems: 1) humans are definitely not part of an ecosystem; 2) unsure, but final conclusion is that humans are not; 3) unsure, no final conclusion; 4) unsure, but final conclusion is that humans are, but may leave out some components; 5) humans are definitely part of an ecosystem. Using these categories, we described participants' changes in conceptions 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 of the lab and lecture sections, interviewing the students, and preforming 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 the use of transcribed interview data, student written work, participant observation notes, transcribed audio recordings of lecture, and Power Point presentations of lecture.

Findings

Students had fairly well-developed conceptions of ecology at the beginning of the course, which fell into categories *Uncertain-Inclusion* to *Inclusion* (Table 4.1). 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 along the scale. 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 4.1), and described different aspects of the capstone class as influencing this change (Table 4.2). The way instructional strategies influenced students varied, however, we did not find any specific relationships between students' conceptions of ecosystems or conceptual change and the factors they described as influential.

Table 4.1: *Shifts in student conceptions of ecosystems from pre to post interviews. 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.*

	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

Table 4.2: *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

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 of 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 4.1). 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 4.1). 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 of 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.

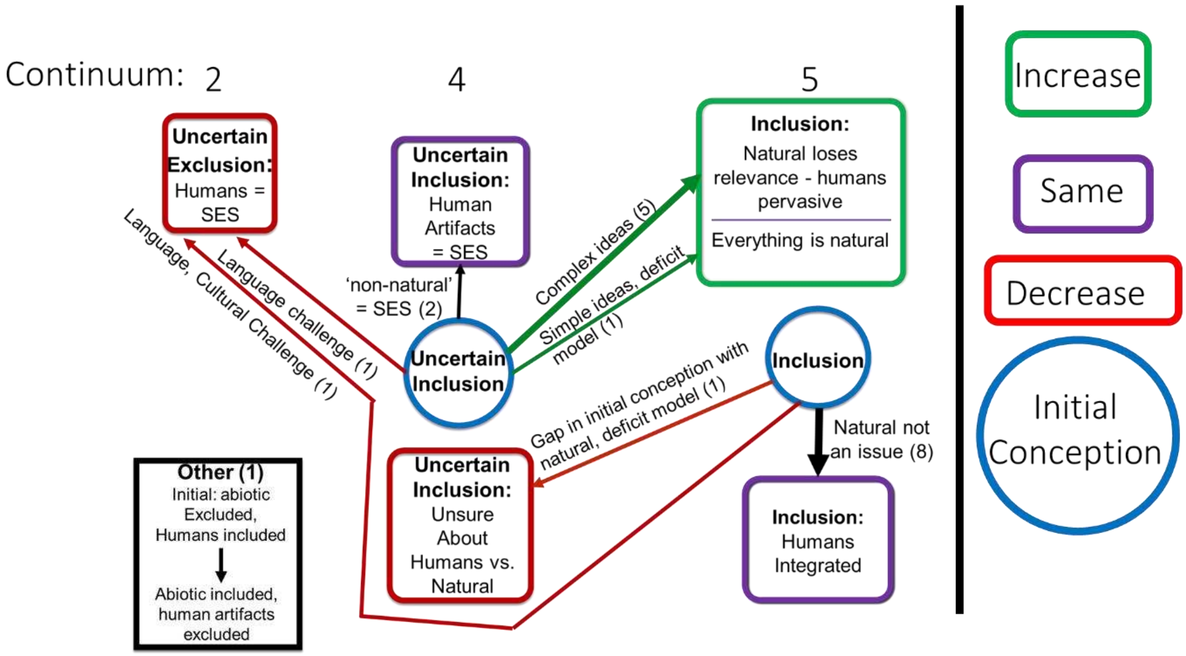

Figure 4.1: Student conceptual shifts in their ecological literacy were mediated by the way they constructed the relationships between 1) the term natural, 2) ecosystem and natural, 3) human and natural.

Humans are a part of SES

Two students, Jim and Jade, navigated their perceived conflict of 'natural and 'human' deciding that humans only belonged in SESs, and only 'natural' things were part of ecosystems, designating their conceptions as *Uncertain Exclusion*. Jim shifted from *Inclusion* and Jade shifted from *Uncertain Inclusion*. Both navigated the perceived conflict between 'human' and 'natural' by classifying humans into SESs and outside of ecosystems. The term SES was new to both students at the beginning of the semester.

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 he transferred to the institution where this study was performed. He struggled with English and differences between how human-environment relationships were framed differently at his Asian and American undergraduate institutions, both at which he studied natural resources. He described the differences between his two majors: "r*esource science 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 generally talked about struggling with the specialized language used during her studies.

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 classifying humans and human influence. 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 also sometimes conveyed confusion during class sections, and her written responses often focused on material presented in the readings, rather than synthesizing and going deeper into the material.

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, struggled with language, and added the new term “social-ecological system” into their vocabularies, they both determined that SES involved all things human, and ecosystem did not involve humans.

Human artifacts are a part of SES

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’ (Figure 4.1). By the post-interview, both students had resolved this conceptual conflict by determining that human artifacts are components of SESs, 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, “r*ecognize the holistic nature of the ecosystem even when dealing with just one variable.”* But, because Sam does not explain what he means by holistic, so we cannot know if he is thinking of looking at all of the non-human factors as integrated, or using the term differently.

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 (Figure 4.1). 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 a component of an ecosystem, “*really, everything's natural. It’s a weird thing to think about. Like that [tv monitor] came from nature, somehow, like 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 how humans and human artifacts related to their ideas of 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 …. ecosystem I believe would influence the stakeholders because they really make it what it is …. 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; rather it was imbedded 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. She repeatedly discussed how she did not want to go into 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, is 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 resource 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 reveals that she has a simplistic, deficit view of other cultures. She perceives providing clean water to the world as simple, only requiring going out and digging wells. She does not think that the complexity she wants to avoid in NRM exists within the challenges of bringing water to the world. Therefore, even though she developed a more integrated view of ecosystems during the class, she shifts her ideas in a way that supports 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. However, when he initially described an ecosystem in his pre-interview he first described it as 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 manmade 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 like concrete and motor vehicles I think that's kind of where I draw the line from a natural ecosystem .... Yeah. Alright I guess I'm having a tough time .... I think natural ecosystems like being environmental portions of it, and then ones like the manmade, 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

Natural

Students' conceptions of the technical conception of ecosystem were often tied to their conceptions of the common word, natural. According to the Oxford English Dictionary (OED, 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' **(**OED 2016). Specific definitions given by the OED (2016) include 'without human interference,' 'innate,' 'not spiritual,' 'consistent with nature; normal, expected,' and 'not artificial.' The OED (2016) classifies 'natural' as a common word, and classifies its frequency of use with other words used in everyday speech and writing. Clearly, the term natural is one the students have likely encountered throughout their lives, and can be used in a broad number of ways. This commonality and breadth of use caused students to have multiple conceptions of natural. Therefore, when they tied the conception of ecosystem to 'natural,' they struggled to navigate the relationship between the multiple meanings of natural used in every-day language, and the more technical term 'ecosystem.'

Despite the fact that many of the students equate ecosystem with natural, Tansley (1935) did not describe the term 'ecosystem' as natural. In fact, Tansley (1935) explicitly included human disturbance in his conception*, "regarded as an exceptionally powerful biotic factor which increasingly upsets the equilibrium of preexisting ecosystems and eventually destroys them, at* *the same time forming new ones of very different nature, human activity finds its proper place in ecology"* (p. 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, p. 70).

Even though the student data indicate that ecosystem is equated with 'natural' in every-day language, none of the definitions or usages for ecosystem in the OED (2016), nor in their textbook, include the idea of 'natural.' 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 in-line with somewhat of an integrated human-ecosystem conception, it provides evidence that students may be getting 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.' While these discussions are sparse, and are more likely to discuss issues of 'natural' in terms like 'natural' vegetation for management practices (Willis & Birks, 2006) or 'natural' range of variation (Parrish, Braun, & Unnasch, 2003). Hunter (1996) and Dufour and Piegay (2009) both discuss the human/natural idea and come to very different conclusions about where humans fit in regards to the idea of 'natural.' This difference is likely influenced by the 13 year gap between the two papers (Dufour & Piégay, 2009; Hunter, 1996). Hunter (1996) argued that humans should be explicitly excluded from ideas of 'natural,' to clarify conservation goals, even while acknowledging climate change is a pervasive human influence. In contrast, Dufour and

Piegay (2009) discussed both the culturally-embedded nature of the idea that humans are separate from ‘natural’ environments, and futility of trying to separate humans and human influence from the environment, and the importance of moving beyond goals of returning to an idealized pre-human, natural state. Therefore, we can see evidence for students’ confusion, but the recent literature points to the importance of moving beyond ideas of a ‘natural’ state exclusive of humans (Dufour & Piégay, 2009; Hunter, 1996).

Some of the struggles students had in navigating their conceptions of ecosystem have been previously described in the literature, particularly their confusion with the term SES. The conceptions of four students in the study who determined that ‘non-natural’ things fell into SESs, Jim, Jade, Sam, and Allen, were consistent with Raymond et al.’s (2013) critique of the term SES. Even though these four students defined natural differently, they used the concept of SES to address anything in the overarching system they deemed not-natural, and therefore excluded from the ecosystem. Because of the way social-ecological combines ‘social’ and ‘ecological,’ it can cause people to think that social and ecological systems are separate, rather than integrated, as the term intends (Raymond et al., 2013; Scholz & Binder, 2011). We argue that our data demonstrate that Jade and Jim struggled with the language of the course, making them more likely to fall into 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 weren’t aware of it, the way they resolved their natural-ecosystem cognitive dissonance with SESs indicates that they struggled to make both conceptual meaning – determining the human-ecosystem relationship – as well as understand the specialized language – ecosystem, social-ecological system – that is used to describe these conceptions.

While conceptually, this integrated idea is similar to 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 interact with stakeholders.

While Jade, Sam, and Allen all struggled with language and conceptions as native English speakers, Jim faced additional challenges as an international student and English language learner. Jim's confusion may be 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 ecosystems (Nisbett, 2003). The separation of humans from the environment is a Western construct, according to Nisbett (2003), and East Asians tend towards more generally including humans with other animals, and avoiding creating a dichotomy between humans and the rest of the world. Jim may have also struggled with synthesis because of language challenges and 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 the students who used SES to resolve their cognitive dissonance. For example, Eve and Sam demonstrated simplistic systems thinking overall, indicated by their deficit views of other cultures. Because an integrated view of ecosystems that addresses complex interactions requires complex systems thinking (Meadows & 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 is probably dissatisfied with his existing conception, and Eve's clear desire for a 'black and white' world indicates that she is unmotivated to address the limitations caused by her simplistic thinking (Posner et al., 1982). While several authors have suggested ways to promote systems thinking in undergraduate NRM courses (Bosch et al., 2007; Habron et al., 2012; Hiller Connell et al., 2012; Monroe, Plate, & 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.' Even though the written assignments that students completed throughout the class 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 on in the semester. Even though the instructional strategies that students reported as helpful ranged greatly, 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 that the students resonate with (Pritchard, 2014)

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). 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 what conceptions and language participants were exposed to before our study. 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 link exists for other conceptions that students struggle with in the classroom as well.

As with any study, this study has limitations. The results are from one 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. In particularly, we posit that students need guidance to address simplistic systems viewpoints and avoid cultural deficit models. We believe that our study contributes to the growing literature on ecological literacy and conceptual change.

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CHAPTER 5: SYNTHESIS AND FUTURE WORK

Overarching Findings and Implications

There are several major findings described in the preceding chapters of this dissertation and appendix IV:

1. Students experienced conceptual change in their capstone course (Chapters 2 and 4)

2. Students' conceptions of biophysical and social systems changed from *separate* to *integrated* (Chapter 2)

3. Students developed cross-scale and dynamic conceptions of resilience in social-ecological systems (Chapter 2)

4. Students conceptions of the human-ecosystem relationship varied and were not necessarily consistent with the conceptions presented in class (Chapter 2, 3, and 4)

5. Students' conceptions of the human-ecosystem relationship were influenced by how they described the relationship between natural and ecosystem. Students who described ecosystems as natural struggled with how to relate humans, human impact, and human artifacts (things people make) to natural, and therefore ecosystem (Chapter 4).

6. Students' experiences in large-scale ecosystems, as well as their perceptions of these experiences may influence their conceptual change of the ecosystem concept, as well as their awareness of their conceptual change (Appendix IV).

Students in both years of the study (2014 and 2015) experienced conceptual change. This, in and of itself, is important, since promoting conceptual change, particularly for concepts that may be well established, is challenging (Georghiades, 2000; Linnenbrink & Pintrich, 2002; Posner, Strike, Hewson, & Gertzog, 1982; Sinatra, Kienhues, & Hofer, 2014). While it was determined that students' conceptions of the technical term ecosystem were tied to the colloquial term natural, it was challenging to determine specific factors within the class that helped students develop integrated conceptions of ecosystems (Chapter 4). It is possible that specific assessments designed to target conceptual change regarding ecosystems and the ecosystem-natural construct would be helpful in identifying the factors that facilitated students' conceptual change, since our study relied primarily on student recall.

Language Embedded in Experience

One of the key overarching findings of this dissertation is the importance of creating shared meaning in the classroom, even for concepts for which one might assume that students already have shared meaning. Language and social interactions have meaning because we assign meaning to them, we build this meaning encounters with others and with the world (Lemke, 2001; Wickman & Östman, 2002). Therefore, knowledge and learning are dynamic, not static, and occur through social meaning-making (Lemke, 2001; Wickman & Östman, 2002).

Students in this dissertation drew from their personal experiences and background knowledge, and used this prior experience and knowledge to make meaning in different ways in the same social context. Individuals were involved in social interactions and, without knowing, making meanings based on differing conceptions. By not explicitly creating shared meaning of ecosystems in the capstone class, students integrated new information into existing knowledge in different ways.

How students integrated the concept of social ecological systems (SES) into their existing knowledge structure exemplified the phenomenon (Chapter 4). Two students determined that 'natural' did not include humans, and therefore humans and human artifacts were only part of SES. Two other students, using the same reasoning structure – things that are not 'natural' are only in SES not ecosystems – defined 'natural' as inclusive of humans, but excluding human artifacts. This led these two students to include humans in ecosystems, but only include human artifacts in SES. Students who did not think that ecosystems needed to be natural did not struggle to determine if humans and/or human artifacts were natural, they simply included both in an ecosystem. All of these students worked with the same conceptions, and experienced the same overall social context of the capstone course. However, their different background knowledge and assumptions (e.g., are ecosystems only natural?) influenced how they interpreted the class, and made meaning of a term new to many of the students, SES.

Implications for Instructors

My research supports constructivist teaching approaches that remind instructors of the importance of avoiding assumptions that students enter classrooms with the same background and conceptions (Bransford, Brown, & Cocking, 2000; Luykx et al., 2007). Even students at the end of their undergraduate degree, who are in the same major, and who have experienced the same general set of courses had widely varying conceptions of the term ecosystem (Chapters 2, 3 and 4). Therefore, it is important that socio-cultural theory (Lemke, 2001) and conceptual change theory (Chi, 2005; Georghiades, 2000; Linnenbrink & Pintrich, 2002; Posner et al., 1982) are used to help frame the development of the classroom curriculum and explicitly create shared meaning in the classroom, especially for key concepts.

As instructors develop curriculum, they also need to be aware of their own underlying assumptions of the common constructs they use in their courses because these personal biases influence how instructors present material (Luykx et al., 2007). Since students are not blank slates when they enter the classroom (Lemke, 2001), curriculum that requires students to build new knowledge anchored in existing conceptions is more likely be meaningful. In addition, these opportunities may cause some students to become dissatisfied with prior conceptions and subsequently motivated to resolve their misconceptions. There is some evidence that if instructors discuss their own experiences and provide examples with personal meaning, students are more likely to experience conceptual change (Heddy & Sinatra, 2013). In other words, when instructors create classrooms environments that recognize and legitimize the resolution of conceptual confusion, students may be more willing to replace prior conceptions with new ones.

Building rapport with students and helping them value their learning experiences are component of working to build a learning environment that fosters conceptual change (Balgopal, 2009). Balgopal (2009) found that undergraduate biology majors who were receptive to both the instructional style of the professor and to learning about evolutionary theory were the ones who underwent conceptual change, increasing their understanding of natural selection. Students who wanted to learn about evolution, but did not enjoy the instructional style, and vice versa, were not able to resolve conceptual confusion. In the current dissertation, students' awareness of their conceptual change may be another factor that influences conceptual change that warrants further study (Appendix IV). Because these factors dealt with students' experiences outside of the classroom, mentoring students may be an important component of facilitating conceptual change as well. Students such as Kevin likely could have gained access to the opportunities he was seeking, if he had better guidance in finding programs or jobs related to NRM while in his degree program. Furthermore, it is important to create opportunities for students who lack experience, so they are not stuck in the "can't gain access to experience because they have no experience" loop.

For students such as Denise (who initially excluded abiotic factors from ecosystems, and was unaware of her conceptual change), experiences outside of the lab may be important in conceptual development (Appendix IV). Therefore, it may be important to encourage students who are lab-focused to work in large-scale ecosystem settings, and to help them move beyond negative or neutral perceptions of these opportunities. While we do not know how Denise felt about being in outdoor large-scale ecosystem settings, or performing research in them, discomfort in these types of environments for students that did not have prior access to these environments may create an additional barrier (Soga & Gaston, 2016).

Implications for Research

Similar to the suggested implications for instructors, researchers also need to be aware of the influence of their own knowledge and assumptions, but in the context of framing research questions. I did not begin this dissertation research with any knowledge that students' conceptions of ecosystems varied greatly (Chapters 2, 3, and 4), nor that some students' conceptions of ecosystem were tied to their underlying assumption that the components of an ecosystem had to be natural (Chapter 4). If I had framed this dissertation research based on my assumptions of students' conceptions, Chapter 4 likely would have been a paper discussing the benefits of different instructional strategies on how students learned about resilience and systems thinking. While this is an important question, which is discussed more under 'future research,' our ability to understand the factors that influenced students' conceptual change would have been limited because we would not have known that their conceptions of colloquial terms (e.g., natural) influenced their meaning making about a fundamental concept.

Future Research

The findings from this dissertation indicate that future research on NRM students' conceptions is necessary. Due to the limitations in time and scope of a dissertation, and because research always leads to new research questions, there are still many questions to be asked, both within and beyond this study. Students' lack of shared conceptions regarding ecosystems indicate that they may lack shared meaning for other foundational conceptions important to natural resource management. Because of the socially-embedded nature of learning (Lemke, 2001), and the challenges of promoting conceptual change (Chi, 2005; Dole & Sinatra, 1998; Georghiades, 2000; Posner et al., 1982; Sinatra et al., 2014), students each make meaning through their lens of their own perspectives, and therefore will move through conceptual change in different ways and based on different reasoning. The initial research questions proposed for this dissertation addressed a much broader scope than the manuscripts within cover. The benefits, and challenges of constructivist grounded theory study lead to shifts and changes in research as it progresses (Charmaz, 2014). While the focused study of students' conceptions of ecosystems provides important insight into the way students construct one particular construct, the proposed research on systems, resilience, and social-ecological systems is still important.

In some ways, students' conceptual change regarding ecosystems was the least rich of the data sets collected during this dissertation research. Overall, students described their conceptions of systems, resilience, and social-ecological systems changing much more than their conceptions of ecosystems. Additionally, I had much less written data that demonstrated students' conceptions and potential conceptual change throughout the semester for ecosystems than for the other conceptions I collected data for in the interviews (systems, resilience, and social-ecological systems). The relationships between how students describe these different concepts in their interviews and write about them in their assignments may help provide more depth to our understanding of the processes that promote conceptual change in the capstone class. Because the students often struggled with conceptualizing an abstract system – many provided the concrete example of an ecosystem instead – the relationship between their abstract systems conceptions and other conceptions may be important as well.

Further study of the course context may also broaden our picture of students' conceptual change in the course. Two instructional strategies, the long-term group project and the guest speakers and stakeholder panels, both merit further study, and would add to the existing literature on NRM instructional strategies.

Long-Term Group Work

Several studies of NRM classes have discussed long term group work on an authentic project, but the studies did not have rigorous assessments of student learning outcomes (Arthur & Thompson, 1999; Berkson & Harrison, 2002; Habron, Goralnik, & Thorp, 2012; Pile, Watts, & Straka, 2012; Prokopy, 2009; Yeon-Su, Dewhurst, & Hospodarsky, 2007). Authentic projects are those that engage students in activities professionals perform, in the NRM this includes things such as developing management plans. While there have been extensive studies on small group work in science-related disciplines (Hmelo-Silver, 2004; Springer, Stanne, & Donovan, 1999; Walsh & Wicks, 2014), we have been unable to find literature that assesses the effectiveness of semester-long group work projects in capstone courses. In an International Business capstone class Paul and Mukhopadhyay (2005) found that their large group project and real-world problem solving situations significantly increased student learning, based on analysis of student surveys. Analysis of our data set could help provide insight about how these projects help students learn, as well as for instructors who want to implement authentic long-term group work, but need guidance. Because students often complain about long-term group work, further literature that supports its importance and effectiveness could also be used to justify its use.

Guest Speakers and Stakeholder Panel

The extensive use of outside speakers in undergraduate classes has been less studied than group work. In the NRM capstone class we invited both local stakeholders and guest speakers into the classroom. Local stakeholders were individuals influenced by management of the local watershed, including landowners, ranchers, farmers, as well as city, county, and federal employees involved in NRM. These individuals participated in stakeholder panels, where they answered students' questions. Students relied heavily on this material for one component of their management plan, the stakeholder analysis. I was unable to find any literature on the influence of bringing stakeholders into the classroom. While some literature may exist regarding this teaching technique, analysis of stakeholders in the classroom will help fill an existing hole in the literature.

Guest speakers were professionals or graduate students in their field, and brought in expert knowledge and opinions about many topics in the class. These individuals presented an entire lecture, and provided a significant amount of course content for the capstone class. Much of the literature I found from my search about the influence of guest lecturers in post-secondary education was in other fields, such as accounting and business (Karns, 1993; Metrejean, Pittman, & Zarzeski, 2002; Paul & Mukhopadhyay, 2005), but the results from these studies indicate that guest speakers are effective in facilitating student learning. Paul and Mukhopadhyay (2005) found that guest speakers significantly increased student learning, based on a student survey. For a marketing student capstone class, Karns (1993) statistically grouped student feedback on class activities, and found that guest speakers were the most preferred of all of the activities, and one of the activities perceived as most effective. Metrejean et al. (2002) evaluated student surveys of a guest speaker event over the course of five years. The students reported the event very helpful for many reasons that overlap with NRM, including: the many career paths available, the need to plan for both short and long term careers, gaining exposure to diverse views from people with different backgrounds and experiences, and gaining access to informal networking opportunities.

Students who participated in the event early on filled out surveys at the end of the study, providing longitudinal data, and they reported that the guest speakers had been very beneficial to them (Metrejean et al., 2002).

While guest lecture studies were performed in disciplines quite different from NRM, the importance of the guest speakers to the students in the other studies, and parallels that do exist between NRM and these fields, indicate that further study of our guest speaker data would add to the literature. All of the cited studies have weaknesses that our study shares – reliance on student perceptions, recall, and reporting to identify factors that fostered conceptual change. Our study would add particular depth to the existing literature, due to the presence of guest speakers throughout the semester, and extensive material that guest speakers presented. Additionally, while we are mostly reliant on student's reports of their conceptual change in the interviews, the written student data provides more depth to our data set. Our guest speaker data is particularly interesting, because the different speakers presented different perspectives, and we can analyze how these different perspectives influenced student learning and conceptual change in the class. Additionally, if warranted, it may be possible for me to interview some of the guest speakers and stakeholders we invited into the classroom. These additional interviews would add another perspective to a future study, which I have not seen in the published literature I reviewed.

Beyond this Study

Further studies that 1) dig deeper into students' conceptions of ecosystem, human, and natural, 2) work to understand why some students require ecosystem components to be natural, and 3) explore how to shift this conception, are necessary to help students develop integrated human-ecosystem conceptions. Additionally, the relationship between student conceptions, awareness of their conceptions, and experiences in large-scale ecosystems is another area where further research would be highly beneficial to the field of NRM undergraduate education, as well as undergraduate research as a whole. By better understanding and describing how students learn about ecosystems, NRM instructors can better design instructional environments to support learning.

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APPENDICIES

APPENDIX I: CHAPTER TWO 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, so 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, so 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 if, and if so, how has the work you did in NR 420 helped you be prepared for your current job.
10. Please describe if there were any aspects of nr420 that were particularly beneficial in preparing you for the field of nrm.
11. First, what would have helped you be more prepared for working in the field of nrm, first that wasn't part of NR420? Not part of your whole degree program?
12. Is there anything else you would like to add?

APPENDIX II: CHAPTER THREE INTERVIEW QUESTIONS

As part of a longer interview, all students were asked the following questions regarding their conceptions surrounding ecosystems.

1) 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?

2) 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?

3) 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?

4) 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.

   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?

APPENDIX III: CHAPTER FOUR INTERVIEW QUESTIONS

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?

APPENDIX IV: AWARENESS OF CONCEPTUAL CHANGE[6]

Theoretical Framework

Conceptual Change Model (Posner, Strike, Hewson, & Gertzog, 1982).

Research Questions

1. Was the way students described their conceptual change consistent with the conceptual change evident from their pre- and post-interviews?
2. What characteristics describe the students who are a) more aware or b) less aware of their conceptual change than most of the other students

Methods

The study context and data for this study are the same as those in Chapter 4, and it is also a grounded theory study.

Findings

Awareness of Conceptual Change

Students perceptions of their conceptual change were usually roughly in-line with the change we could detect, based on their pre- and post-interviews. Students were not always aware of more nuanced changes in their ideas, and were often vague in their language. Two students in the study, whose conceptions changed according to the continuum, did not fall within the general vague awareness of possible change of most students who shifted along the continuum. Denise's ideas changed, but she was not aware of this change, and Kevin was much more aware of his conceptual changes than other students.

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[6] The material contained in this appendix was originally part of the manuscript in chapter 4, but was separated out as its own story during the revision process. It is included because it will be developed into a full manuscript for submission, and it provides important information about students' awareness of their conceptual change.

Denise was the only student whose conceptions of change were clearly misaligned with the difference in her conceptions about ecosystems from the pre to the post interview. She was also the only student classified as ‘other’ on the continuum, because her conception of an ecosystem was not consistent with the basic, standard conception that all other students had – some variation on ‘an ecosystem is a system made up of all of the biotic and abiotic factors in a given area’ (Casper, Fernandez-Gimenez, & Balgopal, in review; Casper and Balgopal, unpublished manuscript). Instead, she explicitly excluded abiotic factors from ecosystems in the pre-interview, explicitly included abiotic factors in the post interview, and claimed that her ideas about ecosystems had not changed over the course of the semester, having been solidly formed long ago.

In the pre-interview Denise acknowledged that the concept of ecosystem was challenging, and open to change, but by the post interview she was closed to change. When discussing ecosystems in the pre-interview she stated, *“I would say it’s [an ecosystem is] the same definition as system, but specifically related to biological organisms, given that humans are also part of an ecosystem too.”* In response to the clarifying question by the interviewer, “*is it just biological organisms including humans, or does it include other components as well*,” Denise responded, *“I think just biological, is what I’m thinking right now.*” She discussed how her concept of ecosystems was influenced by lab work, and talked about her conception as something she was still developing:

> *I really started to think more about ecosystems working in that lab and being able to talk with other researchers who have some great ideas about ecosystem functioning as well. But, I feel like an ecosystem is something that I’m always thinking about, and I know there's so many different ways to think about what the scale of an ecosystem is. So, in some ways it's kind of been a challenging word for me to put a definition on really specifically, because I think depending on what scale you’re looking at it could be a lot of different things.*

In contrast, in the post-interview Denise's definition of ecosystems had shifted to include abiotic factors, but to explicitly include the built environment:

> *I would define it [an ecosystem] similarly to a system, but I think a system could apply to anything. It could be people, an environment, it could be a business, but I think an ecosystem is specific to the environment. And people can be a part of that environment …. I think, built structures are not part of an ecosystem. People are part of the ecosystem, depending on the scale …. it [an ecosystem] is biotic and abiotic.*

But, when asked about how her ideas about ecosystems had changed throughout the semester, she replied, "*I don't know that they really have been [changed]. I think I was pretty solid on like my abstract understanding of what an ecosystem was."* While Denise did state that the class, particularly the group work, helped her think about ecosystems at a large scale, since her lab research experience all occurred at a microscale, she was not aware that her concept had undergone a fundamental shift during the semester:

> *I think having experience at the microscale is helpful, and I spent 4 years kind of looking at that whole world, and this management plan was definitely on the macro scale looking at a while watershed. So I think it's good to have both of them.*

While Denise was the only student who excluded abiotic factors in an outright manner, one student, Sam, was a bit uncertain about how to situate abiotic factors in ecosystems in his pre-interview, "*when I think of an ecosystem, I know that it's very highly effected by the climate and topography, but I'm really just assessing the organisms within that environment, and basing itself off the organisms, not any abiotic factors."* By his post interview Sam inherently included both abiotic and biotic factors, "*I would define an ecosystem as a natural system that you think of on any scale that seems convenient, and within that scale has its own species and populations and its own unique abiotic and biotic factors."* However, like Denise, Sam was unaware of his recent uncertainty, *"My thoughts [about ecosystems] were probably extended but, I feel as* *though I had a rather set definition and idea of ecosystem coming into the class."* Therefore, both students who struggled with situating abiotic factors in relationship to ecosystems both had some shift in their perspective. But, by the end the course, both students thought their existing ideas had been solidly formed before the course.

While Denise included humans in ecosystems during both interviews, in the second interview she explicitly excluded the built environment. Because the built environment would generally classified as abiotic, these factors are inherently excluded when abiotic factors are excluded. Sam explicitly excluded human artifacts in both his pre- and post-interviews.

While Denise stood apart from others in the class due to her conceptual change, she was also different from her peers in her experiences with large-scale ecosystems. Unlike all of the rest of the participants, except Kevin, Denise did discuss any large-scale ecosystem experiences beyond those required for her degree program. Instead, she discussed her work in an ecosystem function lab, as well as her experiences as a journal editor. And, unlike almost everyone else in the study, she did not mention the required residential field course during her interviews. In her writing Denise talked about being from an urban background, and not having many of the outdoor experiences her peers had. And, while students had mixed opinions on the self-guided field trip required for the capstone class, Denise was highly critical of the requirement, and felt it did not help her learn:

> *The field trip as an absolutely waste of time. Uh, I don't think I used anything from that field trip. Maybe like a paragraph or two, that I could have written without going on the field trip …. because the substance of the field trip was not, there was no substance to it, it wasn't really that necessary to do.*

For this project, students traveled together in small groups through the watershed they were studying to answer research questions about the system.

In contrast to Denise, Kevin was more aware of his conceptual change than most students who changed. Instead of having a vague idea about conceptual change, when asked about how his ideas about ecosystems changed over the semester, he stated:

> *I think at the beginning of the semester I saw each, I saw ecology and humans separate from each other. And through our field trip especially I was really able to see how much impact both sides have on each other. And how meshed we really are. And I guess when I thought about a system at the beginning of the semester I just thought about different sets or groups of things and this class really helped me define it kind of at the landscape scale …. like when I talked about it [natural ecosystems] I was talking about how before the semester as humans and nature as separate from each other. And almost to the extent that like nature as in plants and animals and that stuff, everything would be completely. It would be, it would work different if we weren't involved, in some cases better. But now I realize that nearly every natural system is actually influenced by us*.

In these statements Kris clearly describes his conceptual change, from the initial interview, when he stated:

> *An ecosystem would just be a group of um, (pause) you know plants, animals, just beings, life, different life, working alongside each other. It doesn't have to necessarily be together, but, um, each being needs the other to survive. And prosper …. and ecosystem is kind of a term for just the way I see it it's just the, a thing to put on like a biome, you know.*

And added, in response to the question, "are there any things that you consider not part of an ecosystem, *"I mean aside from humans, I can't think of anything, because I mean topography and geography, that's a big part of how an ecosystem works."* To his final interview, when he defined ecosystem as:

> *An ecosystem I guess would be just a group of living species, living together. Um a lot of them would be interact with each other. Mostly um, and the ecosystem, like the general health of it would degrade if a lot of those if a lot of species were removed from it. So each species is integral and important.*

And added, when asked if anything was not part of it: "*at this point, I mean, at this point not really. I can't think of anything. I mean even, air quality effects it. So, I guess in a way we're all in this together.*"

Unlike all of the other students in the class, Kevin did not have NRM related job or volunteer experience, a fact he saw as problematic and was trying to remedy:

> *So far I haven't had any occupational work, or any volunteer stuff. That's something I've been looking to try to do this summer, since I need an internship to graduate, and I need to get in the field …. in order to boost my resume I've become a wilderness first responder.*

However, he enthusiastically talked about his residential field course, as well as the required self-guided field trip for the capstone course. As mentioned his quote above, Kevin talked about the field trip as influencing his concept of an ecosystem. For his field trip assignment, Kevin went far above and beyond the requirements of the self-guided field trip, engaging deeply in an assignment that required students to develop a question about the local watershed, spend time driving around the watershed collecting data to help answer their question, and synthesize their responses through video recordings made during the field trip and written work composed after the field trip. He talked extensively about the influence of his field trip during the interview:

> *The field trip was a great way for us to visualize what was actually happening in the system. I don't think we could have been as effective as we were in our management plan and resilience assessment without it …. I think that's [the field trip is] what made me really think about how much humans have affected our environment. We talked to the manager I forget the portion near the [river]. He really brought up a lot of the human impacts to the river and the dam and how it killed so many fish and that really hit home for me. That water is there just so we can have clean drinking water, I mean that dam is there because we had to drink water, and we killed so many fish just turning it off, you know. and he talked about how there was an oil spill right on the bridge, and there's just so many potential issues that can arise just by us being here and living in the lifestyle that we have.*

While Kevin talked a lot about the influence of the field trip throughout his interview, he also mentioned more types of influential factors as influencing his concept of ecosystems than any other student in the class. In addition to the field trip, Kevin stated that many other factors influenced his ideas of ecosystems in the class, including the group work, especially working with other students with diverse backgrounds; stakeholder panel; stakeholder analysis; guest speakers; exposure to different types of management; and the conflict simulation. Therefore, Kevin was aware of how he was influenced by many different types of experiences in the capstone class.

Another student, Dennis, started the class at Inclusion, but this conception was relatively new. He described his volunteer NRM experience in Thailand, which helped him develop an integrated conception:

> *I was thinking about this [an integrated human-ecosystem conception] a lot recently too, that we've lost. And, I realized this in Thailand, really like it was an epiphany for me. that, people are every part, like we're just another animal on this earth, and we have this amazing, like we've effected the ecosystems so much that we've kind of taken ourselves out of it, but we have this amazing chance to realize that we do effect and that we can modify what effect we do have on systems …. when I was in Thailand I was eating food that was growing food like 20 yards away from where I was sleeping and drinking water from the river and stuff, and so I was like, it was like an epiphany like I said that we are every part a part of the system as say like a tree or an animal.*

Even though Dennis' conceptual shift occurred before the capstone class, it was an intensive experience immersed in an ecosystem, where he could clearly see his integrated nature that helped him question his previous conception, consciously replace it with an integrated conception of the human-ecosystem relationship.

Contrasting Levels of Awareness

Denise and Kevin provide contrasts in awareness of conceptual change, particularly because of some of their similarities. They are the only two students in the study who did not discuss having experiences in outdoor settings beyond coursework (Kevin discussed his required residential summer field course and the field trip required for the capstone course, Denise only discussed the field trip for the capstone course). Denise and Kevin both wrote about growing up in urban environments, and how this limited their pre-college outdoor experiences. However, Kevin talked extensively about the influence of his in-class experiences in outdoor settings, whereas Denise did not. All of the relevant NRM experiences Denise discussed during her interview related to lab or other indoor settings (e.g. helping businesses look at their climate impact). Kevin was dissatisfied with his experiences, and was trying to change his lack of experience, whereas Denise was satisfied of her experiences, and talked proudly of being paid to work in a lab. Additionally, Kevin discussed six instructional strategies as influencing his conceptions of ecosystems, where Denise only talked about one.

We know that both students participated in at least some NRM experiences in outdoor settings, because of the field trip requirement in the course, as well as a required is a four-week residential field course for the NRM major. As discussed earlier, Kevin felt that he greatly benefited from his field trip experience, and thought it influenced his conceptions of ecosystems. In contrast Denise thought it was "a waste of time." While students' perceptions of the field trip project varied overall, Kevin and Denise's perceptions of the field trip fell at opposite ends of the spectrum.

Kevin and Denise were also contrasts in regards to the required field course. Kevin discussed his field course experience and its influence in his interview, "*I feel like when I went, when I first went into [residential field course] I didn't feel very confident in my major at all, and as soon as I got that over with, I was just like I can do this.*" While Denise must have participated in field-based NRM experiences in her field course, she never discussed these experiences in her interview. Many students discussed the field course in their interview, because they found the experience so influential. However, Denise only talked about her lab-based experiences when others talked about the field course and other outdoor experiences.

Discussion

Awareness of Conceptual Change

Kevin and Denise, who fall at the opposite ends of the spectrum of conceptual awareness, provide an interesting contrast, particularly due to their shared lacking in outdoor experiences prior to college, as well as their lack of large-scale ecosystem experiences during their undergraduate program.

It is possible that Denise did not see the inclusion of abiotic factors in an ecosystem as an important shift, even though this is a fundamental component of the ecosystem concept, and was key in the development of the field of ecology as a whole (Hagen, 1992; Lindeman, 1942; Tansley, 1935). Even in the second interview, the interviewer needed to explicitly ask Denise about the relationship between abiotic factors and ecosystems, she did not initially bring them up when describing her conception. While she included them when asked, they were not a key component she initially brought up, unlike other students in the study. Therefore, even though her conception shifted to include abiotic factors, it was not a component that stood out to her as important to initially include when describing ecosystems.

Scott’s shift was smaller than Denise’s but his similar lack of awareness indicate that these students may not see abiotic factors as highly influential, and therefore, inclusion or exclusion of abiotic factors in ecosystems may not seem like a significant conceptual change. This lack of awareness, and possible lack of importance is interesting, because it parallels some of the challenges that the field of ecology faced during its development in the early 1900s (Golley, 1993). While Tansley (1935) argued that it was important to include abiotic factors into the study system, Lindeman (1942) was the first to apply the concept of ecosystem to quantitative research, and 'ecosystem' did not become an organizing concept in ecology until after E. P. Odum used ecosystem in his popular text, *Fundamentals of Ecology,* first published in 1953 (Golley, 1993).

Because the exclusion of abiotic factors from an ecosystem parallels the historical development in the field of ecology, using a pedagogical approach that embeds ecosystems into a larger historical context may be effective in promoting conceptual change. By describing the historical development of the field of ecology and ecosystems, students' misconceptions are legitimized. Through following the shift to include abiotic factors, it is likely that students will need to grapple with limitations of their existing conception, and therefore are more likely to experience conceptual change (Chi & Roscoe, 2002; Posner et al., 1982). This strategy also contextualizes the knowledge.

Denise's experience working in a soil biodiversity and ecosystem lab for several years as an undergraduate makes her initial conception of excluding abiotic factors from ecosystems particularly surprising. Because of her experiences working in a lab focused on soils and ecosystem function, one might expect her to be much less likely than other students to exclude abiotic factors, instead of being the only student that excludes abiotic factors. But, the key to her initial conception may be in the micro-scale focus of her research within the lab. She, personally, worked on temperature tolerance of an invertebrate, and she was the only student in the study who did not talk directly (specific experiences) or indirectly (involvement with groups, such as wildlife or rangeland club) that involved interacting with ecological systems in outdoor settings. Therefore, she was very focused on a single organism in a lab setting, not interactions within a larger ecosystem during her research experiences.

Kevin's awareness of his conceptual change, and ability to specifically describe it, is particularly interesting in light of his lack of experiences in NRM beyond his degree program. It is possible that Kevin's lack of opportunities in NRM, despite his attempts to create opportunity, put him in a good position to respond strongly and positively to the experience and the assignment (Balgopal, 2009). Because the field trip was a noteworthy experience for him, it may have helped him be more aware of his conceptual change.

Therefore, both *exposure to* and *valuing* experiences in large-scale ecosystem settings (outside of their day-to-day life) may be important for students' conceptual development of ecosystems, as well as their awareness of their conceptual development. She and Fisher (2002) found that students can be unmotivated to learn because they don't trust the instructor, similarly Balgopal (2009) found that the way students resonated with an instructors' teaching influenced student's learning. Therefore, previous research supports our idea that students' perceptions of the material influence their learning.

Implications and Future Research

Further research needs to explore if experiences that are social or experiences that are alone matter. Students need to be given more opportunities for extra-curricular career-related experiences in large-scale ecosystems. While most of the students in our study already valued these type of experiences, not all did. Students who do not already value these experiences may be less likely to already have them or seek them out, as with Denise. Therefore, some students may need help in seeing the importance of large-scale ecosystem experiences so that they seek and value career-related experiences beyond the lab. While we know that most of our students were having experiences embedded in large-scale ecosystems outside of the classroom, we did not collect data on the specific nature of these experiences. It is possible that the type of experience, including the types of social interactions it involves (such as peer-peer, and mentor-peer), many influence student conceptual development, particularly since conceptual change studies often involve socially embedded interventions (Heddy & Sinatra, 2013). The social setting of an experience may also alter how a student perceives the experience, which, in turn, can alter how transformative the experience is. For example, in our study, Denise worked with others in her lab, but we were unclear if she worked with peers (other undergraduates) or only graduate students and those with PhDs. Additionally, the lab was not focused on NRM, so the cross-discipline dialogue may have created confusion. While the capstone course used the term SES frequently, it is not a term used frequently in the biological and ecological sciences.

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