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Exploration of Student Biodiversity Knowledge and Decision-making for a Wildlife Conservation Socioscientific Issue

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EXPLORATION OF STUDENT BIODIVERSITY KNOWLEDGE AND DECISION-MAKING FOR A WILDLIFE CONSERVATION SOCIOSCIENTIFIC ISSUE

by

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EXPLORATION OF STUDENT BIODIVERSITY KNOWLEDGE AND DECISION-MAKING FOR A WILDLIFE CONSERVATION SOCIOSCIENTIFIC ISSUE

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Global biodiversity, a foundation for ecosystem function, is diminishing at a rate unprecedented in the last 50 years. Biodiversity loss and ecosystem services deterioration is linked to increased food insecurity, reduced water quality and availability, decreased energy security, higher economic losses and human suffering (Millennium Ecosystem Assessment, 2005). Consequently, educators should invest in supporting students in their development of ecological understanding and formal decision-making skills so they are equipped with meaningful tools they can use as scientifically literate citizens. To contribute to that mission, this study seeks to explore student 1) comprehension and explanation of biodiversity concepts and 2) decision-making in the face of a conservation issue.

Past research shows that students at all levels of education have difficulty explaining genetic variability, which is a key concept underlying biodiversity, natural selection, and species conservation. In the first part of the study, I explore middle school, high school, and undergraduate student understanding of genetic variability in the context of a captive breeding program for wildlife conservation. Results suggest that several alternative conceptions of genetic variability persist across all grade levels.

In the second part of the study, I explore how undergraduate students make decisions in unstructured and structured decision-making settings when posed with a question relating to mountain lion conservation in Nebraska. Some variables (e.g., value orientations, demographic information, or ecology knowledge) are predictive of students' management decisions depending on the context of the question. Findings suggest that student decision-making may be more closely linked to students’ value orientations, social identity and conservation knowledge than to students' stated objectives and evaluation criteria related to mountain lion hunting. This study also suggests that a structured decision-making framework can be an effective tool to support students’ examination of value tradeoffs among options for solving complex problems. I provide teaching implications for using these tools in supporting students to make formal, holistic decisions for complex socioscientific issues that transfer to real-world contexts.

Dedication

I would like to dedicate this thesis to a few people very special to me. First, I dedicate this work to my parents, Susan Alred and Kelly Alred; my grandparents, Melvin and Edith Alred; my late grandmother, Catherine Smith; and my brother, Christopher Alred. Without all of their support, I would not be where I am today. Freedom and exploration is important in education, and I never felt unnecessary pressure to excel throughout school. My family provided a platform to express my views, as well as encouragement to travel around the country to pursue various employments, including this current opportunity to further my education. I am extremely grateful to have such loving people in my life. Thank you to all of my family.

I also dedicate this to one of my best friends, Chandan Gouri, who unexpectedly passed away two months before I defended this thesis. Chandan reminded me on multiple occasions that he had the utmost respect for me for pursuing a master's degree. Those words meant so much, not only because he was one of the most intelligent people I have ever known, but also because he believed wholeheartedly in my abilities every step of the way. I know he would have been proud of my work, and he is an integral part of why I persevered to complete it. Thank you for your support and friendship, Chandan.

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Finally, I want to thank the UNL College of Agricultural Sciences and Natural Resources, the School of Natural Resources, and the W.H. Thompson Scholars for funding my graduate research and teaching endeavors.

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CHAPTER I: DEVELOPING SCIENCE LITERACY FOR CONSERVATION

Since the state of ecosystems directly influences the sustainability of commodities we use on a daily basis, humans should have a vested interested in the responsible care of our lands and oceans. Aldo Leopold, the "father of wildlife management" and an avid naturalist and conservationist, understood the necessity of responsible land management. He promoted what he coined a "land ethic."

"The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land."

- Aldo Leopold (1949)

Essentially, we are each part of a worldwide community and have the responsibility to be stewards of the land to sustain it for perpetuity for all species. However, fostering a land ethic is easier said than done, and the rate of biodiversity loss is not slowing down in the near future. Steps need to occur with immediacy to shape a scientifically literate citizenry that values conservation and is equipped with tools to make responsible decisions with positive impacts for global sustainability.

Encouraging people to value our land and, specifically, biodiversity conservation, is a daunting challenge. One cannot value something in the absence of a meaningful connection or relationship with it. If you were to ask a random person on the street to care about one of your personal hobbies, could you expect that person to care about it if they do not even recognize the hobby, much less begin to understand the role it plays in your life and the lasting impacts it can have on an entire community of people who enjoy the same hobby? In the same way, we cannot expect everyday citizens to value conservation blindly and make conscious effort to make daily decisions to improve the Earth's sustainability. It is a tall order to ask people to commit to selfless acts without any background or motivation to do so.

"*Conservation, without a keen realization of its vital conflicts, fails to rate as authentic human drama. It falls to the level of a mere utopian dream.*"

–Aldo Leopold (Parkins, Whitaker, & others, 1939)

As societies become more urbanized, populations may become more removed and disconnected from nature. Additionally, people are faced with difficult economic decisions that may impact the environment directly or indirectly. Many people may hold intrinsic value for nature and appreciate that they can still "escape to nature" for recreation and relaxation. Over time, people can begin to lose sight of their connectedness to nature, whether consciously or unconsciously. Richard Louv coined the term "nature deficit disorder" to describe human's alienation from the natural world. In his book *Last Child in the Woods*, Louv also discusses how humans as a whole are detached from the source of their food (Louv, 2008). This increasing disconnect from nature relates to our detachment to individually taking responsibility to making environmentally sustainable decisions.

"*There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace.*"

—Aldo Leopold (Leopold, 1970)

If students have difficulty identifying the source of their food, water, and other commodities, we cannot reasonably expect them to recognize, without guidance and support, the importance of conservation for local species, much less conservation of global biodiversity. The United States, as well as other countries, promotes an individualistic culture, when in reality, we all share one planet collectively as a global community (Triandis, 1995). Landmasses may be privately owned and separated by human-determined boundaries, but ecological processes have no such strict bounds. Biodiversity loss is not confined to certain areas; species loss is felt through multiple trophic levels, across landmasses and oceans, and can have global impact (Millennium Ecosystem Assessment (Program), 2005).

Many environmentally minded people desire positive change and pay close attention to scientific evidence. Education and community engagement are two places where this positive change toward effective biodiversity conservation and global sustainability can begin. These two practices are best informed by scientific evidence whereby student understanding, for example, is continually assessed. The evidence then provides feedback for improved future instruction.

In terms of biodiversity education, what do students know about how the natural world works? How do students make complex decisions for a conservation issue? Our world is extremely complex in so many ways. The intricacies of biodiversity are just one part of what impacts our lives. Biodiversity, though, is integral to global ecosystem functioning. It is unnecessary for every student to deeply understand the inner workings of a bacterial community in a tablespoon of soil from the Amazon basin in order to make informed daily decisions. However, we also cannot expect students and citizens to be told to make decisions or vote a certain way for conservation purposes “just because it’s important.” For a scientifically literate citizenry, we propose that people must first develop a certain level of connection to nature by understanding aspects of how ecosystems function, as well as a capacity to make informed, holistic decisions. The starting point is assessing the current state of affairs in student knowledge and understanding.

This study seeks to understand students’ “current state of affairs” in relation to conservation education through exploring student biodiversity knowledge and conservation decision-making.

Objectives:

1. Explore how middle school, high school, and undergraduate students discuss genetic variability in relation to the conservation of a wildlife species.

2. Explore indicators of informal and formal decision-making by undergraduate students in the context of a wildlife conservation-related issue.

The culminating product of this study is a rich description of how students across broad bands of time think about genetic variability, as well as how a structured decision-making framework may support undergraduate student decision-making and transfer. We provide teaching implications based on our findings. By way of deliberatively assessing student knowledge and understanding, instructors and researchers can play a meaningful role in continually improving the educational experience of students one evidence-based step at a time. Perhaps such a commitment will contribute to the development of scientifically literate citizens who actively engage with others in making informed decisions supportive of biodiversity conservation for the benefit of the global community of which we are all a part.

"We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect."

–Aldo Leopold (Leopold, 1970)

CHAPTER II: BIODIVERSITY LITERACY

1 Introduction

Biodiversity education is one key to influencing a scientifically literate citizenry and environmental decision-making. In a world under the influence of anthropogenic transformation, it is increasingly important for citizens to be aware of how human actions influence ecological communities, specifically genetic variability. Human actions have decreased habitat availability and, consequently, decreased ecological biodiversity (Butchart et al., 2010). Biodiversity loss sometimes results in species extinctions and alterations in ecological community structure and functioning. Occasionally, entire ecosystems are lost (Vitousek, Mooney, Lubchenco, & Melillo, 1997). The current rate of extinction is 1000 times higher than the background rate, which equates to 1000 species lost per million species per year (Dirzo & Raven, 2003). Dirzo & Raven (2003) pessimistically predict that by the end of the 21^{st} century, two-thirds of global species will be extinct.

At the consumer level, we depend on the maintenance of biodiversity for the sustainability of our world's resources for production of everyday goods and services needed for survival. These ecosystem services, which include but are not limited to food production, climate regulation, disease mitigation, medicinal treatments, species gene pool viability, recreational opportunities, and spiritual benefits are directly and indirectly impacted by the biodiversity level in a given area. While humans have certainly benefited from the exploitation of biodiversity and the conversion of natural habitat to a human-dominated landscape, there are also negative consequences due to the Earth's subsequent diminishing biodiversity. These consequences include a lower standard of living or sometimes a path to poverty for entire communities of people (Millennium Ecosystem Assessment (Program), 2005). Unfortunately, poorer communities are disproportionately negatively impacted by the loss of biological resources. The Millennium Ecosystem Assessment (2005) found biodiversity loss and ecosystem services deterioration to be linked to increased food insecurity, reduced water quality and availability, decreased energy security, higher economic losses and human suffering, poorer health, and damaged social relations. Although biodiversity has value and is the backbone of many ecosystem services, the monetary value of biodiversity is not accurately represented by current standard economic measures (Millennium Ecosystem Assessment (Program), 2005). The true value of biodiversity is poorly reflected economically and is sometimes difficult even to calculate due to the natural complexity of ecosystems and different emerging models of biodiversity decline (Pimm, Russell, Gittleman, Brooks, & others, 1995). In a global economy, biodiversity protection is thus not always a priority.

Even though economists do not always place accurate monetary value on our resources, it remains important for students to understand how ecological changes, such as biodiversity loss, can have real consequences in their lives. A working understanding of ecological biodiversity can encourage an engaged citizenry that makes responsible decisions to impact future species conservation. One key component of a deeper biodiversity understanding is the role genetic variability within populations plays in species conservation. Within species, genetic variability can be described at three levels: 1) within an individual, 2) between individuals in a population and 3) between populations (Dirzo & Raven, 2003). Our study specifically examines student understanding of genetic variability between individuals in a population and between populations. A population’s ability to respond, or resilience, to environmental stressors, such as the direct and indirect impacts of global climate change, is dependent upon the population’s genetic variability. A population with low genetic variability is more vulnerable to environmental threats such as habitat change and disease, as well as inbreeding depression that results in lower survivability and decreased fertility (Charlesworth & Willis, 2009). The more varied the collective genes are within a population, the more resilient the population will be to environmental change, and the more likely the species will persist into the future (Sgrò, Lowe, & Hoffmann, 2011). High genetic variability is therefore key to successful species conservation, and ultimately to biodiversity conservation at the community scale (Dirzo & Raven, 2003).

The United States' education system recognizes that biodiversity education is important for students. The Next Generation Science Standards (NGSS Lead States, 2013) emphasize that students should understand genetic variation and its relationship to natural selection, adaptation, population resilience, and ultimately biodiversity. As early as elementary school, students should be able to describe that variability exists between individuals and that this variability can influence survival and reproductive success of individuals within a population. Additionally, survivability of individuals can be dependent on the habitats in which they live. By the end of middle school, students should be able to explain more deeply how genetic variability impacts survival and reproductive success in terms of natural selection and adaptation, and that distribution in traits within a population changes over time. They should also understand that the process of a species changing over time through succeeding generations is a response to changes in environmental conditions. In addition to understanding that genetic variability exists in populations, high school students should recognize that variability also exists in the *expression* of individual traits and that this trait variation leads to differential survivability and reproduction within a population. By the end of high school, students are expected to have a deeper understanding of adaptation and natural selection in terms of mutation, sexual reproduction, competition for resources needed for survival, and that differential survival, based on genetic variability and expression, leads to the biodiversity we have on Earth (NGSS Lead States, 2013).

1.1 Challenges to Understanding Genetic Variability

Despite the magnitude of biodiversity loss and its reverberating impact on the world, the ill-structured and abstract nature of biodiversity concepts, like genetic variability, proves challenging both for teachers in creating clear lesson plans and for students to comprehend (Ramadoss & Poyyamoli, 2011; Van Weelie & Wals, 2002). There has been significant work on students' alternative conceptions related to biodiversity and genetic variability, as well as cognitive construals that may underline these alternative conceptions.

1.1.1 Alternative conceptions: psychological underpinnings to student understanding

Alternative conceptions, or misconceptions, are believable, alternative understandings developed based on prior knowledge and experience (Munson, 1994) that can prevent students' deeper, accurate comprehension of complex ecological concepts. They represent conceptions contrary to accepted scientific theory (Bishop & Anderson, 1986). Although alternative conceptions can be challenging to overcome, they are still productive because they are a point from which to construct new knowledge. In the past, instructors viewed alternative conceptions as flawed ideas that must be replaced (Smith III, Disessa, & Roschelle, 1994). However, students do not hold alternative conceptions lightly; these ideas are deeply ingrained in their schemata and cannot be easily confronted by traditional means and quickly replaced. Constructivist theory states that more advanced knowledge is constructed from prior knowledge (Smith III, Disessa, & Roschelle, 1994), so this "replacement" theory conflicts with the basic underpinnings of constructivism. Alternative conceptions are the starting point: science instruction cannot improve without an understanding of the depth of their roots in students' prior knowledge frameworks (Carey, 1986). Once teachers identify alternative conceptions to ecological concepts such as genetic variability and biodiversity, they can more effectively facilitate learning so that students reconstruct knowledge in an accurate way that is transferable to other areas of study (Bruning et al., 2011).

1.1.2 Cognitive construals driving ecological alternative conceptions

Variability of individual organisms within a population is central to understanding evolution because natural selection acts on this variability (Anderson, Fisher, & Norman, 2002; Nehm & Reilly, 2007). It follows that species conservation management is dependent upon understanding these connections. However, students hold a host of alternative conceptions about natural selection, even at the undergraduate level (Nehm & Reilly, 2007). Students specifically have difficulty reasoning about natural selection at the population level (Lehrer & Schauble, 2012). Connected to this notion, two common alternative conceptions undergraduate students have of natural selection relate to 1) an understanding of intraspecies variation and its influence on natural selection and 2) how a species accumulates adaptations over multiple generations (Ferrari & Chi, 1998). Some of students' alternative conceptions of ecology may be rooted in several informal methods of interpreting the world, or their cognitive construals. Two cognitive construals in particular may influence development of these alternative conceptions: teleological and anthropomorphic thinking.

Teleological thinking is the idea that there has to be a reason, or cause, for a phenomenon. Coley and Tanner (2012, p. 210) provide the examples of "Birds have wings so they can fly" and "Evolution is the striving toward higher forms of life on earth." Teleological thinking can be productive, as it helps beginning learners make sense of the world. However, students sometimes make inappropriate teleological connections (Coley & Tanner, 2012). Concerning evolution by natural selection, students may have the alternative conception that individual animals can "learn" and "change" adaptations as a goal to survive a changing climate, which is an inadequate understanding of the mechanisms of evolution (Bishop & Anderson, 1986). This thought process emphasizes adaptations as an individual goal rather than part of a process of population change over time through multiple generations. Even at the undergraduate level, students express teleological thinking when they think new traits or adaptations result from individual animals "generating" them out of necessity rather than through random genetic mutation and sexual recombination (Bishop & Anderson, 1986).

A second type of informal thinking is anthropomorphic thinking, which occurs when students understand unfamiliar organisms or processes based on analogy to humans (Coley & Tanner, 2012). For example, a student may think that all animals live in family units and the parents "teach" instincts to their young. Anthropomorphic thinking may influence students' understanding of conservation in the way they think about mechanisms of survival and reproduction. Some students, for example, think that a species' survival is dependent upon the "parents" teaching survival skills to their young, rather than the reality of natural selection acting upon the existing genetic variation within a population.

Both of these teleological and anthropomorphic cognitive construals ignore the value and function of genetic variation within a population for determining a population's survival in response to environmental change. The focus on individuals rather than entire populations in terms of generating or learning adaptations causes students to miss the role genetic variability plays in evolution by natural selection over multiple generations. Using these lines of thinking, variation would not be important at all for species conservation.

1.1.3 Recognizing that variability exists among individuals and populations

For students to understand and evaluate the larger issues of biodiversity and conservation, they first need to develop an understanding of what genetic variability is and how it influences populations over time. Students have difficulty even at the basic level of identifying different kinds of species (Randler, 2008) and recognizing that variability exists among individuals within a population (Ferrari & Chi, 1998; Lehrer & Schauble, 2012), both of which are building blocks to understanding ecosystem biodiversity.

2 Objectives

To explore student understanding of species conservation, we used a learning progression approach to evaluate student explanations. This research contributes to a broader effort to describe a learning progression for community ecology (Zesaguli et al., 2009; Hartley, Anderson, Berkowitz, Schramm, & Simon, 2011), of which biodiversity and, more specifically genetic variability, is of focus. Learning progressions describe increasingly sophisticated levels for how students explain topic concepts (Duncan & Rivet, 2013; Duschl, Maeng, & Sezen, 2011). Previous biodiversity learning progression development used environmental systems literature to hypothesize a lower level of sophistication for how students reason about biodiversity and used ecological literature and the Next Generation Science Standards (NGSS Lead States, 2013) to define an upper level of sophistication. The empirically collected data in this study contributes to refining the lower and upper levels for how students understand genetic variability, as well as to define middle levels of sophistication (Hartley et al., In preparation). The community ecology learning progression describes how students explain concepts related to individual, population and community ecological dynamics and responses to a changing environment in broad bands of time from middle school to college (Hartley et al., In preparation). This work is foundational research specifically on students' understanding of population-level processes that will be useful in building a theoretical learning progression.

To elicit student scientific or informal explanations of genetic variability, we asked students about a scenario related to conservation. Our research question was "How do middle school (MS), high school (HS), and undergraduate (UG) students address genetic variability, natural selection, and ecological resilience during explanations of a captive breeding program?"

We examined data from grades 7-12 and the undergraduate level in order to clarify, expand, and validate the biodiversity learning progression framework across broad bands of time.

This study was designed to reveal student thinking about genetic variability, which will ultimately allow us to develop adaptive instructional methods to address gaps in knowledge integral to understanding topics of ecological biodiversity.

3 Methods and Data Collection

To learn more about student understanding of biodiversity, a written prompt was created to ask students how they would choose individual animals for a captive breeding program. We collected student written responses and conducted interviews to develop a coding framework to describe students' biodiversity knowledge sophistication in relation to genetic variability.

3.1 Middle and High School

Middle schools and high schools in five different states (California, Colorado, Maryland, Michigan, and New York) participated in this study. Data was not systematically taken on whether or not students had prior lessons related to genetic variability.

3.1.1 Middle and high school written responses

Student written responses were collected (*n*=665) in 2010-11, 2011-12 and 2012-13. The written responses were administered during class time on classroom computers. There was no time limit given, but students usually had the length of one class period to complete the task. The interviews were conducted in person within a few weeks of the written response activity.

Depending on the location of the school, the written prompt reflected a local wildlife species. Species for the middle and high school prompts included the polar bear (*Ursus maritimus*), lynx (*Lynx spp*.), shortnose sturgeon (*Acipenser brevirostrum*), snowy plover (*Charadrius nivosus*) and Kirtland's warbler (*Setophaga kirtlandii*).

> Prompt: "If you wanted to preserve the [insert animal species], an endangered [animal type] in [geographic location], by starting a captive breeding program and then reintroducing the offspring into the wild, how would you select a group of [animal species] for your program? What characteristics would you look for? How many [animal species] would you choose?"

All students completed the written response electronically, and those data were downloaded and de-identified in a spreadsheet.

3.1.2 Middle and high school interviews

Think-aloud interviews were conducted within weeks of collecting the written responses. These were clinical talk-aloud interviews (*n*=17) that lasted 15-30 minutes. During the interview, students were instructed to read out loud the prompt and their written response. Afterward, students were asked a series of follow-up questions, which provided students an opportunity to expand upon their written response. Interviews served to gain a more in-depth understanding of what the student meant in their written response, as well as to validate whether the original written prompt elicited an accurate representation of students' understanding. In this study specifically, the interviews' primary purpose was to inform the development of the captive breeding coding framework. The semi-structured interviews were audio-recorded, transcribed, de-identified, and entered in a spreadsheet.

3.2 College

College-level data for this project were obtained from students enrolled in a required introductory undergraduate science literacy course, *Science and Decision-making for a Complex World* taught at a large Midwestern university. These students represented STEM (two-thirds of class) and non-STEM (one-third of class) majors. The course was structured around four two-week instructional units exploring controversial socioscientific issues salient to Nebraska. The unit of focus for this study is the controversial issue of mountain lion management in Nebraska.

3.2.1 Undergraduate interviews

In fall 2014, we used convenience sampling to recruit 15 students from two undergraduate lecture sections to participate in pilot exploratory interviews. All students in this sample previously responded "Yes" to the IRB consent form. Two researchers independently conducted the interviews, and students were compensated for their time with $20.00 for a 45-60-minute interview. These interviews included scripted questions about an in-class decision-making assignment as well as the captive breeding prompt, the latter of which is the data included in this study.

The species chosen for the undergraduate interview prompt is another predator with small population numbers in the Midwest, the swift fox (*Vulpes velox*). The following questions, modeled after the middle and high school questions, were posed to interviewees (for full list of follow-up questions, please see Appendix A):

> Prompt: "Imagine you are a wildlife biologist and you want to preserve one of our endangered predators in [state], the swift fox, by starting a captive breeding program and reintroducing them into the wild.
>
> A. What is the purpose of a captive breeding program?
>
> B. How would you select a group of swift fox for your program?"

The wording was modified from the middle and high school prompt in that the question was framed as if the student was specifically a wildlife biologist (rather than as if they were just an everyday person), and the species was relevant to Nebraska specifically. We did not initially ask the two specific follow-up questions after Part B of what characteristics they would look for and how many individuals they would choose, as was asked for the middle and high school students.

We found in middle school and high school written responses those two prompts were not especially useful in soliciting distinguishing information from students and distracted from the main interview goals, so they were only asked after their responses to A and B. We wanted to see how undergraduate students immediately described their selection process and if they mentioned variability from the onset.

3.2.2 Undergraduate written responses

The undergraduate written response data were collected from a separate pool of students one year after the undergraduate mountain lion interviews. In fall 2015, written response data were retrieved from two undergraduate lecture sections with 109 students in the first section and 114 students in the second section. Inclusion criteria were used to collect student data. Data were only included for students who 1) responded "Yes" to the IRB consent form and 2) completed the Ecological Knowledge Assessments. The final sample size for the written responses consisted of a total of 134 students from the combined two lecture sections.

The written responses were part of an optional bonus quiz administered through an online Qualtrics survey during the mountain lion unit. The prompt was similar to that asked during the undergraduate interviews, and the swift fox was the focus species. It asked students "How would you choose a group of swift fox for the captive breeding program?" However, "What is the purpose of a captive breeding program?", a question only asked during the undergraduate interviews and not the middle and high school prompts, was removed because students' responses to this question during the interviews did not contribute to understanding what students know about genetic variability. The question "How many swift foxes would you choose?" was added back to the undergraduate written prompt as it was written in the original middle and high school prompt. There were also no follow-up questions asked after the student's initial response to questions A and B as was done in the interviews. We did not find it necessary to provide the additional questions about characteristics and the number chosen (as in the middle and high school responses or the undergraduate interviews) because overall, student interview responses to those questions were mostly arbitrary and did not effectively elicit reasoning related to variability. There was no word limit imposed on these questions.

3.3 Coding Framework Development and Data Analysis

We performed multiple iterations of emergent coding to produce three levels of biodiversity knowledge sophistication for the captive breeding question beginning in summer 2014. The middle and high school interviews informed the initial framework to code the written responses because the interview responses were much more extensive than the written responses and thus provided insight into the wide range of possible student responses. After reading through the interviews multiple times and memoing about possible categories, preliminary indicators were developed for how students reasoned about how they would choose individuals for a captive breeding program. Multiple iterations of emergent coding were performed by a collaborative research team of five researchers to produce three levels of biodiversity knowledge sophistication for this item.

Although genetic variability was the original topic of focus for this study, three dimensions (i.e., progress variables) were identified with which to categorize student responses: “Variability,” “Purpose of a Captive Breeding Program,” and “Traits.” Within the three dimensions, “Low,” “Medium,” and “High” categories were developed to describe students’ level of knowledge sophistication within each of the three dimensions. Finally, specific coding sub-indicators were developed within the each of the “Low,” “Medium,” and “High” categories to help coders more precisely distinguish between “Low,” “Medium” and “High” categories (See Appendix B).

3.3.1 Middle and high school written responses

A spreadsheet was used for all coding procedures for the written responses and interviews. Preliminary development of the emergent coding framework was informed by the 17 think-aloud interviews. After primary researcher created the preliminary coding framework, the full team of researchers began the coding process. A sample of 3 of the 17 student think-aloud interview responses were assigned for developmental coding, then approximately 20 written responses were assigned to all four coders to see if consensus could be reached at the Low-Medium-High level before moving on to code all responses. Upon reaching consensus on the samples, full coding and reliability coding was assigned to 4 coders for all of the written responses (*n*=567).

After each round of practice coding, adjustments were made to the indicators to be more representative of the written responses. After the first reliability check, agreement among the four coders for all three dimensions fell in the range of 65-80%. After the second round of coding, average agreement was 85% for Variability, 84% for Purpose of a Captive Breeding Program, and 83% for Traits. After the third and final round of coding, average agreement was 89% for Variability, 84% for Purpose of a Captive Breeding Program, and 83% for Traits.

3.3.2 Undergraduate interview responses

The captive breeding responses from the fall 2014 undergraduate interviews (*n*=15) were coded using the Captive Breeding Coding Framework. Two researchers coded these responses. While there were some discrepancies on some of the sub-indicator coding, 100% agreement was reached for coding the main category level of “High-Medium-Low” for each of the three dimensions (Variability, Purpose, Traits).

3.3.3 Undergraduate written responses

The written responses (*n*=134) from the fall 2015 “bonus quiz” were initially coded using the same Captive Breeding Coding Framework that was developed for the middle school and high school responses. Three researchers coded these responses. After a few practice coding rounds, though, it was determined that the responses should only be coded for the Variability dimension, as the Purpose of the Captive Breeding Program and Traits dimensions added very little additional information for what students understood about genetic variability, which was the primary intent of the question. Even though undergraduate students would sometimes talk about reproduction (Purpose of a Captive Breeding Program dimension) or traits (Traits dimension), we wanted to focus on the students’ ability to talk about genetic variability in relation to the captive breeding program. It was useful to use emergent coding categories for the middle and high school students as a way to describe everything students say in relation to the captive breeding program, and distinguishing between Variability, Purpose and Traits may be useful for other contexts in the future. However, ultimately, the focus of this study is how students reason about genetic variability specifically, so for the undergraduate data we focused on only the Variability dimension code for analysis.

4 Results and Discussion

Students at the middle school (MS), high school (HS), and undergraduate (UG) level seldom mentioned genetic variability in their responses to the captive breeding program prompt. The students who did so rarely explained genetic variability with high sophistication, suggesting that most students do not recognize the importance of genetic diversity for population resilience. Alternative conceptions related to genetic variability persisted across all levels of education, some of which are consistent with the existing ecological alternative conceptions literature.

4.1 Variability Themes and Alternative Conceptions: Exemplar Students

We found three levels of proficiency in students' explanations of genetic variability for the captive breeding program. We provide exemplar student responses in Table 4.1 to illustrate these three sophistication levels. We also describe separate themes that were found within each level of proficiency. The following responses are drawn from the middle school and high school responses that informed the development of the captive breeding coding framework. Alternative conceptions present at all levels of education are discussed. For the purposes of this discussion, these alternative conceptions are representative of both the Variability category and the Traits category since there was much overlap between the two categories in terms of students' discussion of genetics.

4.1.1 High level sophistication (Level 3): Variability for population resilience

Students in this category explained that individuals should be chosen for the captive breeding program in a way that 1) increased genetic variability in the population and 2) linked variability to the success of future generations. One key commonality in these responses is students linked the choosing of individuals to how it would impact their offspring. Students in this category expressed that, given there is a variety of individuals in the population, there is a higher chance of future population survival through the generations. For example, Student 757 said, "I would probably choose polar bears that are diverse. This way, the offspring would not be very similar and there would be more of a chance that some would have characteristics that helped it survive in the wild." This student recognizes the importance of variety for sexual reproduction.

Some students took their explanations a step further and mentioned environmental uncertainty as a reason to emphasize genetic variability. Student 792 said, "I would choose fish with as many different characteristics as possible. If I pick fish with many similar characteristics than if something came up, all the fish would be wiped out because of the lack of biodiversity…" This represents a target response for what we would want students to understand. The response is short and to the point, but the student shows they understand genetic variability is important for the species at the population level because it contributes to population resilience when faced with future environmental change.

Within this "High Level" category of responses referencing environmental change, some students mentioned a specific threat. Student 1078 said, "…choose individuals of mass variety or else it could come to a point where the genome is so consistent that one targeted disease to the genome would wipe out the whole population (or at least has potential to)." This is also a target response because the student is demonstrating their accurate understanding that a homogenous population is vulnerable to disease and a population's resilience to disease is dependent upon its collective genetic variability.

These are some of the most sophisticated responses and are representative of what the baseline goals are for student understanding of genetic variability. These students grasp that genetic variety is key to helping a species be resilient in a world where climate change, habitat loss, or disease can pose a very real threat to wildlife populations. Populations with little genetic variability are much more vulnerable to extinction, which could have lasting impacts on the rest of the ecosystem of which they were a part.

4.1.2 Middle level sophistication (Level 2): Variability is important

Students in the middle level category recognized that variability is desired and important for a captive breeding population, but they did not specifically connect genetic variability to future generations, population resilience, or an uncertain future environment. For example, Student 954 said, "I would get different types of Polar Bears so their offspring would not be all the same." Similarly, Student 593 said it did not matter how many sturgeon were chosen, but that variety was important: “Select the most capable fish whether it be by age length, weight, sexual maturity. There would not be a certain number but enough to increase genetic variation.” However, these are incomplete explanations in that they do not say why variation in offspring is important. Additionally, Student 593’s inclusion of the word “capable” may allude to an alternative conception of anthropomorphism or an emphasis on focusing on the individual organism level rather than variability at the population level. The majority of student responses categorized as Level 2 reflected similar reasoning.

Like Student 954, students did not always use the words “diversity” or “genetic variability,” but explained that the best approach would be to select individuals randomly or select a large number of individuals. Variability was inferred in these instances. Student 1075’s explanation represents this well: “The polar bears should be selected randomly to be sure you don’t get a group of polar bears that are very close related. You also want to get them from a similar area to be sure that they will be able to get along and mate.”

In contrast to choosing individuals based on phenotypic or genotypic differences, some students focused on choosing individuals from different geographic regions as a way to increase variability for the captive breeding program. For example, Student 1166 said, “I would choose birds (warblers) from several different locations. I would make sure they have beneficial characteristics for the environment they are inhabiting. I would choose around 40 each of males and females.” With the exception of one sturgeon prompt response, all of the Level 2 responses mentioning location variability were in the context of the warbler prompt. All of these location variability-related warbler responses (n=7) came from the same state, but from different middle and high schools. We are uncertain why location variability seemed to be associated with warblers. It could have something to do with the state curriculum, or local knowledge about this species, or in how students think about spatial locations and habitats of small birds versus other species like sturgeon that may be more spatially confined. Further investigation would need to be performed to answer this question.

4.1.3 Low level (Level 1) sophistication: Dichotomous variability or does not value variability

Student responses in this category reflected a focus on the act of breeding, as well as the types of traits, typically personality-related, they would choose in individuals. There was a lack of regard for having a diverse pool of individuals. For example, Student 1092 focused on physical traits when describing how he or she would pick individuals: “I would pick healthy big cats. Strong coloring, a thick coat, and strong claws. I would pick 6 girls and 6 boys.” Anthropomorphic descriptions were common within this coding category (See Section 4.6.1).

4.1.4 Not applicable (NA): No variability explanation

Student responses in this category did not include an explanation of variability. Some students simply mentioned how many individuals they would select for the program. For example, Student 17a said, “I would have at least 100 newborns because some may run away but most would stay.” Sometimes the student only focused on physical characteristics. Student 17b said, “The characteristics that I would look for is intelligence, bravery, quickness, and coming up with great plans.”

4.2 Student Written Response on Variability: All Education Levels

For all levels of education, less than 50% of students mentioned variability at a Level 2 or 3 in their response to the Captive Breeding prompt (See Table 4.2). Very few students (MS: 0.37%, HS: 3.05%, UG: 8.96%) explained genetic variability at the highest sophistication level (Level 3).

Across all levels of education, 4 to 10 times as many students provided Level 2 than Level 3 explanations of Variability. These results tell us that students are more likely to explain genetic variability at an individual survival level (Level 2) without a clear connection to the mechanism by which genetic variability relates to conservation. Students are less likely to explain the importance of genetic variability in terms of Level 3, population level resilience. Ideal student achievements would include student explanations of genetic variability at the forefront of students' responses to a question about conservation of a species, since genetic variability is key to population-level resilience in the face of environmental change.

4.3 Student Written Response on Traits: Middle and High School Levels

Compared to middle and high students' inclusion of variability concepts, a greater percentage of students generally discussed traits with more sophistication (See Table 4.3). In particular, many students achieved a Level 2 explanation that included discussing traits desirable in a captive breeding program. Level 2 responses reflected student knowledge that traits were passed on genetically, linked to reproductive success, or reflected a valuing of traits that would increase individual survival. Within the Level 2 responses, there were a notable higher percentage of students within the Traits category (MS & HS: 68%) compared to the Variability category (MS & HS: 17%). However, for both middle and high school levels, the percentage of students in the Level 3 category remained identical to that reported in the Variability category because the Level 3 category was essentially the same for both categories: responses had to include a description of wanting genetic variability at the population level for the purposes of future generational resilience. Essentially, if a student was coded a Level 3 for Traits, the student was also coded a Level 3 for Variability. In comparing the trends seen within the Variability and Traits categories, students were more likely to discuss choosing individuals based on specific traits they thought would increase the likelihood of survival or reproductive success for the species at the individual level than discuss choosing individuals according to genetic variability. In line with other findings in the literature ((Bishop & Anderson, 1986; Ferrari & Chi, 1998; Lehrer & Schauble, 2012)focused on student difficulties connecting genetic variability with natural selection and evolution, our results support that students also neglect to talk about or link genetic variability to the conservation success of a species. Additionally, as found in several other studies, students are more likely to talk about genetics in terms of individual survival and reproductive success and are less likely to make genetic connections at the population level.

4.4 Student Written Response on Purpose of a Captive Breeding Program: Middle and High School Levels

While "Purpose of a Captive Breeding Program" was one of the emergent themes from the data (See Appendix B), it was not necessarily an important contribution to understanding the focus of this study: student understanding of genetic variability. Students at a Level 3 (High Sophistication) expressed that the purpose of a captive breeding program was to 1) breed more individuals to release into the wild or 2) create a diverse captive population that would be resilient for a changing environment. Only 9% of students achieved a Level 3. Students at a Level 2 expressed that the purpose was to 1) breed more individuals or 2) save the species but did not recognize a future changing environment. The majority of students who mentioned the purpose of the captive breeding program fell in the Level 2 category (35%). Finally, students at a Level 1generally expressed concern for sick or injured animals, while others indicated the animals would remain captive for human benefit (8%). The remaining 48% of students did not mention the purpose of a captive breeding program (NA). Overall, approximately 52% of students explicitly mentioned the purpose of a captive breeding program. While the written prompt did not direct students to explain the purpose of a captive breeding program, perhaps such a direct question would provide insight as to why students provided certain responses. It is possible that students with a better understanding of a captive breeding program would be better equipped to discuss genetic variability. This could be a consideration in future research design.

4.5 Interview Summary

All 17 middle and high school students who interviewed also completed the written prompt prior to the interview. Of the written responses, only three students originally mentioned including variability (at a Level 2 sophistication) when choosing individuals for the captive breeding group, and the remaining 14 students did not mention anything about variability (See Table 4.5).

Once students were interviewed, nine students talked about variability being a positive consideration for a captive breeding program: eight students talked about variation at a Level 2 and 1 student talked about variation at a Level 3. Only one of these students mentioned variability *without* any prompting from the interviewer, and five students were able to talk about variability *with* supportive prompting from the interviewer. The remaining three students who mentioned variability were those who originally mentioned variation in their written responses. Thus, it appears that students' responses to the written prompt were representative of the students' knowledge of genetic variability within the context of a captive breeding program.

In contrast to the middle and high school interview results, almost all undergraduate students mentioned variability in the interviews. Of the 15 undergraduate students interviewed, 14 students mentioned variability in their response, and a majority (*n*=12) explained Variability at a Level 3. However, only three of these 12 students were able to talk about variability at a level 3 without follow-up questions from the interviewer that provided additional prompts. Since these interviews included semi-structured follow-up questions to clarify what students meant by their responses, it provided the opportunity for greater expansion of their thought processes and gave a better representation of what students knew about genetic variability than was seen for the undergraduate written responses.

Within the 12 Level 3 undergraduate interview responses, we noticed nuanced differences in sophistication that revealed some gaps in understanding of genetics or natural selection. In less sophisticated Level 3 responses, students mentioned that inbreeding should be avoided, but the response revealed students' limited understanding of what inbreeding could mean for a population. For example, Student U represents a "lower" Level 3 response:

> "You have to think about how you can spread out the genes so you don't just create one family that interbreeds of foxes because that's ultimately going to harm your population we think… Inbreeding has been shown time and again that it's not a good thing… if you ensure there are opportunities for the foxes to breed with other animals outside of their litter for example, it encourages natural selection to pick the best genes of the 2 foxes and put them out there."

This explanation also reveals the student's uncertainty in how to explain the natural selection process. It reflects a "survival of the fittest" mentality where natural selection is a force that actively selects the "best" genes. The student knows that inbreeding has negative consequences for a population, but does not clearly articulate what those consequences may be. It is important to understand, for example, that inbreeding can lead to inbreeding depression and a vulnerability to viruses that can potentially wipe out a population.

Students representing a somewhat less sophisticated Level 3 response mentioned inbreeding and explained the negative consequences. Student AA said:

> "…there would be less chances of inbreeding because they will have more choices. There won't be you breed these two foxes and then you breed their offspring on down the line because that will just end up bad, I guess, for them as a population. They won't have any genetic variation. They will all be the exact same. Then eventually, they'll still probably

> get a mutation or something that will result in bad fur production, which they won't survive very long in the winter with that."

This student recognizes that inbreeding results in less genetic variability for the population and provides an example of what could happen if the individuals within the population are too similar.

Finally, students representing a Level 3 response with the greatest sophistication provided an explicit explanation connecting genetic variability to population resilience in the face of future environmental threats. Student W specifically connects variability to how disease could impact a population:

> "Variation also leads to more resilience in whatever group that you have of a species. The more resilient, they're more able to survive whatever diseases or able to adapt better. Your health is definitely important but different variations are also important so that not one single, I don't know, effect can affect the whole group…I guess the disease, definitely. The more varied they are probably have … Some foxes are able to withstand disease better than other foxes. It's like the potato famine in Ireland when they just have one kind of potato and then one disease came and wiped them all out. That's definitely, I think, an important factor."

This student not only connected genetic variability to possible future disease impacts—they incorporated relevant past knowledge of an example of inbreeding consequences in a plant species. However, this student also revealed a novice idea that a population can "adapt better" (See Section 4.6.2).

Compared to the middle and high school interview responses, the highest Level 3 undergraduate students were more thorough in their explanations of inbreeding, used prior knowledge from class or high school, talked about environmental resiliency in terms of disease or environmental changes rather than more basic issues of fur color differences, used more advanced genetics vocabulary, and expressed clearer reasoning in connecting concepts.

4.6 Alternative Conceptions of Genetic Variability

4.6.1 Anthropomorphism

Several responses revealed a priority placed on characteristics usually attributed to humans, such as compatibility, companionship, and family relationships. In Student 1075's response (Level 2), he or she states that individuals need to "be able to get along." Such language was common and pronounced at the Level 1 category, subtle yet pervasive at the Level 2 category, and nonexistent at the Level 3 category. Students sometimes also included anthropomorphic adjectives in their explanations. Student 657 (MS, Level 2) said: "I would randomly select one-fourth of the lynx in the area. Then I would release the lynx with *aggressive* characteristics." In saying "aggressive," we can assume Student 657 links this personality trait to higher survival likelihood for the lynx. Another student, Student 673 (MS, Level 2), said: "In order to preserve the lynx, I would start off by collecting lynx that are not from the same family…The characteristics I would mainly look for would be if they are healthy, and if they are *friendly*." It is not necessarily incorrect to want healthy and able individuals for a captive breeding program (Student 657), or to desire compatibility among individuals for reproductive purposes (Student 1075 and Student 673), so these can be seen to be decent baseline explanations from which to build more sophisticated responses. However, these student's explanations are based on an individuals' anthropomorphic personality trait, which may not be useful because 1) "aggressiveness" or "friendliness" may not in fact translate to the species in question and 2) in focusing on one trait, the value of genetic variability is ignored.

Some Level 2 and Level 3 responses additionally described males and females holding stereotypical gender roles. For example, Student 1117 (MS, Level 1) said: "The characteristics I would look for if I was starting a breeding program would be, a strong male who has keen instincts and a protective female that could watch over the kids and protect the species and

Student 10 (MS, Level 1) said: "I would want some with good motherly characteristics, some with more energy, and some that are just in between." Some students described wanting to choose "parents" who actively teach their young survival behaviors. Student 593 (HS, Level 1) said: "I would chose a mom and baby so the mom could teach the baby the new ways of living. I would pick healthy bears, and then I would take care of them then let them go."

4.6.2 Teleological conceptions of adaptation

Students sometimes had a teleological explanation of "why" adaptations would "need" to occur within individuals, rather than a "how" explanation of adaptations as a response to environmental change and the subsequent consequences for the population (e.g., Student W in section 4.5 talked about animals that could "adapt better"). Other students also had limited understanding of how traits and adaptations occur within a population. In response to the interviewer's follow-up question to expand upon why variation is important for environmental changes, Student EE (UG, Level 3) responded:

> "I suppose if there was- I guess I don't know about for swift foxes, but maybe if there was a really dry year or wet year, you would want the fox to be able to adapt maybe the length of their coat or, I don't really know that much about it. Maybe just the variation in different physical traits that would allow them to adapt better to the environmental conditions of the season."

This student reveals a common alternative conception represented by the literature (Bishop & Anderson, 1986) that individual animals can "adapt" or respond (i.e., for a "purpose") to current environmental change, rather than understand that natural selection acts upon the genetic variability within the entire population. For example, in the face of an exceptionally wet and cold year, the individual swift foxes who have traits expressed for denser, longer fur may in fact have a higher survival rate than swift foxes with thinner, shorter fur. However, foxes within the population could not actively make their fur grow longer in order to survive the environmental conditions. This sort of explanation for adaptation was the most pervasive alternative conception for the undergraduate interview responses.

4.6.3 Naïve explanations of genetics and inheritance

Within Level 2, students would often attempt to talk about genetics, however, while some explanations had elements of scientific accuracy, at other times they revealed alternative conceptions related to eugenic preference, dominant and recessive traits, and genetic inheritance. For example, Student 645 (HS, Level 2) emphasized eugenic characteristic preferences in saying he or she wanted "…the strongest survivors in multiple different settings," implying a degree of variability in the location from which individuals should come. Student 645 continues by saying individuals should be "good at hunting, strong, well built, fast, furious…You want the lynx with the best strands of DNA." Students in the Level 2 category who discussed eugenic preference prioritized how healthy or well-suited the individuals were for individual survival while also including some aspect of variability, yet neglected to connect these characteristics to population-level resilience.

A few students revealed surface-level comprehension of the concept of recessive and dominant traits. For example, Student 988 (HS, Level 2), explained that some degree of variability among the captive breeding population is desirable using genetic vocabulary, although was incorrect in their application of these terms: "I would get the best polar bears, with recessive and dominant traits. I would choose 16 Bears so then you could have 8 recessive bears and 8 dominant bears…you could interbreed and see the different types, however you could also make a recessive trait more dominant." Student 988 thinks individual polar bears can be "dominant" or "recessive" and does not understand the expression of dominant or recessive genes within individual polar bears. While this was not a common explanation among this sample, it was common for students to misuse genetic-related terms, showing that students generally have a surface-level understanding of these concepts.

Alternative conceptions of genetic inheritance were revealed in how some students explained characteristics were passed on to future generations. For example, Student 1125 (MS, Level 2) says: "…I would get a large variety of polar bears so the good traits will rub off on to the cubs." While Student 1125 was coded at a Level 2 because he or she wanted a "variety" that would thereby influence the genetic makeup of future generations, he or she described traits as things that can "rub off" on the young as opposed to being passed on through sexual reproduction (via genetic recombination). This reveals a fairly naïve conception of how traits are passed on to future generations, or an inability to express his/her understanding of this process. This explanation also provides another example of eugenic preference because he or she prioritizes the "good traits" being passed on rather than focus on the importance of genetic variability of the population as a whole.

4.6.4 Mutations are negative and undesired

Interestingly, the idea that mutations are "bad" was present in several of the undergraduate interviews. Student R (Level 3) states that inbreeding is bad and that it can cause mutations, which are implied to be negative: "I would look for the healthiest ones…need a large enough population…since inbreeding causes other problems outside of…not having a habitat such as disease, and cause mutations, anything like that." Student AA, an example in the following "medium" Level 3 category, claimed that a mutation could result in something bad for a particular trait needed for survival. This notion that mutations are negative for individuals or a population is interesting because mutations are natural, heritable changes that occur in genetic sequences that actually contribute to a population's genetic variability. These mutations may or may not result in negative outcomes for individuals or populations. The negative connotation associated with the word “mutation” probably stems from what students have learned over time through watching cartoons and movies (e.g., X-Men are “mutants”, Teenage Mutant Ninja Turtles, etc.). This alternative conception also emerged in the middle and high school written responses.

5 Conclusions and Teaching Implications

Our research aligns with other literature findings of alternative conceptions in students’ ways of thinking about genetic variability (Lehrer & Schauble, 2012; Moore et al., 2002). In particular, students at the middle school, high school, and undergraduate level had a tendency to focus on the individual rather than population-level genetic variability in the context of species conservation. Genetic variability is essential to population-level resilience in the face of environmental change. An understanding of population-level genetic variability is foundational to comprehending the processes of natural selection and evolution, and is integral to making connections between climate change and its impact on species conservation. On a grander scale, genetic variability is also important to interactions between intra- and inter-species populations—increasing genetic variation is essentially key to sustaining the world’s biodiversity and its resulting ecosystem services upon which we all depend.

A body of literature about students’ alternative conceptions of genetic variability exists (Bishop & Anderson, 1986; Ferrari & Chi, 1998; Moore et al., 2002; Nehm & Reilly, 2007), and our study indicates that these alternative conceptions persist even into undergraduate education. This compelling evidence suggests it is important that instructors identify these alternative conceptions and guide their students in refining these conceptions to reflect a more accurate understanding of genetic variability. This study is unique and important to exposing alternative conceptions of genetic variability in the specific, unexplored context of conservation biology.

Based on our findings, we propose there are three main areas for which to focus instructional efforts related to alternative conceptions genetic variability and biodiversity. First, many students, especially at the middle school education level, are prone to use anthropomorphic descriptions in speaking about genetic variability. This line of thinking is not altogether detrimental in early learning because humans are animals as well, and it may be useful to think about complex concepts in relation to a familiar model. However, as we saw in responses from this study, students tend to focus on human-based characteristics and behaviors when choosing individuals for a captive breeding program, most likely because they believe the animals need to be "compatible" and have the health and skills needed to survive, breed, and "raise" their young. Having healthy individuals for a captive breeding program is indeed a worthy consideration, but it is also important that students connect successful species conservation to genetic variability. This anthropomorphic prioritizing ignores the foundational role of genetic variability within a population because at the baseline level, genetic variability within a population is what ultimately impacts the survival of the species as a whole. We suggest that educators be especially mindful of how they use anthropomorphic comparisons in the classroom when discussing genetic variability. If it is not essential to use a human as a model, it is probably best not to do so in order to avoid encouraging the persistence of anthropomorphic thinking in students.

Secondly, along the lines of wisely choosing comparisons to help students make useful connections, educators should also use vocabulary with care and thoughtful intention. Teleological explanations of genetic variability concepts like "adaptation," for example, may be a result of educators themselves using the associated vocabulary inaccurately, or perhaps students misinterpret the meaning of the words used in a scientific, compared to everyday, context. Educators should explicitly inform students of how different academic fields may use the same words, but in ways that are operatively distinctive. In everyday, non-scientific conversation, we use the words “adapt” and “adaptation” to describe something a human can actively do to improve or progress in a given situation. Concerning evolutionary theory, though, these words have quite a different meaning. Adaptations occur at the population level, rather than the individual level, and they occur over multiple generations through natural selection. Regardless, a prevalent alternative conception students had is that individual animals can “adapt” to new situations in order to survive, or even to evolve. Students may easily miss this important distinction, so it is important for educators to refrain from overly simplistic explanations for “why” species evolve and focus on teaching the “how” of this complex process. Instructional short cuts such as these can ultimately have lasting impacts on student understanding of these very important concepts.

Looking at student thinking through the lens of one or more of these cognitive construals, in addition to understanding the background of how educators traditionally present concepts of evolution and biodiversity to students, can help teachers understand, identify, and predict themes across student learning of these ecological concepts. For example, if a teacher understands that sometimes students interpret ecological information in a teleological manner, the teacher is more equipped to comprehend why that student may hold surface-level understandings of concepts and be better able to redirect and guide students to a deeper and more accurate comprehension. An understanding of cognitive construals can help teachers predict and recognize alternative conceptions (Coley & Tanner, 2012), inform their instruction, and make the students’ learning experience as impactful as possible.

Finally, the most common alternative conception present in our data was students’ focus on the individual-level rather than the population-level in their explanations of a captive breeding program. Thinking at the individual level may sometimes reflect anthropomorphic or teleological ways of thinking. When students choose particular characteristics, such as good health or an aggressive personality, they focus on individual survival and reproduction, and are thus miss the big picture of species conservation for perpetuity. Given the imminent threats of climate change and human-induced habitat alteration, it is imperative for students to think at the population level when formulating their understanding of global biodiversity and sustainability. Therefore, educators should pay special attention to this individual-population-level distinction. One method to do this is through consistent "check-ins" throughout the course such as simple, short surveys to assess student understanding (e.g., pre-course questions, clicker questions, reading through student homework responses, etc.) and adjust instruction accordingly to best guide students in developing a deeper and more accurate understanding.

Language itself may influence how students understand natural selection and evolution. Teachers sometimes use anthropomorphic and teleological shorthand to illustrate evolutionary concepts in understandable ways by which students can relate (Moore et al., 2002). On an even larger scale, throughout time biological discourse has presented evolutionary theory with simplistic figurative language so that the vast history and complex mechanisms of evolution can be more accessible to learners. Using the word "adapt," for example, attributes a sense of agency to individual organisms whereby they can individually respond to environmental perturbations and influence the evolutionary process, rather than natural selection acting upon genetic variability within a population. Experts in the biological fields are more likely able to recognize the nuance of the conceptual differences for words like "adaptation," "fitness," and "competition." In their phenomenological study on students' linguistic usage in relation to alternative conceptions of evolutionary processes, Moore et al. (2002) found a clear relationship between undergraduate students who ascribed agency to organisms and a greater inability to offer accurate scientific explanations of genetic variability. Overall, few of the students in their study provided scientifically appropriate responses to the prompt about genetic variability and natural selection. Although figurative language can be a strong communicative device, educators should make students explicitly aware that different educational fields use the words uniquely, and perhaps such acknowledgement can shift students' naïve ascription of agency at the individual scale to understanding the accurate picture of genetic variability at the population scale driving the process of natural selection.

Students' understanding of variability among species and individual animals may be underdeveloped partly because their exposure to biodiversity concepts has been largely limited to exotic animal and plant species rather than local species and ecosystems with which they can relate. Some of the culprits of the limited representation of global biodiversity are largely the Internet and other forms of media (Ballouard, Brischoux, & Bonnet, 2011), as well as literature. One study in South America found bias toward exotic species in textbooks and children's literature (Celis-Diez, Díaz-Forestier, Márquez-García, Lazzarino, Rozzi, & Armesto, 2016). The authors argue that this type of depiction potentially contributes to the loss of local biodiversity knowledge and is a threat to conservation efforts. This is but one challenge to students gaining an accurate and holistic understanding of the Earth's biodiversity. Based on this research, it is possible that by teaching students about local species and using those species in examples of important environmental issues, such as species conservation, this will potentially assist students in applying the science concepts they learned in school to these larger issues of biodiversity conservation.

A growing body of literature supports that when instructors draw upon the local environment to teach students, a method seen in place-based learning (Smith, 2007), positive learning gains result such as increased achievement motivation and improved critical thinking skill (Ernst & Monroe, 2004; Parrish et al., 2005), both of which are important to apply to real-life complex issues such as conservation. Based on these findings, it follows that the species to which students are exposed may influence their understanding of science-related concepts such as genetic variability and biodiversity. Place-based learning sometimes means immersing students in outdoor environments so that they can see and interact with nature in a more impactful way than is usually possible when learning about the environment within the confines of the classroom. However, it is not always feasible, depending on the school's location or even curriculum standards, to take students outside for this sort of experience. In line with place-based education, instructors can enact at least one component of this educational method in teaching about biodiversity and genetic variability: use local wildlife and plants as examples in teaching these complex concepts. One study found that students across multiple countries were able to list local animals, but often did not list specific species names. These students commonly listed animals such as birds, but listed fewer types of invertebrates, aquatic species, or mammals (Patrick et al., 2013). Learning about local species can help students more readily notice what lives in their local environment and promote an appreciation for biodiversity (Patrick et al., 2013). Fostering an understanding and appreciation for local species in students' on backyards may be one step in helping students make concrete realizations and connections for genetic variability, conservation, and the sustainability of global biodiversity.

Our country's educational focus needs to shift from one that directs students in memorizing scientific terms and processes for the sole purposes of passing tests and meeting standards to one that promotes connecting these terms and processes to real life scenarios. Educators should strive to facilitate students' deeper understanding of biodiversity and conservation. In just teaching students textbook concepts, educators effectively miss an opportunity to teach students the holistic concepts of community, sustainability, and the role we play in impacting processes such as species conservation. Every organism on earth shares natural resources, and our actions as humans disproportionately affect these resources more so than any other species.

Ideally, students graduate from school equipped with a working science knowledge that assists them to become responsibly minded citizens who understand how the natural world operates. Humans have already caused rapid global biodiversity decline, but mindful, scientifically literate humans also have the power to slow this decline and positively influence the continued, necessary sustainability of our planet.

Table 4.1. Variability coding framework and student exemplars

Sophistication Category	Sub-Indicator Description	Student Exemplars
High *Responses in this category recognize variability as being important to a captive breeding population for the purpose of future population resilience.*	**Variability for Population Resilience.** Relates variation to being able to have traits or adaptations for a changing environment, future survival, future generations, etc.	"...choose individuals of mass variety or else it could come to a point where the genome is so consistent that one targeted disease to the genome would wipe out the whole population (or at least has potential to)." (Student 1078)
Medium *Responses in this category recognize variability as being important to a captive breeding population, but do not expand upon why.*	**Variability is Important.** States or describes variability within the population as important or a positive factor (e.g., for survival), but does not explain why it is important.	"I would look for warblers who are healthy, large in size, and are dominant in their environments. I would choose a variety of warblers, and probably multiple warblers." (Student 986) "One would select the greatest diversity of short-nose sturgeon, meaning to collect the greatest contrastable physical characteristics." (Student 782)
	Location Variability. Mentions taking individuals from different locations, but does not explain why this is advantageous.	"I would select a group of warblers for my program by just getting any random group. I wouldn't look for any certain characteristics. I would choose a female and a male from about 10 to15 different areas of Michigan." (Student 1237)
	Avoid Inbreeding. Says inbreeding is negative because it is "bad" in general, but does not explain how it affects genetic resources for future generations.	"...I would ideally, have a breading stock of two hundred to work with-enough to prevent happenings of incest, which could weaken the gene's of the species as a whole." (Student 991)
Low *Responses in this category reflect naïve understandings or alternative conceptions of variability for a captive breeding population. These responses do not represent variability in the conventional sense.*	**Dichotomous Variability**. The extent of "variation" for the captive breeding population is limited to choosing males and females or other types of dichotomous variation (e.g., weakest and strongest, oldest and youngest).	"I would pick two females and two males. All four would be as healthy as they can and have no birth defects."" (Student 1167) "I would select the oldest ones and the youngest. I would look for the oldest as I started choose all the oldest 6 and the youngest 6."" (Student 1219)
	Does not value variability. May recognize variability, but does not value it. They may explain that the best method would be to artificially select out the variation.	"I would select a group of sturgeon that live in the same waters, in the same area. I would also make sure they were all the same species of sturgeon. I would choose about 50-100, enough to get a good outcome of offspring." (Student 1229)
NA *Not Applicable*	Responses do not include an explanation about variability	"I would choose the group of warblers best suited to winter." (Student 1235) "I would choose birds that didn't have any diseases and nothing was wrong with them. I would take 10 birds." (Student 905)

Table 4.2. Student written responses on genetic variability. Percentage of students at different sophistication levels for explanations of genetic variability in the written responses.

		Education Level		
Category Description	Sophistication Level	Middle School	High School	Undergraduate
Variability for population level resilience	Level 3	0.37	3.05	8.96
Variability is important	Level 2	3.68	13.22	38.81
Does not value variability	Level 1	47.79	43.39	33.58
Not applicable	NA	48.16	40.34	18.66
Total Students		*272*	*295*	*134*

Table 4.3. Student written responses on traits. Percentage of students at different sophistication levels for explanations of traits in the written responses.

Category Description	Sophistication Level	Education Level	
		Middle School	High School
Population-level description of traits, connected to genetic variability	Level 3	0.37	3.05
Genetic or survival explanations for traits	Level 2	24.26	43.73
Basic descriptions or alternative conceptions of traits	Level 1	50.00	43.05
Absence of traits explanation	NA	25.37	10.17
Total Students		*272*	*295*

Table 4.5. Student interview responses on genetic variability. Total student count of captive breeding learning progression level for explanations of genetic variability for all education levels.

	Education Level		
Sophistication Level	Middle School	High School	Undergraduate
Level 3	0	1	12
Level 2	2	6	2
Level 1	3	2	0
NA	1	2	1
Total students	*6*	*11*	*15*

6 References

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of research in science teaching*, *39*(10), 952-978.

Ballouard, J.-M., Brischoux, F., & Bonnet, X. (2011). Children prioritize virtual exotic biodiversity over local biodiversity. *PloS One*, *6*(8), e23152.

Bishop, B. A., & Anderson, C. W. (1986). Evolution by Natural Selection: A Teaching Module. Occasional Paper No. 91.

Bruning, R.H., Schraw, G. J., & Norby, M. M. (2011). *Cognitive Psychology and Instruction*. Boston: Pearson Education, Inc.

Butchart, S. H., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J. P., Almond, R. E., … others. (2010). Global biodiversity: indicators of recent declines. *Science*, *328*(5982), 1164–1168.

Carey, S. (1986). Cognitive science and science education. *American Psychologist*, *41*(10), 1123.

Celis-Diez, J. L., Díaz-Forestier, J., Márquez-García, M., Lazzarino, S., Rozzi, R., & Armesto, J. J. (2016). Biodiversity knowledge loss in children's books and textbooks. *Frontiers in Ecology and the Environment*, *14*(8), 408-410.

Charlesworth, D., & Willis, J. H. (2009). The genetics of inbreeding depression. *Nature Reviews Genetics*, *10*(11), 783–796.

Coley, J. D., & Tanner, K. D. (2012). Common origins of diverse misconceptions: cognitive principles and the development of biology thinking. *CBE-Life Sciences Education*, *11*(3), 209–215.

Dirzo, R., & Raven, P. H. (2003). Global state of biodiversity and loss. *Annual Review of Environment and Resources*, *28*(1), 137–167.

Duncan, R. G., & Rivet, A. E. (2013). Science learning progressions. *Science*, *339*(6118), 396–397.

Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: A review and analysis. *Studies in Science Education*, *47*(2), 123–182.

Ernst*, J., & Monroe, M. (2004). The effects of environment-based education on students' critical thinking skills and disposition toward critical thinking. *Environmental Education Research*, *10*(4), 507–522.

Ferrari, M., & Chi, M. T. (1998). The nature of naive explanations of natural selection. *International Journal of Science Education*, *20*(10), 1231–1256.

Hartley, L., C. W. Anderson, A. Berkowitz, J. C. Moore, J. Schramm, S. Simon. (2011, April). *Development of a Grade 6-12 Learning Progression for Biodiversity: an Overview of the Approach, Framework, and Key Findings*. Paper presented at the meeting of the National Association for Research in Science Teaching, Orlando, FL.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*, *96*(4), 701–724.

Leopold, A. (1950). *A Sand County almanac, and Sketches here and there: illus. by Charles W. Schwartz*. New York.

Leopold, A. (1970). *A sand county almanac: With other essays on conservation from Round River*. Random House Digital, Inc.

Louv, R. (2008). *Last child in the woods: Saving our children from nature-deficit disorder*. Algonquin Books. Millennium Ecosystem Assessment (Program) (Ed.). (2005). *Ecosystems and human well-being: synthesis*. Washington, DC: Island Press.

Moore, R., Mitchell, G., Bally, R., Inglis, M., Day, J., & Jacobs, D. (2002). Undergraduates' understanding of evolution: ascriptions of agency as a problem for student learning. *Journal of Biological Education*, *36*(2), 65–71.

Munson, B. H. (1994). Ecological misconceptions. *The Journal of Environmental Education*, *25*(4), 30–34.

Nehm, R. H., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*(3), 263–272.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. National Academies Press.

Parkins, A. E., Whitaker, J. R., & others. (1939). Our natural resources and their conservation. *Our Natural Resources and Their Conservation.*, (2nd edn).

Parrish, D., Phillips, G., Levine, R., Hikawa, H., Gaertner, M., Agosta, N., & Doyal, D. (2005). Effects of outdoor education programs for children in California. *American Institute for Research. Retrieved March (I, 2007. from Www. Sierraclub. Org*.

Patrick, P., Byrne, J., Tunnicliffe, S. D., Asunta, T., Carvalho, G. S., Havu-Nuutinen, S., … Tracana, R. B. (2013). Students (ages 6, 10, and 15 years) in six countries knowledge of animals. *Nordic Studies in Science Education*, *9*(1), 18–32.

Pimm, S. L., Russell, G. J., Gittleman, J. L., Brooks, T. M., & others. (1995). The future of biodiversity. *Science-AAAS-Weekly Paper Edition*, *269*(5222), 347–349.

Ramadoss, A., & Poyyamoli, G. (2011). Biodiversity conservation through environmental education for sustainable development-a case study from puducherry, India. *International Electronic Journal of Environmental Education*, *1*(2).

Randler, C. (2008). Teaching species identification—a prerequisite for learning biodiversity and understanding ecology. *Eurasia Journal of Mathematics, Science and Technology Education*, *4*(3), 223–231.

Sgrò, C. M., Lowe, A. J., & Hoffmann, A. A. (2011). Building evolutionary resilience for conserving biodiversity under climate change: Conserving biodiversity under climate change. *Evolutionary Applications*, *4*(2), 326–337.

Smith, G. A. (2007). Place-based education: Breaking through the constraining regularities of public school. *Environmental Education Research*, *13*(2), 189–207.

Smith III, J. P., Disessa, A. A., & Roschelle, J. (1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences*, *3*(2), 115–163.

Triandis, H. C. (1995). *Individualism and Collectivism: New Directions in Social Psychology. Boulder, CO*. Westview Press.

Van Weelie, D., & Wals, A. (2002). Making biodiversity meaningful through environmental education. *International Journal of Science Education*, *24*(11), 1143–1156.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, *277*(5325), 494–499.

Zesaguli, J., Wilke, B., Hartley, L., Tan, E., Schenk, C., & Anderson, C. W. (2009). Developing a K-12 learning Progression for biodiversity in environmental systems. In *annual meeting of the National Association for Research in Science Teaching, Garden Grove, CA*.

CHAPTER III: CONSERVATION DECISION-MAKING

7 Introduction

The ideal goal for science education is to have students practice science in the classroom, integrate it into their knowledge base, and apply it directly to their everyday lives in a way that benefits the natural world and society simultaneously. Thus, students would become scientifically literate. However, the mechanisms by which science education contributes to individuals' scientific literacy remains unclear, including the role of science education in the pathway for adults to become informed citizens who can apply science in responsible decision-making throughout their lives.

The National Science Education Standards describe a prescriptive version of science literacy whereby students must gain scientific knowledge and skills to become responsible, productive citizens. Specifically, the National Research Council states that science literacy is "the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22). The ultimate goal of science literacy research, then, is to suggest mechanisms by which we can improve students' knowledge acquisition and understanding of scientific concepts so that they may become productive citizens who allow science to play a role in their decision-making.

Some schools of thought promote science literacy via the "deficit model" (a term coined by Burgess, Harrison, & Fillius, 1997) whereby instructors place priority on students learning content knowledge, i.e., rote memorization, to sufficiently learn about different subjects. This model reduces science to facts and disregards its societal and cultural influences (DeBoer, 2000;Hewitt, 2014) and is generally discounted as an effective, holistic educational approach.

Empirical evidence in science education reveals that students' science content knowledge does play some supporting role in students' ability to do sophisticated reasoning about real-life scenarios. Some studies show no significant relationship between content knowledge and quality of informal reasoning or argumentation (Kuhn, 1991; Perkins, Farady, & Bushey, 1991). Argumentation skills are not necessarily always higher quality with advanced content knowledge (Zohar & Nemet, 2002). However, there are also studies that support an existing relationship between content knowledge and informal reasoning (Fleming, 1986; Hogan, 2002; Tytler, Duggan, & Gott, 2001; Zeidler & Schafer, 1984). For example, one study found that students who scored higher on a knowledge assessment integrated relevant knowledge into their reasoning in a more sophisticated manner than students who scored lower on the knowledge assessment (Hogan, 2002). So, it can be certainly be argued that content knowledge has a role to play in decision-making, but neither instructors nor students should rely on increasing content knowledge as the sole means to becoming responsibly informed on complex issues. The National Academy of the Sciences (2016) recently acknowledged that the expectation that scientific knowledge translates into informed opinions and actions is overly simplistic. Other factors besides knowledge significantly impact attitudes, norms, and behaviors around complex real-world issues.

Feinstein (2011; 2013; 2015) paints a modified picture of science literacy divergent from the blanket notion that current models of science education focused on knowledge attainment are inherently useful and produce responsible citizenry that use science in everyday life. The focus of this new picture of science literacy is on students connecting science to their lived experiences in ways that are significant and satisfying to them. Feinstein combines elements of public engagement research, such as the importance of civic discourse (Dewey & Rogers, 2012) with science education research findings. He views science literacy as being a collective social phenomenon, rather than individualistic process (Roth & Lee, 2002), whereby students learn about science through relevant educational scenarios and by engaging in group discourse and shared experiences.

Simply put, Feinstein redefines science literacy as *engagement with science*. Average citizens are, in effect, outsiders to the scientific community where there are very few "expert insiders." Feinstein thus introduces the term "competent outsider" as being the goal for science literacy education. As educators, we should strive to guide students in becoming competent outsiders who are able to recognize when science is relevant to situations in their lives and integrate scientific information in a way that allows them to meaningfully understand their world (Feinstein, 2011).

Teaching structured decision-making in undergraduate courses is arguably a way to promote science literacy through group discourse about controversial societal issues relevant to students (Aikenhead, 1985; Kolsto, 2006; Zeidler, Sadler, Simmons, & Howes, 2005). Research supports that there is essentially a "gap" in what people know (i.e., content knowledge) and how they apply that knowledge to decision-making. For example, early models of environmental behavior showed environmental knowledge directly influencing environmental attitude, and finally pro-environmental behavior. However, behavior and decision-making is much more complex than previously thought. Much more than knowledge influences our behavior and decision-making (e.g., values, personal experiences, societal norms, etc.) (Kollmuss & Agyeman, 2002). It is imperative for students to know *when* and *how* to apply that content knowledge to their daily decision-making. Students also need to know how to engage in debate or discussion of complex issues that involve multiple stakeholders who have a variety of personal values and unique views on economics, politics, social issues, and ethics, in addition to collective content knowledge on a myriad of topics (Feinstein, 2011). Engaging in structured decision-making in the classroom allows students to practice applying scientific information to relevant complex issues as well as practice group decision-making.

To prepare students for a complex world where they will face difficult decisions, instructors could explicitly teach decision-making strategies in the classroom (Simmons, 1991). Decision-making strategies equip students with tools to navigate the complex interplay of values, knowledge, and other influencing factors that any complex issue presents. Classroom instruction focused on decision-making may include revealing psychological traps and the difficulties of analyzing value-tradeoffs, and teaching deliberative decision-making strategies (Arvai, Campbell, Baird, & Rivers, 2004). Some studies have explored undergraduate student decision-making in health-related research or global warming (Bell & Lederman, 2003)or even in business (Benson & Dresdow, 2015). However, few studies have explored influencing factors of decision-making in the context of a science literacy course focused on a conservation-related issue or evaluated the role of a decision-making framework in the context of the undergraduate classroom.

In this study, we describe how undergraduate students are making decisions about a controversial issue in an effort to elucidate what is influencing their decision-making as well as to propose alternative instructive methods and curriculum development that could improve the quality of student decision-making and engagement with complex issues. Our study contributes to the science literacy goals as described by Feinstein (2011). By making decisions in a way that integrates collective knowledge, multiple personal values, and the values of other stakeholders, students practice a public engagement process they can use throughout their lives as “competent outsiders.” Such practices help students recognize when science is relevant and applicable to different situations, allows them to integrate pieces of science into their lives in a meaningful way, and supports students in making informed decisions.

7.1 Theoretical Framework for Decision-making

In thinking about decision-making goals for students in science classrooms, we find it useful to distinguish between two kinds of decision-making, formal and informal (Dauer, Lute, &

Straka, 2017), based on theories of dual-processing models in social and cognitive psychology. Informal decision-making comprises the majority of our decisions in daily life and involves using emotive, intuitive, and cognitive reasoning. This form of decision-making is automatic, instinctive, unconscious "fast-thinking" that comprises the majority of day-to-day decisions (Kahneman & Tversky, 1974; Arvai et al., 2004; Kahneman, 2011). Little deliberative thought is given to routine decisions such as removing a hand from a hot object or swerving on a bike to avoid treacherous glass in the road. Our minds rely on a few heuristic principles that guide our daily motions with little effort or time (Arvai et al., 2004). Evolutionarily, this behavior is essentially key to survival. However, this "fast-thinking" causes people to overlook uncertainty and is based on value judgments, which are subjective and therefore variable among a group of people. Applying simple heuristics to complex decision-making results in systematic errors in judgment (Tversky & Kahneman, 1974). For example, one heuristic commonly used is the "availability heuristic" whereby conclusions about an issue are drawn based on how well related instances can be brought to mind, in spite of how often they actually occur (Tversky & Kahneman, 1974; Arvai et al., 2004). For example, in the case of large apex predators, one might think wolves or mountain lions attack humans often because of attention-grabbing media stories, when in reality attacks by wolves or mountain lions on humans are quite rare. Students may also make value-based judgments where they make a decision based on a single value, identity or social norms rather than making a balanced decision based on multiple personally held values.

Conversely, formal decision-making requires a deliberative, "slow-thinking" process that is conscious, deliberate and logical and recognizes uncertainty (Kahneman, 2011). Complex decisions are difficult because an individual may have conflicting values but must weigh them against each other to reach a solution to a problem. Formal decision-making consciously takes into consideration individuals' multiple personal values and tradeoffs among them. Arvai et al., (2004) suggested that to support students learning to make higher quality, formal decisions instructors should alert students of heuristic-based, psychological traps in judgment and teach a structured decision approach. Formal thinking often involves the use of a decision-support tool to minimize cognitive biases that can otherwise occur. Structured decision-making approaches can ease the burden of navigating the complexity of an issue, helping individuals make decisions that appropriately reflect what they prioritize (Wilson & Arvai, 2006).

Informal decision-making is often an inappropriate means of coming to a solution for a complex problem such as a socioscientific issue because it can result in biases or fallacies that lead to sub-optimal decisions. Classrooms provide an environment where students can learn about psychological traps, reflect on their own potential biases, and learn how decision-support tools can provide a formal framework for decision-making may guide them to become more thoughtful and deliberative in their decision-making about SSIs.

7.2 Role of Socioscientific Issues in the Classroom

Over half a century ago, Hurd (1958) emphasized that because science influences issues of “human welfare and social progress,” scientific knowledge can give citizens a different, more-informed perspective on these issues. Using science alone to problem solve ignores the equally important influences of society, but a perspective *informed* by scientific knowledge, combined with consideration of values, political, economic, and social factors, helps foster one’s ability to evaluate an issue holistically. However, sometimes citizens do not know how to research, interpret, or apply science knowledge to their decision-making regarding a societal issue. Additionally, it is challenging to integrate that science understanding with personal values and the values of others (Kolsto, 2006). One proposed method to support students in making informed decisions is to use socioscientific issues (SSIs) as a platform for exploration and discussion in the classroom. Socioscientific issues are current, controversial issues that require careful consideration of science and moral reasoning for the decision-making process (Zeidler and

Nichols, 2009). Furthermore, SSIs can provide excellent contexts for situated learning, where students learn practices to engage in and negotiate complex issues much as they would experience as active, participatory citizens in society (Sadler, 2009). In a review of studies supporting implementation of SSIs as a learning context in the classroom, Sadler (2009) found evidence that SSIs garner student interest and motivation, facilitate learning science (i.e., content knowledge), encourage improved higher order thinking (i.e., argumentation, creativity, and reflective judgment), and provide environments promoting a "community of practice," where teachers and students are co-constructing the learning and knowing experience. All of these skills are also integral to informed decision-making, so using SSIs as a context for teaching structured decision-making is a worthwhile venture. Additionally, both the National Research Council and the American Association for the Advancement of Science support the pairing of SSIs with decision-making in science education endeavors (NRC, 1996; AAAS, 1989).

The SSI literature includes a variety of topics such as genetic engineering (Sadler and Zeidler, 2005), genetically modified food (Walker and Zeidler, 2007), water quality issues (Sadler, Barab, & Scott, 2007), and organ transplants (Zeidler, Herman, & Ruzek et al., 2013). There are also several studies of beliefs and attitudes toward conservation of apex predators (Kellert, Black, Rush, & Bath, 1996; Røskaft, Händel, Bjerke, & Kaltenborn, 2007; Romanach, Lindsey, & Woodroffe, 2007; Casey, Krausman, Shaw, & Shaw, 2006). Rarely, however, has a wildlife conservation issue been the SSI of focus at the undergraduate level.

Wildlife conservation is a highly relevant environmental science context for teaching decision-making in the classroom, considering wildlife managers in real life are constantly navigating the waters of scientific evidence and the challenges posed by the human dimension. Students of today are the future leaders of our world's conservation and sustainability efforts, and educators may need a more active approach to help students responsibly and effectively make decisions about complex environmental issues (Arvai et al., 2004). In one study, high school students performed a conservation decision-making exercise. Although students used both science and values in their decision-making, greater weight was placed on values in the decision-making process, which supports that 1) values are naturally part of conservation decision-making and are therefore important to address in conservation education instruction and 2) future conservation decision-making instruction should focus on helping students integrate values and ecological knowledge in a more balanced manner (Grace & Ratcliffe, 2002).

Conservation of a large predator species is an example of a wildlife conservation socioscientific issue that provides an opportunity to weigh the complex needs, values and fears of humans with strategies to protect the species in question. Some conservation-related SSIs may be more heatedly controversial than others (Saunders & Rennie, 2013). Conservation-related SSIs may become more controversial when the issue involves an apex predator species or when people perceive that the species is a threat to both humans and their livelihoods. In other words, humans might attribute little to no benefit to the existence of the species in question depending on the degree of its direct impacts on humans.

The SSI context of this study is mountain lion (*Puma concolor*) conservation. Native to Nebraska, humans extirpated mountain lions from the state in the late 1800s, and no recorded observations of mountain lions occurred again until 1991. As of 2015, genetic surveys indicate a small resident population of 22-33 individual mountain lions (Nebraska Game and Parks, 2016). Most of Nebraska is unsuitable habitat for mountain lions to establish breeding populations, except for a few forested habitat patches in the northwest and north-central regions of the state. The Nebraska Game and Parks Commission held the first and only managed hunting season for mountain lions in 2014. Controversy over management of this apex predator stems from a myriad of concerns related to human safety, livestock and pet protection, ecological biodiversity, genetic variability, economics, politics, and ethics.

Because mountain lions are relatively new to Nebraska since their extirpation in the early 1900s, it is still unknown how mountain lions will impact the existing ecosystems, especially in a predominantly agricultural landscape. Mountain lions are an apex predator and thus will naturally impact various prey populations like white-tailed deer, especially in their forested breeding habitat in the northwest corner of the state. It is possible that mountain lions' predation of herbivorous species like deer, in addition to the mountain lions' mere presence in the region, may influence herbivores' foraging behavior and movement patterns, which can impact plant community generation. This powerful ecological process of predators indirectly impacting plant communities, known as trophic cascades, has been documented in other apex predator species, such as in the reintroduction of wolves in Yellowstone National Park (Ripple, Larsen, Renkin, & Smith, 2001).

7.3 Variables Influencing Decision-making

Several variables may play a role in students' decision-making about apex predators such as mountain lions. Demographic, identity and gender variables, as well as ecology content knowledge and value orientations, may play a role in students' attitudes and beliefs that are important to understand in order to investigate students' formal versus informal heuristic-based decision-making. Below we review several variables that have the potential to be important in understanding students' stance on this issue.

7.3.1 Gender

In a study on the public's concern about mountain lion attacks, gender was found to be a predictive variable. Women expressed greater concern for mountain lion attacks than men express, yet were less likely than men to support lethal control methods in residential areas (Zinn & Pierce, 2002). Additional studies have supported that men more strongly support hunting of mountain lions than women (Thornton & Quinn, 2009). Another study found that gender was more often predictive of environmental concerns when the issue was specific and local rather than general and global in scope. For example, women expressed significantly more concern with site-specific studies involving nuclear power. On the global scale, gender differences in degree of concern were inconsistent (Davidson & Freudenberg, 1996). Since the mountain lion issue is local for the students in this study, and because previous research on perceptions of predatory species has shown that gender predicts concern, we wanted to explore whether this variable predicted students' decision-making in our context.

7.3.2 Rural background

Because the mountain lions' breeding grounds are located in rural areas of Nebraska, rural students are naturally more likely to encounter mountain lions than urban students are. There are few urban areas in Nebraska, all of which are located in eastern Nebraska where mountain lion encounters are infrequent. Livestock owners also live in rural areas of Nebraska, so students' whose families own livestock may have more experience with mountain lions because of livestock being a possible prey item for mountain lions. One study on attitudes and beliefs toward mountain lions reported that livestock owners perceive greater risk of mountain lion attack than non-livestock owners do. They also found that rural residents had overall positive attitudes toward mountain lions compared to urban residents. This was a result of rural residents having more knowledge and experience with mountain lions, whereas urban residents (especially newer residents) had less experience, felt less informed, and thus expressed more fear of mountain lion attacks. This study, however, took place in Alberta where mountain lions have inhabited the area for an extended period of time (Thornton & Quinn, 2009). Although the mountain lion density in Alberta is roughly equivalent to Nebraska's, mountain lions have only recently returned to Nebraska, so this may affect rural and non-rural students' risk perceptions, which in turn may influence their management decisions.

7.3.3 Stakeholder identity: Hunting participation

Stakeholder identity may play a role in how students make a decision regarding the mountain lion issue. The state’s current management strategy is to hold management hunting seasons dependent upon the population size from year to year, so we wanted to see if students who participate in hunting tend to make different management decisions than students who do not participate in hunting. In a study of public attitudes toward mountain lion recolonization in the Midwest, hunting participation was the strongest variable predictive of people’s management choice. Hunters were more likely than non-hunters to support measures to “control,” rather than protect, the mountain lion population (Davenport, Nielsen, & Mangun, 2010). This most likely occurs because hunters tend to have more utilitarian wildlife value orientations where dominance over wildlife is important, whereas non-hunters are more likely to express protectionist values where “right to existence” is important.

7.3.4 Ecology content knowledge

It is unclear how well people understand the concepts of ecology, biodiversity, and conservation underlying the mountain lion hunting issue, and how often or how well people apply this knowledge to their opinions and decision-making about the issue. Ecological alternative conceptions are important to understand and address in the context of conservation decision-making. One common alternative conception expressed by students is that within a food web, certain organisms are only important to certain other organisms, meaning they fail to see the complex interconnectedness of food webs (McComas, 2002), which is particularly important in the context of apex predator species that strongly impact trophic relationships.

Another ecology concept important to this issue is genetic variability and its role in population resilience to environmental change, which some biologists regard as being an important consideration for wildlife decision-making processes (e.g., Morrone, Katinas, & Crisci, 1996). In the Midwest context, although it is possible for individual mountain lions from neighboring states to disperse through Nebraska's northwest corner where the breeding population currently resides, that area is reasonably isolated compared to other mountain lion breeding areas in the United States. Genetic variability within that population could possibly be a concern not only because of the geographic isolation, but also because current management involves the harvest of individuals from the breeding unit.

7.3.5 Value orientations

To explore student values, we measured value orientations. While values are stable guiding principles in one's life of which there are few across cultures, (Schwartz, 1992) value orientations are dimensions upon which related values cluster and predict general beliefs (De Groot & Steg, 2008). The value orientations we used are based on the Value-Belief-Norm (VBN) Theory (Stern, 2000), where individuals are aligned along three sets of beliefs regarding human-nature relationships (i.e., egoistic, altruistic, biospheric; Stern, 2000). VBN Theory has been widely used to understand environmentally significant decision-making and predict behaviors relevant to diverse contexts and across cultures (Huffman, Van Der Werff, Henning, & Watrous-Rodriguez, 2014; Sussman, Lavallee, & Gifford, 2016). According to VBN Theory, there is a causal chain that moves from relatively stable, central elements of values, to beliefs and personal norms and then to behavior (Stern, 2000).

Value orientations may indicate interesting information while exploring students' mountain lion management decisions, as they may represent affective stances on the issue rather than reasoned analysis. In other words, a decision that value orientation scores predicts may possibly represent an informal decision based on a single value-heuristic. For example, a student could take a stance that mountain lions should killed or hunted liberally because the student comes from a ranching family that is concerned about economic loss (an egoistic value), and the consideration of the economic or ecological benefit of mountain lions to grazing ecosystems is never considered even if the student holds some biospheric values. In formal decision-making, the causal chain between values, beliefs, and norms is somewhat altered by individuals' reasoned analysis, so value orientations may be a weaker predictor of formal decisions using a structured decision-making tool.

7.4 Instructional Strategy

We propose a novel teaching approach for supporting students' decision-making about complex socio-scientific issues. In an introductory, multidisciplinary science course for STEM and non-STEM majors, we used a teaching approach that focused on complex place-based SSI's including mountain lion hunting. The teaching approach included explicit instruction on formal and informal decision-making practices and cognitive biases, and the use of a formal decision-making support tool to hypothetically reduce students' cognitive biases in decision-making (Dauer & Forbes, 2016; Dauer, Lute, & Straka, 2017).

The decision-support tool was based on normative models of decision-making as well as previous science education literature (Ratcliffe, 1997; Grace,, 2009). Students were asked to work through the steps of this decision-making framework as the primary summative assessment for four SSIs, which we considered our structured mode of evaluating students' decision-making.

The decision-making framework was meant to give students the experience of using a formal decision-making approach to the problem and practice explicitly defining what they value in terms of "Criteria," practice applying scientific information to evaluating a problem, and the systematic evaluation of value-tradeoffs. Theory from decision-sciences supports the idea that decisions should be based on values (Keeney, 1992), but people often have difficulty considering diverse values during decision-making without structured guidance (Slovic, 1995; Arvai et al. 2001). Writing multiple explicit "Criteria" should supports students' ability to evaluate multiple values. Moreover, students' expression of "Criteria" with pro-conservation or ecological themes may predict students' final decision about hunting mountain lions.

Decision-making Framework

1. Define the Problem: What is the crux of the problem as you see it?

2. Options: What are the options? (List the possible solutions to the problem.)

3. Criteria: How are you going to choose between these options? (Explain important considerations and what is valued in an outcome.)

4. Information: Do you have enough information about each option to evaluate based on your criteria? What scientific evidence is involved in this problem? What additional information do you need to help you make the decision?

5. Analysis: Discuss each option weighed against the criteria. What are the trade-offs of each option?

6. Choice: Which option do you choose?

7. Review: What do you think of the decision you have made? How could you improve the way you made the decision?

Figure 7.4 Structured decision-making framework. Students used this formal decision-making framework during class to propose and evaluate solutions to different socioscientific issues. Adapted from Ratcliffe, 1997.

The hope is that practice using this framework will result in transfer of some of these practices and reasoning to an unstructured setting for decision-making. Transfer is the initial learning of new skills and the application of these skills at a later time (Bransford, Brown, & Cocking, 1999; Day & Goldstone, 2012; Nokes-Malach & Mestre, 2013) and is often the ultimate goal for education. Students were asked before and after instruction about their opinions about biofuels in an open-ended format, which provided an opportunity to determine if students were using scientific information and evaluating value-tradeoffs during informal, unstructured reasoning about the SSIs that we discussed in class.

7.5 Research Questions

This study explores the relationships between demographic factors, values, and content knowledge and decision-making in unstructured and structured assessments with regard to the conservation of a semi-isolated mountain lion population in the Midwestern United States. The objectives of this study are to determine indicators of students' formal and informal reasoning based on their ability to make a decision based on multiple value-tradeoffs versus single value heuristics, and to describe the conditions by why students tend to make pro-conservation decisions in the context of the mountain lion issue. Specifically, we asked the following research questions:

RQ1. Do demographic factors, value orientations, or ecology knowledge explain students' unstructured pretest decision and posttest decision or their structured in-class decision about mountain lion conservation?

RQ2. Do students' demographic factors, value orientations, or ecology knowledge explain students' inclusion of ecologically themed "Criteria" in their structured in-class decision-making?

RQ3. Do students' inclusion of ecologically themed "Criteria" in their structured decision-making predict their management decision?

We use the results from this study to begin addressing complex questions about what impacts students' decisions and the effectiveness of the decision-making tool. This will contribute to revision of current decision-making models in classrooms, and provide feedback to instructors who plan to implement structured decision-making in their classrooms in the future. The ultimate goal is to provide instructors a means of guiding students in effective and reflective decision-making.

8 Methods and Analysis

To explore factors that explain students' decision-making and opinion-formation, we collected data from students enrolled in a required introductory undergraduate science literacy course, "Science and Decision-making for a Complex World," taught at a large Midwestern university in Nebraska. These students represented STEM (two-thirds of class) and non-STEM (one-third of class) majors. The course was structured around four two-week instructional units exploring controversial socioscientific issues salient to the geographic region. The unit of focus for this study is the controversial issue of mountain lion management in Nebraska.

A primary course objective was for students to distinguish between (a) scientific information and (b) values, ethics, culture, economics, or politics, and use both in support of a position about what should be done about complex socioscientific issues. A second objective was for students to work with peers to use consensus values and scientific information to make a case for the best solution to an important and complex socioscientific problem.

Active learning instructive methods were employed within two separate, large lecture sections. Graduate learning assistants stimulated group discussion throughout the class period. Students worked in small groups of 3-4, and there were numerous opportunities throughout each lecture period to engage with their group members to discuss the issue of focus and collaborate on structured decision-making assignments.

8.1 Study Rationale and Data Collection

Data were retrieved from two lecture sections with 109 in the first section and 114 students in the second section. Inclusion criteria were used to collect student data. Student coursework data were only included for students who 1) responded “Yes” to the IRB consent form and 2) completed all of the data including the Demographic Information, Value Orientations Survey, Ecological Knowledge Assessments, unstructured Pretest decision and Posttest decision, and the Unit Assessment structured decision-making assignment. The final sample size consisted of 110 students from the combined two lecture sections.

The data for the value orientations survey, knowledge questions, demographics, pretests, and posttests were all collected electronically through online survey software, Qualtrics. These responses were downloaded and de-identified in Excel. The decision-making framework was embedded within an end-of-unit assessment that students submitted to an online course management system or grading. The Microsoft Word files were downloaded and de-identified, and then their responses to the decision-making questions were entered into an Excel spreadsheet.

We calculated student scores for each set of data gathered using both quantitative and qualitative methods. Scoring frameworks were a mix of quantitative scoring, scoring based on existing coding frameworks, and new qualitative coding frameworks created because of this research.

Since the unit of analysis characterizes this study (Merriam, 2009, p. 41) and lies within a bounded system, a case study approach was chosen. The students in the study experienced the same process of completing a structured decision-making framework pertaining to mountain lion conservation. There are multiple data points for this study, including pre- and posttest opinions, knowledge assessments, a value orientations survey, and a decision-making framework. Because of the clear class bounds, the multiple data types, and the replicability of these research methods for this same course in the future, a case study was deemed appropriate for this research.

8.1.1 Demographic information

Demographic information was collected for the following variables: gender; major area of study; whether they hunt or do not hunt; their hometown; and whether their hometown is rural, suburban, or urban. For the purposes of this study, suburban and urban statistics were combined, so the comparison was ultimately between "non-rural" and "rural." In Nebraska, the rural environment was a more different setting than the difference between suburban and urban environments. Additionally, sometimes students considered their hometown suburban while other students considered the same hometown to be urban.

Students in this sample were representative of the course and were 34% male, 66% female, 61% STEM majors (Animal Science, Fisheries & Wildlife, and Environmental Science were top majors), 39% non-STEM majors (Hospitality, Restaurant, & Tourism Management; Agribusiness; and Agricultural Education were top majors), 57% were from rural areas, and 43% were from non-rural areas (See Table 8.1.1).

8.1.2 Value orientations survey

The value orientations survey (De Groot and Steg 2008), developed based on the Value-Belief-Norm Theory (Stern, 2000), is a tool used to measure three sets of beliefs, or value orientations, regarding human nature: egoistic (concern for self), altruistic (concern for other humans), and biospheric (concern for all lives, human and non-human). The survey for the current study consisted of four items that represented each value orientation: egoistic (e.g., "Control over others, dominance"), altruistic (e.g., "Working for the welfare of others"), or biospheric (e.g., "Protecting natural resources"), for a total of twelve items. Students responded to these items by indicating on a 9-point Likert scale how important the twelve values were as "guiding principles" in their life. The scale ranged from -1 ("Opposed to my values"), 0 ("Not important") to 7 ("Extremely Important"). The purpose of including this variable was to assess first, where individual students fell along those spectrums and second, if certain value orientation tendencies explained how students proposed solutions and expressed opinions for the mountain lion issue. Students took this survey as part of a pre-course assessment. Egoistic, altruistic, and biospheric mean value orientations scores were calculated for each student. Overall, students' value orientations were higher for altruistic and biospheric value orientations than egoistic value orientations (See Table 8.1.2).

De Groot and Steg (2008) found that egoistic value orientations were a negative predictor and biospheric value orientations were a positive predictor of subjects' engagement in pro-environmental behavior. There was no correlation between the two variables (R^2=0.03). We therefore decided to calculate the difference between students' biospheric and egoistic value orientation scores to create a fourth "Bio-Ego" score as a composite score that incorporates both variables to see if this was predictive of their unstructured and structured decisions. There was a mean "Bio-Ego" score of 1.43 (ranging from the lowest difference score of -2.00 to the highest of 5.25).

8.1.3 Ecological knowledge sophistication assessments and coding rubrics

To explore the relationship between students' level of ecological knowledge and decision-making about mountain lion conservation, students were given an ecological knowledge assessment. Students were asked one multi-part question to assess their knowledge of food web complexity and a second multi-part question to assess their knowledge of small population-related concerns. These two questions were administered twice: once as part of their course pretest and a second time as part of a bonus quiz during the mountain lion unit. It was administered twice to see if there was a significant difference in how students scored prior to and during the mountain lion unit, but no significant difference was found. Thus, data from the bonus quiz post-instruction only were used for the purpose of this study. Lectures relating to food webs and small populations took place before this knowledge assessment bonus quiz was assigned to students.

The Ecological Knowledge assessments were evaluated separately for the two questions regarding Food Webs and Small Populations. Both questions were designed as open-ended prompts to elicit a range of sophistication in student responses. Coding frameworks were developed based on previous work related to learning progressions (Hartley et al., 2014). For Food Web knowledge, the specific focus was how well students could identify connectedness among organisms in an ecological community. For Small Populations knowledge, the specific focus was whether or not students expressed concern for genetic variability in small populations in a captive breeding setting.

Knowledge of food webs. A simple food web model was developed to gauge how well students could identify food web complexity (See Appendix C). This food web model was based upon a real-world situation in Venezuela where trophic cascades play a major role in ecosystem dynamics (Terborgh et al., 2001). One of the apex predators on the Venezuelan mainland is the puma, or mountain lion, and one of its main prey species is deer, thus providing a parallel scenario to mountain lion and deer dynamics in Nebraska. The Venezuelan food web model presented three apex predators, four herbivorous prey species, and two vegetation types. Students were asked a series of increasingly complex questions to identify direct and indirect connections between the predators, prey, and vegetation. We asked what kind of effect decreasing or increasing one species would have upon another species. We posed simple questions about direct relationships between a predator species and prey species (e.g., “What kind of effect would decreasing the number of jaguar and puma have on the deer?”), whereas a more complex question would be about indirect effects between a predator species and a seemingly unconnected prey species (e.g., We adapted these questions from a format outlined in a biodiversity literacy project (Hartley et al., 2011).

Students received a score of 0 to 5 (See Rubric in Appendix D). A zero represented that a student could not make any food web connections, but all students in the sample were able to identify at least one connection. A lower score (Score 1-3) indicates students who identified simpler, direct and indirect species relationships and a higher score (Score 4-5) indicates students who identified more complex, indirect connections in the food web model. For running analyses, these 5 score categories were condensed into two categories, reflective of a lower score ("0"=Score 1-3) or a higher score ("1": Score 4-5). The mean score is reflective of this scoring scale of 0 to 1.

Greater than 50% of students scored a 5, indicative of recognizing at least two complex indirect food web relationships, and greater than 96% of students could recognize at least one indirect relationship (Score 2-5; See Table 8.1.3).

Knowledge of small populations. To gauge how well students could identify factors important to conserving a small wildlife population, an open-ended question was adapted from the Hartley et al. biodiversity literacy project (*In progress*; Alred, 2016, Thesis Chapter 2). The question's context was that of a captive breeding program scenario for an endangered species.

Students were asked 1) How they would select individuals of a native, endangered species, the swift fox (*Vulpes velox*), for a captive breeding program, 2) How many swift foxes they would choose, and 3) Why? These were all open-ended responses (See Appendix E). This small populations variable was scored on a scale of 0-2 for each student (0= No concern for genetic variability; 1= vague concern for genetic variability in terms of individuals or the current population; 2= concern for genetic variability in terms of future generations). Since the primary intent of this question was to explore whether or not students could *identify* genetic variability as a concern for small populations, and because the set-up of the question did not specifically ask students *why* genetic variability was important for the future population, scores 1 and 2 were combined. A lower score reflected that students did not mention concern for genetic variability

(“0”=Score 0) and a higher score reflected that students included concern for genetic variability (“1”: Score 1-2). The mean score is reflective of this scoring scale of 0 to 1. Greater than 45% of students considered genetic variability when discussing how they would choose individuals for a captive breeding population (See Table 8.1.4).

Three independent researchers coded responses and reached an average 90% agreement for the food web knowledge scores and 72% agreement for the small populations knowledge scores. After resolving discrepancies, coders reached an average 95% agreement for food web knowledge and 90% agreement for small populations knowledge.

8.1.4 Decision coding framework: Unit assessment and pretest & posttest assessments

Inductive coding framework development for student Decisions was initially informed by the Unit Assessment structured decision-making responses. Within the Unit Assessment, students completed 7 structured decision-making steps designed to support students’ formal decision-making at the end of the mountain lion unit. We analyzed students’ structured “Choice” (Step 6; See Figure 7.4) from their Unit Assessment decision-making framework, in addition to students’ unstructured pretest and posttest decisions (See Appendix F).

We created a Mountain Lion Management Decision coding scheme to categorize the themes present in students’ decisions based on 1) whether students supported or opposed mountain lion hunting and 2) the general type of management plan they proposed. Through the constant comparative method (Creswell, 2013), 20 specific themes emerged for students’ structured decision-making responses to the question, “Should we hunt mountain lions in the region?” on the Unit Assessment. Those themes were grouped into eight categories descriptive of students’ management solutions (See Appendix G). Upon refining the rubric, we performed this study’s analysis on a further-condensed four groups reflective of student decisions (See Table 8.1.5). Both the primary researcher and an undergraduate researcher coded the structured Unit

Assessment decisions. After the first coding round, coders reached 86% agreement. Once discrepancies were resolved, coders reached 100% agreement.

We then used the initial Mountain Lion Management Decision rubric that was created based on responses to the Unit Assessment in preliminary coding of the unstructured pretest and posttest decisions. After preliminary coding, we modified the rubric slightly to account for nuances in students' pretest and posttest decisions. Then, researchers re-coded the Unit Assessment decisions responses to reflect the modified rubric. After the second coding round of the decision responses, coders reached 88% agreement for pretest, 96% agreement for Unit Assessment, and 86 % for posttest decisions. After resolving discrepancies, coders reached 100% agreement for pretest, 100% agreement for Unit Assessment, and 99% for posttest decisions.

8.1.5 Ecological and non-ecological criteria coding framework development

We created an Ecological Criteria coding framework based on two themes of interest as well as the constant comparative method to find emergent themes in their "Criteria" within the Unit Assessment structured decision-making. The two themes of interest were how students expressed ecological values: 1) "Food Web Criteria": Concern for apex predator impacts on food webs and 2) Small Populations Criteria: Concern for small populations (See Table 8.1.6). We focused analysis on these two specific categories because they align with the food web and small populations knowledge assessments.

Both the primary researcher and an undergraduate researcher coded for Ecological Criteria. Coders reached 87% agreement for Food Web Criteria and 80% agreement for Small Populations Criteria. After resolving discrepancies, researchers reached 100% agreement for Food Web Criteria and 98% agreement for Small Populations Criteria.

The Non-ecological Criteria framework was used to note other types of values students expressed in their criteria (See Table 9.3.5). A total of 18 non-ecological criteria themes emerged, including values related to human and livestock safety, economics, hunting rights, and ethics. These 18 criteria were coded for presence-absence, rather than on a scale as was done for the Ecological Criteria.

Both the primary researcher and an undergraduate researcher coded for Non-ecological Criteria. Coders reached 90% agreement for all 18 combined criteria themes. After resolving discrepancies, researchers reached 97% agreement for Non-ecological Criteria.

8.2 Statistical Analysis

Because the intent of this study was to explore the factors that may influence student decision-making, the dependent variables of analysis were 1) their structured management Choice (Step 6) in the Unit Assessment, 2) their unstructured Pretest and Posttest Decisions and 3) the Criteria (Step 3) that represent students' values in the Unit Assessment.

To determine which variables (demographics, value orientations, and ecology knowledge) explain students' decision on the Pretest, Unit Assessment, and Posttest, a multinomial logistic regression was performed (SPSS). Additionally, a multinomial logistic regression was performed to determine whether the identical variables explain students' Criteria on the Unit Assessment. A Likelihood Ratio Test p-value of 0.1 was used to determine significance for the decision and criteria analyses based on precedence in the literature of similar research (Theobald & Freeman, 2014). A chi-square analysis was performed to determine if students' inclusion of vague or specific ecologically themed Criteria explained students' management decisions on their Unit Assessment.

9 Results and Discussion

We found differences between the unstructured and structured assessment contexts in terms of how students' decisions were predicted by value orientations, demographic variables or student performance on knowledge questions. In structured Unit Assessments where students practiced the 7-step decision-making framework, none of our variables were significant predictors of students' decisions. However, in the unstructured Pretest and Posttest settings, students' choices were predicted by several variables. This may reflect differences in students' formal and informal decision-making processes, which we will explore below.

In order to frame general patterns in student thinking about mountain lion hunting, we first describe the types of decisions that students offered and patterns of students' change in opinion throughout the course. We include quotes from students using pseudonyms. Then we discuss our analysis of variables that predicted Pretest and Posttest decisions. Finally, we briefly discuss students' use of the 7-step decision-making framework on the Unit Assessment, including their use of evaluation criteria.

9.1 Decision Themes

We found four major themes in student decisions about what should be done about the mountain lion issue. There were two "pro" and two "anti" hunting themes, ranging from the most extremely positive toward hunting to the most against hunting. In general, the majority of the students were pro-hunting.

9.1.1 Yes: Hunt throughout entire state

Students in this category wanted hunting to occur in some capacity in the state and did not explicitly exclude mountain lion breeding areas. It should be noted that the state's current management plan does allow hunting throughout the entire state, but the hunting quota is dependent upon where resident breeding mountain lions exist and where lone mountain lions simply disperse through the state. Responses often referenced a hunting quota, as well as other stipulations such as whether dogs could be used in certain areas of the state or designated seasonal hunting seasons. For example, Colin said in his Unit Assessment "This is the best option because it allows the mountain lions to continue living in the state, and slowly keep their population under control in order to avoid as much young mountain lion wandering as possible. The season must be limited to only killing 10 to 14 percent of the population to avoid too many females from running away from the young cats." Many students cited a need to control a growing population and protecting people or livestock. For example, Hannah said on the Pretest, "I think that there should be a hunting season allowed for mountain lions. Their population is growing and can damage farmlands and harm other people who may be in the areas the mountain lions are in. They only allow a certain number of permits to go hunting for them, so we are not harming their population but keeping it under control."

Although it was common for students in this category to express concern for safety, keeping the population "in check," generating money for the state, and preserving traditional hunting culture in the state, many students still wanted this management strategy to support the sustainability of the mountain lion population. They believed responsible hunting, even in the breeding areas, could achieve a compromise among stakeholders. One student in particular, Peter, paid special attention to weighing different values among stakeholders in his response to the Unit Assessment:

> "I would choose option #3 to allow limited hunting. But I mean very limited. I would lean towards a completely unmanaged mountain lion population, but as much as I prefer animals to people, I still have to think about the safety of my fellow man. I think we should allow the mountain lion population to grow substantially…at least two to three more colonies to allow a bit more diversity to our cougar population. The public needs to be educated about mountain lions much more instead of blanket fear that most people have. These animals can help us control the deer population and perhaps even smaller critters like rabbits.

> Truthfully I can't stand sport hunting. I think it's atrocious. Hunting out of necessity for food or to protect personal property are fine, but killing this creature just to mount it in a trophy room is appalling…"

Peter also chose "Yes: Hunt throughout entire state" for the Pretest, but in the Posttest, he changed his decision to "No: Do not hunt currently" (See Section 9.1.3).

"Yes: Hunt throughout entire state" was the most popular management decision category throughout the course with greater than 47% of students falling in this category alone throughout the course. A similar number of students fell in this category for both the Pretest (*n*=65) and the Unit Assessment (*n*=64), but the total decreased by 10 individuals for the Posttest (*n*=52).

9.1.2 Yes: Hunt outside of breeding areas

Students in this category determined that hunting could occur within the state, but hunting should not be allowed within the designated breeding areas. In Nebraska, breeding areas are determined based on the existence of a resident mountain lion population (i.e., evidence of a female mountain lion with kittens). The primary breeding area designated by Nebraska Game and Parks is called the Pine Ridge Unit, an area in the northwest region of the state. Students in this category wanted to protect the small breeding population, yet allow people to hunt solo males that disperse across the rest of the state where habitat is unsuitable for mountain lions. On her Unit Assessment, Lily said, "Allowing for unlimited mountain lion hunting with a permit…and no hunting in the resident population of the Pine Ridge Unit would be the best choice…it would give the mountain lion population in the Pine Ridge Unit time for growth and development of a stable population…" As was the case with the "Hunt throughout entire state" category, many of the responses in this category reflected the desire to support the sustainability of the mountain lion population, but these students believed sustainability was more realistically supported if the breeding areas were off-limits to hunting.

Reflecting an understanding of scientific uncertainty, some students in this category also mentioned that enough is not known about the resident Pine Ridge population yet to start hunting in that area. On his Posttest, Charlie said, “We should gather more information than is already known about mountain lion populations in the Pine Ridge Unit by doing more surveys of their habitat. Once a conclusion is reached, then the decision can be made on whether or not to hunt mountain lions in that area. In the Prairie Unit, there is no suitable habitat for mountain lions, and ones seen there are passing through this area and are likely not going to be able to reproduce. Because of this, hunting should be allowed in this area of Nebraska.”

For the Pretest, no students fell in the “Yes: Hunt outside of breeding areas” category. This category emerged in the Unit Assessment data and the Posttest data as a result of discussing different management practices and consequences during class. Students may not have been aware of the distinction between resident breeding populations and dispersing lions at the beginning of the course. Additionally, in the course we discussed how the state enacts specific management stipulations in different regions of the state depending on existence of resident mountain lion breeding populations. This category contained the fewest number of students, comprising approximately 12% of students in the Unit Assessment (*n*=13) and 10% of students in the Posttest (*n*=11).

9.1.3 No: Do not hunt currently

Students in this category only wanted to consider hunting within the state if the mountain lion population becomes large enough for hunting management to be more sustainable *or* if the mountain lions become “overpopulated.” On the Posttest, Marcus said, “I do not think that we should hunt mountain lions in Nebraska. I think that they are still in a relatively small population and should only be hunted if they are posing a threat to livestock and human lives. We should make sure that their populations are stable enough before we start controlling their populations.”

Several students, like Marcus, only wanted mountain lions killed if they were a direct threat to livestock, pets, or humans.

There could be a few reasons why students chose this category. First, perhaps they personally do not think the population is large. For example, in other states where there are hunting seasons, such as nearby South Dakota, there are hundreds of mountain lions, compared to the 22-33 individual mountain lions currently in Nebraska. Second, students may have considered scientific evidence they learned during the mountain lion unit. From science-based studies of mountain lion management in western states, students learned that hunting a maximum of 14 percent of the population was determined to be sustainable harvest because that represents the intrinsic growth rate of a mountain lion population (Beausoleil, Koehler, Maletzke, Kertson, & Wielgus, 2013). Not only does the harvest limit impact population sustainability, but it also impacts predator-prey and predator-human interactions. Nebraska's current hunting quota of 4 total mountain lions a year could possibly be over the limit that has been determined by other studies to be a "sustainable" amount. For example, if there are 22 mountain lions in the state, taking 4 mountain lions would remove 18 percent of mountain lions from the population.

When Marcus said mountain lions should "…only be hunted if they are posing a threat…," we knew he meant *regulated hunting* because he mentioned at the end of this statement, "…before we start *controlling* their populations." However, it should be noted that the words "hunt" and "kill" were sometimes used interchangeably among students in this decision category. For example, when Patricia stated on her Unit Assessment that there should be: "No hunting or killing mountain lions except when livestock or humans are threatened by the mountain lion," her response was coded with the understanding that the she meant "kill," rather than regulated hunting because she said "except when," implying isolated events.

The idea that mountain lions could become "overpopulated" appears to be an alternative conception of students that is not founded by canonical ecology, as top predator species rarely exhibit an overpopulated quality. The alternative conception of a possible mountain lion "overpopulation" was not limited to this category alone, but the idea that mountain lions could become uncontrollable in numbers emerged quite a few times as reasoning for this management decision category. For example, in the Pretest, Molly responded, "I do not think hunting should be allowed until the mountain lion population has stabilized and gotten to a size where hunting would prevent overpopulation." Students expressed this alternative conception more often in the Pretest responses than in Unit Assessment or Posttest, most likely because classroom instruction introduced the concept that large apex predators are not subject to overpopulation because their social dynamics and consumptive behavior differs from that of prey species. Apex predators, such as mountain lions, bears, and wolves, are uniquely able to self-regulate their populations (Wallach, Toms, Ripple, & Shanas, 2014) and therefore arguably do not "need" lethal regulation for the purposes of preventing overpopulation.

In contrast, some students emphasized that mountain lions are a predator species as part of their support for this decision. On his Posttest, Peter said, "I think that mountain lions should not be hunted until the population is able to flourish. We need to give the species time to re-establish itself into its native habitat. Only then should we be able to hunt it, and sparingly. After all, they are a predator species and the population is limited as is." Although Peter did not elaborate as to why it is special that mountain lions are a predator species, it can be inferred that he thinks there should be a distinction between management strategies for predator and prey species since their reproductive cycles and social dynamics are inherently different. It is also noteworthy that Peter made a point to say that Nebraska is, in fact, the mountain lion's native habitat. He is acknowledging the history of the predator's human-induced extirpation from the state. This biospheric inclination contrasts with some students' more egocentric or altruistic desires to hold a hunting season to control the mountain lion's possible impact on human and livestock safety.

“No: Do not hunt currently” was the second-most popular management category Unit Assessment and Posttest. Approximately 19-32% of students fell in this category throughout the course. It was the only category of the four that gained, rather than lost, students between the Unit Assessment (*n*=18) and the Posttest (*n*=35).

9.1.4 No: Do not hunt or kill

Students in this category did not want mountain lions to be hunted or killed in any capacity for various reasons such as they think the population is too small or as an expression of support for animal rights. Bonnie explained in her Pretest response:

> “From an animal lover perspective, humans have done nothing but inflict damage on the earth and particularly the animal kingdom…As long as there are no recorded mountain lion attacks and there is no damage done by the increase in population, I don't believe there is a use in having a hunting season besides people who hunt simply for the joy of the kill. We often go in under the guise of ‘controlling populations’ and then we over hunt and overuse the resource, if you want to consider animals a resource. They have just as much of a right to be here as we do.”

In line with the animal rights sentiment, some students viewed mountain lion harvest as purely sport hunting rather than as a necessary management strategy. In the Unit Assessment, Emma said, “I feel like mountain lions are just being themselves and don’t deserve to be hunted for sport…” Students who expressed this probably held the viewpoint that hunting say, deer or other prey species, is appropriate because the harvested animal are usually used for food products, whereas mountain lions generally are not consumed and are instead more of a “prize” to display in the home. However, there are certainly people who do consume the meat.

A few students thought mountain lions, if left alone, could positively impact the ecosystem. In the Pretest, Tom said, “I do not think that we should hunt mountain lions in

Nebraska. If they are left alone they should be able to compete with other wildlife for food and habitat…there isn't a huge number of them, and they will help decrease the deer population.”

Many students in this category proposed alternative no-kill management plans. Some plans were realistic such as performing further research before determining a management plan. Rose provided an alternative plan in her Unit Assessment: “I’m choosing the option of educating the public to leave the mountain lion population alone.” Other plans were unrealistic, such as relocating all mountain lions to a protected, fenced-in park area. Alice suggested the following in her Unit Assessment, “I think the best option would be to relocate the whole mountain lion population out of Nebraska…as long as we can make sure they don’t come back into Nebraska, it will solve the problem of human encounters with them…wouldn’t have any more damage to the livestock of ranchers and farmers.”

Approximately 11-21% of students fell in this category throughout the course. The number of students in this decision category declined over time (Pretest, *n*=24; Unit Assessment, *n*=15; Posttest, *n*=12).

9.1.5 Management decision summary

The majority of students held pro-hunting positions in their pretest (*n*=65), Unit Assessment (*n*=77), and Posttest (n=63). Within in the “Yes Hunting,” category, the majority of students in the Pretest, Unit Assessment, and Posttest supported hunting mountain lions throughout the entire state compared to only hunting outside of the breeding units. Within the “No Hunting” category, decisions were more evenly split for the Pretest and Unit Assessment. However, for the Posttest, the majority of students (*n*=35) supported not hunting *currently* compared to not hunting at all. Over the course of the semester there were fewer students in extreme views of either pro-hunting throughout the state or anti-hunting in any situation, and more students who had moderate, nuanced positions that stipulated hunting in certain locations or only when the population was larger (See Figure 9.1).

9.2 Variables Predicting Decisions

We examined students' ecological knowledge, value orientations, and demographic variables to better understand these variables relationships with the students' decisions for their Pretest, Unit Assessment, and Posttest. We found that some of the variables we measured predicted students' decisions in the Pretest (multinomial logistic regression; $p<0.001$) and Posttest (multinomial logistic regression; $p<0.001$) unstructured settings, and were significant in predicting students' decisions during the structured Unit Assessments (multinomial logistic regression; $p=0.074$). In general, the broad patterns that we observed in these variables between the four different management types were similar across all of our observation time points. For example, rural males who hunt were more likely to choose a pro-hunting management choice on the Pretest, Unit Assessment and Posttest. Variables that were significant in the unstructured Pretest, Posttest and Unit Assessment settings and the patterns in them are discussed below (See Table 9.2).

9.2.1 Value orientations

The Bio-Ego Value Orientations score was predictive of students' decisions in the Pretest ($p=0.051$) and on the Unit Assessment ($p=0.049$), but not the Posttest. On all three assessment types, students with lower Bio-Ego Value Orientations difference mean scores were associated with more pro- hunting strategies ("Yes: Hunt throughout entire state") and students with higher Bio-Ego Value Orientations difference mean scores were associated with non-lethal management strategies ("No: Do not hunt or kill") (See Table 9.2.1). In previous work, on a different SSI, corn ethanol use for biofuels, value orientations predicted students' stances on a pretest but not posttest assessment (Dauer et al., 2017). It was speculated that this relationship was an indicator of informal decision-making at the beginning of the course, but less so after instruction using formal decision-making. The reasoning follows that value orientations indicate the strength of biospheric or egoistic values, that in Values-Belief-Norms Theory lead directly to observed beliefs, norms and behaviors. In informal decision-making, students may use a value-based heuristic where they make a decision based on a single value, rather than a reasoned analysis of a suite of values, so the connection between the strength of biospheric and egoistic values and decisions may be more transparent in the pretest compared to the posttest (Dauer et al., 2017).

During the Unit Assessment in the mountain lion unit, the students were asked to identify multiple values, generate different kinds of solutions for the mountain lion issue and purposely evaluate them. One of the intents of the structured decision-making exercise in the Unit Assessment is to support formal decision-making by guiding students' recognition of value-tradeoffs in complex decision-making and reduce value-based heuristics. Part of this process is acknowledging that 1) Personal values influence decisions, 2) Individual students may have multiple values that conflict with one another and must be sorted out, and 3) Peers may have multiple personal values and concerns that differ from their own. However, students' mountain lion hunting decisions on the Unit Assessment were also predicted by student value orientations. This either indicates that the Unit Assessments did not support students' consideration of value-tradeoffs or the relationship between value orientations and informal and formal decision making process may not be as clear cut as previously thought. In other words, a relationship between students' decisions and their value orientations may or may not be an indicator of formal decision-making, or a sign that students are noticing tradeoffs among values.

To futher understand the relationship between students' values and their decisions, and students' ability to notice tradeoffs among values, our other areas of investigation may be more promising. In particular, in this study we explore the relationship between student's value orientations and the criteria that they express on their unit assessments to shed light on whether or not students are able to write multiple criteria that accurate expresses their values. In future studies it may be helpful to qualitatively examine students' responses to the Unit Assessment to determine students' ability to discuss value trade-offs among options.

9.2.2 Demographic factors

For the Pretest, gender (p=0.029), rural background (p=0.011), and hunting identity (p=0.072) were predictive of decisions. On all assessments the general pattern was that rural males who hunt were more likely to be pro-mountain lion hunting than non-rural females who do not hunt. In particular, large differences in gender include that male students were 3.0 times more likely than female students to choose "Yes: Hunt throughout entire state" and female students were 3.1 times more likely than male students to choose "No: Do not hunt currently." Rural students were 2.9 times more likely than non-rural students to take the most pro-hunting stance and choose "Yes: Hunt throughout entire state." Non-rural students were 7.9 times more likely than rural students to choose "No: Do not hunt or kill." Hunter students were 3.1 times more likely than non-hunter students to choose "Yes: Hunt throughout entire state" and non-hunter students were 8.1 times more likely than hunter students to choose "No: Do not hunt or kill."

For the Posttest, rural background remained predictive of decisions (p=0.031) with identical patterns, but stakeholder identity and gender were no longer predictive. Rural students were 2.6 times more likely than non-rural students to choose "Yes: Hunt throughout entire state." In contrast, non-rural students were 19 times more likely than rural students to choose "No: Do not hunt or kill." This last results is an approximately two-fold increase from the Pretest results, so it seems that by the end of the course, being a non-rural student was even more strongly predictive of this "No: Do not hunt or kill" decision.

These results (See Table 9.2.2) suggest that demographic variables, which may be strongly ingrained and influence what students value in their decision-making, were more influential in a context where students did not have a decision-making structure. Although we observed similar patterns on the Unit Assessment where rural male hunters were more likely than their counterparts to choose pro-hunting decisions, these variables were less pronounced and non-significant in our model. Students may be more likely to rely on value-based heuristics associated with their personal identity and social norms when making decisions outside of the structured decision-making context (the Unit Assessment), as they do for their pretest and posttest decisions.

The absence of gender and stakeholder identity as predictive variables for the posttest decisions suggests that for the students in this study, rural background identities were more strongly ingrained than the influence of gender or hunting experience. This may support the claim that structured decision-making activities may provide a means to mediate the hold of cognitive biases and thus provide room for other factors such as value tradeoffs, scientific knowledge, and peers' differing points of view to play a role in their decision-making.

Although rural background was still predictive for the posttest after it did not predict Unit Assessment decisions, this may provide further evidence that the structured decision-making activity during class impacted students' thought processes for finding a solution to mountain lion conservation. For example, in the absence of clear, structured decision-making rules, students may be more likely to fall into the trap of "groupthink" whereby they align their views with a group of people who hold values similar to their own such as family and friends (Janis, 1982). Even though working in small groups is supported by the literature as being an effective learning strategy in the classroom, it is worth noting that psychological traps such as "groupthink" and "conformity" can also manifest themselves in structured small group working environments (Arvai et al., 2010). Further research would be needed to determine if groupthink played a role within students' assigned small groups. Overall, we believe structured decision-making may encourage students to engage in formal decision-making, which helps students avoid making decisions based on value judgments.

9.2.3 Ecological knowledge sophistication

Food Webs. Students' food web knowledge sophistication was predictive (p=0.031) of their pretest decision and Unit Assessment decision (p=0.031) but not students' posttest decisions (See Table 9.2.3). Current research supports that apex predators, like mountain lions and wolves, have the ability to self-regulate their populations (Wallach et al., 2014). It would follow, therefore, that if students have an understanding of apex predator social dynamics and their role in the food web, this understanding would influence their mountain lion conservation decision and may be more predictive of "No hunting" decisions or "Yes: Hunt outside of breeding areas." In line with our thinking, students who gave high sophistication food web knowledge were 6.6 times more likely on the pretest and slightly more likely on the Unit Assessment to report a "No: Do not hunt currently." They were also 3.5 times more likely on the Unit Assessment to report a "Yes: Hunt outside of breeding areas" choice than students who gave low sophistication responses. Students with a low sophistication food web knowledge score were slightly more likely on the pretest to report a "Yes: hunt throughout the entire state" choice; unexpectedly, the opposite trend occurred in the Unit Assessment where students with low sophistication knowledge were slightly more likely to report a "Yes, hunt throughout the entire state" choice. Additionally, in the opposite direction of we expected, students who had a low sophistication food web knowledge score were slightly more likely on the pretest and 4.3 times more likely on the Unit Assessment to report a "No: Do not hunt or kill" choice than students who gave high sophistication responses.

It is possible that students in the more extreme categories "No: Do not hunt or kill" and "Yes: hunt throughout the entire state" might highly value animal rights or hunter/rancher rights respectively and place less value on scientific information or ecosystem processes. Perhaps students in the two more moderate categories “No: Do not hunt or kill currently” and “Yest: hunt outside the breeding areas” are incorporating knowledge and values in a more holistic way than students with the more polarized stances. The Food Web knowledge variable was not predictive of the Posttest, so, over the course, it is possible that students’ ecosystems knowledge sophistication was included in their decision-making in a more balanced manner. It is also possible that, overall, students’ decisions were aligned more with economic, cultural, and other dimensions of the issue rather than ecological knowledge. More research is needed to explore the connection between knowledge and its role in students’ understanding and decision formation.

Small Populations. Interestingly, small populations knowledge sophistication was predictive (p=0.47) of their Posttest decision and not their Unit Assessment or Pretest decision (See Table 9.2.4). If students were concerned about the mountain lions’ small population size, we would predict students with higher small populations knowledge would fall in the “Yes: Hunt outside of breeding unit” and the two “No hunting” categories, and students with lower small populations knowledge would fall in the “Yes: Hunt throughout the entire state” category. However, this pattern was not seen in the data. The only part of this prediction that held true was that students with higher small population knowledge were 3.2 times more likely to fall in the “Yes: Hunt outside of breeding area.” Surprisingly, students with *higher* small population knowledge were slightly more likely to fall in the pro-hunting category of “Yes: Hunt throughout entire state,” and students with *lower* small population knowledge were more likely to fall in the anti-hunting categories of “No: Do not hunt currently” (by 2.3 times), and “No: Do not hunt or kill” (by 2.0 times), in the opposite pattern we expected.

Students who received a higher small populations score for their knowledge assessment expressed the importance of genetic variability for a population, so it would follow that more students with a higher small populations knowledge score would choose the “Yes: Hunt outside of breeding areas" category when compared to other categories as they may be more likely than other students to be thinking about mountain lions as a population and long-term effects of in-breeding on population resilence. It is interesting, though, that approximately 50% more students within the "No: Do not hunt currently" category had a low small populations knowledge score than a high score, especially considering that one of the most common reasons students made this decision was because they deemed the current mountain lion population too small for lethal harvesting, but may not necessarily link this to biological reasoning about populations.

Other studies support that content knowledge may not be a primary influence in environmental behavior and decision-making, but may serve a more indirect, intermediary role (Frick, Kaiser, & Wilson, 2004 ; Heimlich, Mony, & Yocco, 2013). Therefore, a student's content knowledge on a subject may not always be a predictive variable in and of itself of how she or he makes a decision. When a controversial topic is relatively new, and students have limited background knowledge on the subject, it may be unrealistic to expect students to effectively integrate or prioritize content knowledge into their decision-making without a certain amount of support and guidance from the facilitator. However, there are environmental education studies that do show that increased knowledge and understanding of a wildlife species can increase support for its conservation (Curtis & Valdez, 2009; Orams 1996). For example, in a study by Espinosa & Jacobson (2011), higher levels of knowledge about the Andean bear in Ecuador resulted in more positive attitudes and behavioral intentions toward the species. These studies took place in the context of experiential environmental education in communities, though, which has been shown to help people internalize information about a wildlife species and impact their attitudes and behaviors (Sponarski, Vaske, Bath, & Loeffler, 2016). The research we performed took place in the context of a university learning environment, so perhaps a more immersive, participatory decision-making activity would change how students utilize knowledge in their decision-making. Our study does not explain why content knowledge was predictive in some decisions and not others. The results in regard to small populations knowledge were unexpected. Future research, such as interviews, can focus on further exploring the connection between ecological knowledge and decision-making.

9.3 Criteria Themes

In the structured decision-making exercise within the Unit Assessment, students wrote a list of 2 to 3 criteria to represent what they value in an outcome (i.e., management decision) to the mountain lion issue. For example, a student might want outcomes including increased safety of livestock, maintenance of mountain lion sustainability, and continued hunting rights. These could represent valuing of ranching livelihood, biodiversity, and the rich hunting tradition of the state. Because this issue is one of wildlife conservation, we were interested to see if and how students expressed criteria related to ecosystems and population conservation in their structured decision-making. We developed a coding framework to identify and categorize students' inclusion of concern for 1) food webs and 2) small populations.

Food web codes indicated whether students mentioned ecosystem-related concerns and if so, how specific their response was. Two main food web themes emerged. Small populations codes indicated whether students mentioned small population-related concerns and if so, the way in which they expressed those concerns. Two small populations themes emerged related to extinction concerns and genetic variability concerns. Whereas the food web codes indicated the sophistication of the response, or "how well" the student could talk about food webs, the small populations codes indicate in *what manner* the students talked about small populations.

If students did not include enough detail in their criteria response for us to code, we coded their criteria according to how they expanded upon their answers later in their decision-making if it helped to clarify their response.

9.3.1 Food web criteria: "Vague Ecosystem Impact"

Some students included an ecosystem-related criterion, but did not say what kind of specific ecological outcome they would want to see from the chosen mountain lion management solution. Students in this category sometimes said that they wanted "healthier ecosystems' without further explanation. Along these lines, Marcus said, "The local ecosystems must remain stable with or without the mountain lion populations." Marcus did not expand upon what "stable" meant at any point in the remainder of his decision-making. With responses such as this, it is unclear whether students understood how this apex predator species could potentially impact ecosystems in Nebraska. The lack of detail used to describe what ecosystem "stability" and "health" mean may also highlight a general lack of knowledge among students regarding real-life measurable indicators of sustainably functioning ecosystems.

9.3.2 Food web criteria: "Specific Ecosystem Impact"

Other students provided more specific ecological criteria detailing an outcome they would value should a particular management decision be chosen. Rather than simply saying that the ecosystem should be healthy, students would include information about food web impacts, such as trophic cascades, or emphasize the intrinsic value of biodiversity. For example, Harry said:

> "I think the two biggest criteria in this matter are maintaining biodiversity and a healthy ecosystem…Another criteria is the risk of overpopulation of mountain lions and the problems that occur with this. To many, biodiversity is very important because it encourages a healthy ecosystem and a strong trophic structure."

Although Harry did not provide a specifically measurable criterion, he included the concepts of biodiversity and trophic structure. This sheds some light on his understanding that having more species in an ecosystem in itself increases biodiversity, as well as reveals his understanding that apex predators can have a disproportionately more powerful impact on multiple trophic levels compared to other prey species at lower trophic levels. Several other students included this concept of trophic cascades, including Joanne: "What impact do these options bring when it comes to the environment? In areas of suitable habitat they could help manage herbivore populations increasing plant diversity."

Interestingly, there were a few students who indicated the possibility that mountain lions could negatively impact the ecosystem. Hannah said:

> "Maintain the food chain, and in no way disturb the pre-existing food chain in the state…The mountain lion population would rise dramatically, the current food chain would be disrupted due to the increase of predators in the area, there would be less small animals and deer, disrupting all other parts of our fragile food chain and ecosystem."

Hannah's response reveals an alternative conception that mountain lions would essentially "disrupt" the ecosystem. The renewed presence of mountain lions in Nebraska will certainly alter the ecosystem within the breeding units in some ways, such as being a natural predator for deer and elk populations, but it is not necessarily accurate to expect the presence of mountain lions to negatively impact the food web. If mountain lions were found to be changing the game species population numbers, the Game and Parks Commission could alter bag limits for those species on their end. However, coding for Food Web Criteria does not reflect scientific accuracy, and since she discussed connections between predator and prey species, her criteria response was still coded as "Specific Ecosystem Impact." In Hannah's Unit Assessment decision response, we see she does value the existence of mountain lions and still wants them in the state: "…Also with the sale of permits, we are providing funding for mountain lion research efforts to help better our understanding of the mountain lion population in our state, such as how many mountain lions are living in Nebraska, how many are of breeding age and finally, the relationships between the lions." She was most likely concerned about the uncertain long-term impacts of mountain lions on the Nebraska ecosystem. Only 34 of 110 students expressed concern for food webs in their criteria. Of those students, it was almost evenly split for the number of students who included vague Food Web Criteria and those who included specific food web criteria.

On the one hand, it was encouraging to see students attempt to include science-related criteria in their decision-making for a conservation issue. With regard to the structured decision-making process, though, evaluating “Vague Ecosystem” criteria in a tradeoffs analysis is unrealistic in terms of determining a management strategy that can meet specific, measurable outcomes. Even the “Specific Ecosystem” criteria was not always measurable. The student examples given above were some of the more “sophisticated” responses. The resultant management solution chosen based on vague or immeasurable criteria will be shallow at best in terms of addressing the real demands and values of multiple stakeholders involved in this complex conservation issue.

9.3.3 Small populations criteria: “Extirpation/Extinction”

The mountain lion as a species is not currently in danger of becoming globally extinct, although they disappeared from their historically native range in Nebraska in the past and are slowly reclaiming it. Students expressed concern for the current small population of mountain lions by including criteria that called for prevention of future extirpation. Some students used the general term “extinction” in place of “extirpation” (which means “local extinction”), although extirpation is the appropriate term for when a species ceases to exist in a specific geographic region as opposed to global extinction.

Some extirpation concerns were explicit, such as when Patricia stated, “Mountain lions cannot get close to extinction.” Other students expressed the same concern in different ways. Charlie mentions that mountain lions are “rare” in Nebraska, expressing concern for small populations in a way that indicates his preferred management strategy is going to keep mountain lions in the state and not eliminate them: "The well-being and continued breeding of mountain lions must be maintained. Mountain lions are rare in Nebraska, which is part of the mountain lion's historic range. Preserving a healthy and reproducing population of cougars in Nebraska's suitable habitat should be a top priority." Only 27 of 110 students expressed concern for small populations in their criteria. Of those students, most (*n*=25) expressed concern for species extirpation from the state.

9.3.4 Small populations criteria: "Genetic Variability"

Nebraska's population is not completely cut off from the rest of the mountain population in the United States. Wandering males from other states pass through Nebraska, and it is therefore possible for them to breed with females of the resident population as part of their travels, thus diversifying the genetic pool. However, the resident breeding populations in Nebraska are relatively isolated in several small, forested habitat pockets. Given this geographic semi-isolation, as well as the small size of the resident population, few of which are female, genetic variability could reasonably be a conservation concern in Nebraska. However, only two students expressed concerns for genetic variability or the possibility of inbreeding in Nebraska's breeding population.

One student, Kathleen, simply stated as her criteria, "Mountain lion inbreeding is prevented." She later explained a little further in the tradeoffs analysis that certain management decisions could influence "…there being more mountain lions, not the same ones will always breed together…"

Peter provided a little more detail in his decision-making. For his criteria, he said, "Maintain a healthy mountain lion population in suitable habitats." He expands upon this later in his final decision by adding:

> "…to maintain a healthy population there needs to be diversity to avoid inbreeding. We can gain diversity by setting up multiple habitats" and "I think we should allow the mountain lion population to grow substantially, closer to one hundred or more. There should be at least two to three more colonies to allow a bit more diversity to our cougar population."

In the Unit Assessment structured decision-making, Peter chose "Yes: Hunt throughout entire state," although he emphasized that the hunting should be "very limited." He chose this management method to balance, in his eyes, the needs of the mountain lions with human safety concerns. Even though he still supported hunting, he also clearly valued genetic variability within the mountain lion population.

9.3.5 Non-ecological criteria

Overall, students included non-ecological criteria more often than ecological criteria. Non-ecological criteria reflected values toward safety, economics, culture and traditions, ethics, conservation program sustainability, and mountain lions' existence in Nebraska. The most common of these concerns were those for the continuation of mountain lion conservation in the state (n=65), human safety (n=61), and livestock safety (n=53). The themes found in the remaining criteria that the students stated, and the percent of students who mentioned them, are in Table 9.3.5.

9.4 Variables Predicting Inclusion of Ecological Criteria

None of the independent variables (Bio-Ego value orientation difference, demographics, or ecological knowledge sophistication) were predictive of students' inclusion of ecological criteria in their Unit Assessment structured decision-making (See Table 9.4). We would normally expect to see some of these variables predict students' ecological criteria, at least in the case of students who have a high Bio-Ego value orientation difference since Criteria should reflect some of the students' personal values. The mountain lion unit was the first of four socioscientific issue units for the semester, so students may not had a strong grasp on the decision-making process well enough to identify core values or write criteria that work as measurable metrics. There may therefore have been so much variability that there was not a clear connection between value orientations and inclusion of ecological criteria. Analyses were not conducted to explore the relationship between non-ecological criteria and decisions, but this could be a useful exploration for future research.

9.5 Influence of Ecological Criteria on Structured Decisions

Students' inclusion of ecological criteria did not predict their Unit Assessment decision. However, it is worth noting that students in any of the four decision categories could justify including ecological criteria. The issue of mountain lion conservation is complex and ill structured, so there is no clear-cut solution for how best to manage the mountain lion population. Students' different management decisions may reflect differences in how much they value the ecological criteria they included, but there was not a way to analyze this because students were not directed to indicate how much they valued certain criteria compared to other criteria. The lack of relationship between criteria and decisions may also highlight students' inability to identify criteria that are represent the objectives they want their decision to accomplish. As in, some students may have listed criteria they either did not truly care about, or they did not effectively complete their tradeoff analysis in a way that lead them to choose a management decision reflective of the criteria they listed.

10 Conclusions and Teaching Implications

The complexity of socioscientific issues warrants careful, informed decision-making from citizens. While citizens often do not directly vote on wildlife management decisions, natural resources managers are still charged with involving the public in the decision-making process, whether that be through mail-in surveys or town hall meetings. How citizens think and make decisions on issues thus influences natural resource managers in their management plans. Everyone realistically has a role to play in wildlife management, and even the small, everyday decisions that citizens make can impact wildlife, which in turn affects larger scale biodiversity and ecological sustainability.

The responsibility of decision-making is ultimately in the hands of individual people. Each individual holds a suite of personal values, and their life is naturally shaped and influenced by these values in addition to other factors such as where they live, their gender, stakeholder identity, and their personal content knowledge of various issues. Because most day-to-day decisions require little deliberative thought, sometimes citizens use these same informal, "fast-thinking" decision strategies when making decisions about socioscientific issues.

To prepare students to become scientifically literate citizens who use formal, slow-thinking strategies to make important decisions, we propose that the undergraduate classroom is an ideal environment where students can learn formal decision-making strategies that will ideally transfer to their future lives. We also support the idea of teaching these structured decision-making strategies within the context of socioscientific issues-based instruction so that students have a relevant frame of reference with which to engage and practice these skills. When people fall into psychological traps and use value-based heuristics, as they do when engaging in informal decision-making, they inadvertently ignore the source of the complexity for socioscientific issues. This includes multiple stakeholders who all hold their own suite of values, knowledge, and background. Thus, the consequences of decisions, or policies, made for particular issues are going to affect each person differently.

We sought in this study to understand better what may predict undergraduate students' decision-making for a conservation-related socioscientific issues in unstructured contexts and in contexts meant to support formal decision-making. As we hypothesized, and is supported by previous studies in the decision-making sciences and human dimensions conservation literature, we found demographic factors (gender, rural background, and stakeholder identity) to be variables that predicted student decisions in an unstructured decision-making setting. In our study, all three demographic variables predicted students' decision-making in the unstructured Pretest setting, indicating that students may have used simplified heuristics such as social norms and identity (rural males who hunt were generally more pro-hunting) to make a choice rather than a reasoned analysis of tradeoffs among their own values. Since none of these variables was predictive of students' structured decision-making in their Unit Assessment, the structured decision-making exercise may have mediated the hold of these demographic variables on some students' decision-making process. Because gender and stakeholder identity were no longer predictive of the Posttest decisions, this further supports the plausibility of structured decision-making practices transferring from the classroom setting to an unstructured setting more akin to everyday life, such as completing an informational attitudes survey about wildlife policy. Rural background remained a predictor of decisions at the end of the course, so at least in the context of mountain lion conservation management, rural or non-rural background was a part of life that strongly permeated student decision-making.

Value orientations, on the other hand, were predictive for both the unstructured *and* structured decision-making contexts and may have been less useful as indicators of formal and informal thinking. This contrasted with our prior assumption, based upon Value-Belief-Norms theory, that when value orientations predict students' decisions it may indicate informal single value-based heuristics being used for decisions. In previous decision-making research in the context of the same course, value orientations were predictive for students' decisions on the Pretest but not on the Posttest during the biofuels unit (Dauer et al., 2017), which we suggested was a reflection of students transferring formal decision-making skills learned on Unit

Assessments to unstructured settings. Because the results from this mountain lion-oriented study differed in that value orientations did not predict students' decisions on the Unit Assessment, our results suggest that the relationship between value orientations and students' informal decision-making are likely not as straightforward as previously thought. In other words, the absence of a significant relationship between value orientations and decisions may not necessarily reflect that students are doing a better job considering multiple values in their decision-making. Values *should* be used in the decision-making process (Keeney, 2009), however, just not in a manner of making quick, values-based judgments that ignore complexity and tradeoffs. A careful weighing of multiple values with other scientific, economic, social, moral, and political concerns should occur in informed, formal decision-making, but the result may still be a prioritization of students' values that match their value orientations. From our results, we believe value orientations simply may not be the most effective, clear-cut way to measure whether students make informal or formal decisions in different settings.

It is also possible that student formal versus informal decision-making in the course depended upon the socioscientific issue context (e.g., mountain lion conservation versus biofuels manufacturing), and depended on how much experience the students have had with using the seven decision-making steps. The mountain lion instructional unit was the first of four opportunities students had during the course to engage in this structured decision-making process, and it is possible students improved in the way they completed the structured decision-making framework within the Unit Assessment in the other three units. The biofuels unit, mentioned above, occurred later in the semester. Since value orientations no longer were predictive for either the biofuels or the mountain lion decisions in the Posttest, this may still provide evidence that the structured decision-making practice used by students throughout the course did improve students' ability to notice value tradeoffs. Further research on the other units would need to be performed to provide stronger support for this hypothesis. More research is needed to better understand the links existent between students' values and their informal and formal decision-making.

Although value orientations may not be a cut-and-dry measure for assessing student informal and formal decision-making, the analysis of criteria students included in their structured decision-making may prove to be a useful lens for exploring how students are using and evaluating values and tradeoffs in their decision-making. We believe findings related to the Criteria shed light on challenges instructors and students may face when engaging in decision-making practices. It was surprising to find that none of the variables (value orientations, content knowledge, or demographics) predicted students' inclusion of ecological criteria. Since the Criteria were supposed to reflect what students valued in an outcome of the management decision, one might logically predict that some of these variables might predict the types of criteria students included. We did not perform an analysis in this study to see whether any of the variables predicted inclusion of non-ecological criteria. However, in terms of ecological criteria, we might expect a student who has a higher Bio-Ego value orientations difference to be likely to include some sort of ecological criteria in his or her list of criteria to weigh across all of the proposed options. Our results show, though, that value orientations were not predictive of students' inclusion of ecological criteria, which is quite interesting, especially in the context of a conservation issue involving an apex predator that can have reasonable trophic impacts in an ecosystem. We interpret this as meaning that students may need more support identifying criteria that more closely reflect their values. In addition to helping students learn to acknowledge when they may fall victim to psychological traps in their decision-making, it should be an equally important instructional goal to provide scaffolding to students that helps them reflect and identify their personal values. In this way, students can be more confident in evaluating a complex issue in a more holistic manner that is meaningful to them.

We also found that students' inclusion of ecological criteria did not predict their management decisions. This may either indicate that 1) students are not referring to tradeoffs among their criteria during their choice of a decision about mountain lion hunting, or 2) students that include ecological criteria may not necessarily value it highly enough that it influences their final decision. To illustrate the second idea: it may be that Student 1 values the ecological role mountain lions in Nebraska, but is more concerned for livestock safety and believes hunting is the best management tool, so they choose "Yes: Hunt throughout entire state" as meeting their values best. Student 2 values the same two criteria, but believes non-lethal management is the best solution that meets their values, so they choose "No: Do not hunt or kill." In reading Unit Assessment responses, though, we found evidence that supports the first hypothesis, that students do not always know how to weight their criteria appropriately across their proposed solutions in a way that is effective and appropriate in a tradeoffs analysis. In Peter's case (Section 9.1.1), he clearly placed more value or "weight" on the possible ecological impacts hunting could have on the mountain lion population, and even expressed that, in reality, he supported a hands-off management approach. Yet, he wanted to incorporate human safety into his decision-making. Ultimately, he choose a management decision that did not accurately reflect the management decision he should have made given his tradeoffs analysis that he articulated. Other students may have completed their tradeoff analysis in a similar manner, resulting in slightly disjointed connections between the criteria they listed and the management category they chose. Our results suggest that students need additional support in weighing tradeoffs among potential options.

In the way the decision-making framework was structured during this course, students were not instructed to explicitly "weigh" how much they valued each criteria (i.e., an expression of how much weight that criteria should have in the decision process). We recommend instructors guide students in learning how to assign numerical value to their criteria, as recommended in the decision-sciences (Gregory et al., 2012; Hammond, Keeney, & Raiffa, 2015) and using a semiquantitative analysis to guide performance of each option and weighing tradeoffs. In this way, students can concretely see how these criteria would conceivably play out in different decision scenarios in a tradeoffs analysis and therefore have a better decision-making aid to make a more informed decision reflective of multiple values they want to see in an outcome.

With regard to content knowledge, there was not a clear trend in how students used their knowledge in their decision-making. Students' Food Web knowledge was predictive of student management decisions for the Pretest and the Unit Assessment, but not for the Posttest. Small Populations knowledge was predictive of the Posttest, but not for the Pretest or Unit Assessment. According to Wilson and Arvai (2006), understanding and incorporating technical science information into the decision-making process reflects one component of a "quality" decision. Assessing student knowledge of ecology concepts and measuring its influence on student decision-making was useful and informative because it showed that some students are incorporating their understanding of these concepts into the decisions they make, which is especially encouraging for decision-making for a conservation issue in particular. However, when students did explicitly incorporate ecological knowledge into their decision-making, responses were, overall, not very sophisticated or reflective of an accurate understanding of mountain lion natural history or of the impacts different management strategies could have on mountain lion conservation. Discussion of scientific evidence relevant to apex predators, as well as an emphasis on considering genetic variability as part of the conservation decision, was infrequent and surface-level depictions at best. It is also notable that a small portion of students included science-related criteria at all in their decision-making for this issue.

A good portion of the mountain lion unit was devoted to providing students background on the mountain lion issue and on the decision-making process. However, the socioscientific issue units in the course were only two weeks long, so instructors could not allot a large amount of time to focus specifically on topics such as food web relationships, threats to conserving small populations, or differences in predator and prey behaviors and dynamics. Many of the students in this course were freshmen or did not have a major directly related to wildlife biology, and a clear understanding of food web dynamics is not required for most majors of the students taking this course. The conservation of mountain lions in Nebraska is also a novel situation given that other states have had more time to acclimate to mountain lion presence. Nebraska has a much smaller mountain lion population than any other state (the exception being the isolated subspecies population in Florida), and the majority of the state is agricultural with little natural mountain lion habitat. It may therefore be more difficult to imagine the types of impacts mountain lions could truly have in Nebraska, so students may have found difficulty in accurately and effectively incorporating knowledge related to ecology into their decision-making.

Global biodiversity loss, which includes diminishing genetic variability among endangered species and isolated populations especially, is becoming a more and more pressing issue for our planet in terms of permanently vanished ecosystems and the resulting disruption to ecosystem services upon which humans depend (Millennium Ecosystem Assessment, 2005). Even if future science supports there is in fact no true threat to the genetic variability of the mountain lion species as a whole (or even in Nebraska), it is still noteworthy that genetic variability did not naturally emerge as something students valued in a wildlife conservation plan. Genetic variability within a population is, in essence, the very backbone upon which natural selection acts. Wildlife conservation plans usually take into account the gene pool of a population when creating a management plan, so a future education goal may be that students also draw upon that knowledge in their own conservation decision-making, not just in the classroom but post-college in political processes such as voting.

These results relating to student use of ecological knowledge in decision-making suggest that in teaching decision-making in the context of socioscientific issues, instructors may need to provide more support in teaching science concepts to their students in the undergraduate classroom particularly situated in a real-life context such as hunting mountain lions. A science literacy course incorporates a wide range of academic fields into one classroom, so sometimes it can be challenging to address all of the different components of a complex socioscientific issue, while also making sure students have a working understanding of relevant science concepts essential for the critical and holistic evaluation of an issue. Educators should not make assumptions about students' prior knowledge from high school since even within the same state, education topics and the depth of that instruction can be variable. Students do not have to know every piece of scientific evidence relevant to the mountain lion issue, for example, to make an informed decision. However, educators are encouraged to occasionally check in with their students (e.g., through "clicker" questions or some other informal survey) throughout the course to see if students are making accurate and useful connections between the science they learn in class. Additionally, educators can assess students' understanding of how the science ties directly to whatever issue they are studying, and finally, how science can inform their decision-making in challenging, real-world scenarios.

While there is still much to learn about the implementation and benefits of structured decision-making frameworks in the classroom, our research supports that this practice is a worthwhile endeavor that can promote skills for science literacy.

Table 8.1.1. Summary of student demographic information

	Gender		Hometown Location		Stakeholder Identity	
Demographic Counts (*n*=110)	Male	Female	Rural	Non-rural	Hunter	Non-hunter
	37	73	63	47	49	61

Table 8.1.2. Summary of student value orientations

	Scale: -1.00-7.00			Scale: -1.00-7.00
Value Orientations Means (*n*=110)	Egoistic	Altruistic	Biospheric	Bio-Ego Difference
	3.77 ±1.12	5.24±1.05	5.2±1.41	1.43±1.64

Table 8.1.3. Summary of student food web knowledge sophistication

Food Web Knowledge (*n*=110)	Knowledge Score	1	2	3	4	5	Mean Score (0-1)
	Count	4	7	12	29	58	0.79±0.41

Table 8.1.4. Summary of student small populations knowledge sophistication

Small Populations Knowledge (*n*=110)	Knowledge Score	0	1	Mean Score (0-1)
	Count	57	53	0.48

Table 8.1.5. Mountain lion management decision rubric	
Decision Category	Description
Yes: Hunt throughout entire state	Hunting should occur in some capacity everywhere, including breeding areas.
Yes: Hunt outside of breeding areas	Hunting should occur, but breeding units are off limits.
No: Do not hunt currently	Hunting should not occur unless the mountain lion population increases or mountain lions pose a true threat. Can kill in self-defense.
No: Do not hunt or kill	Hunting or killing of mountain lions should not occur in any circumstance.

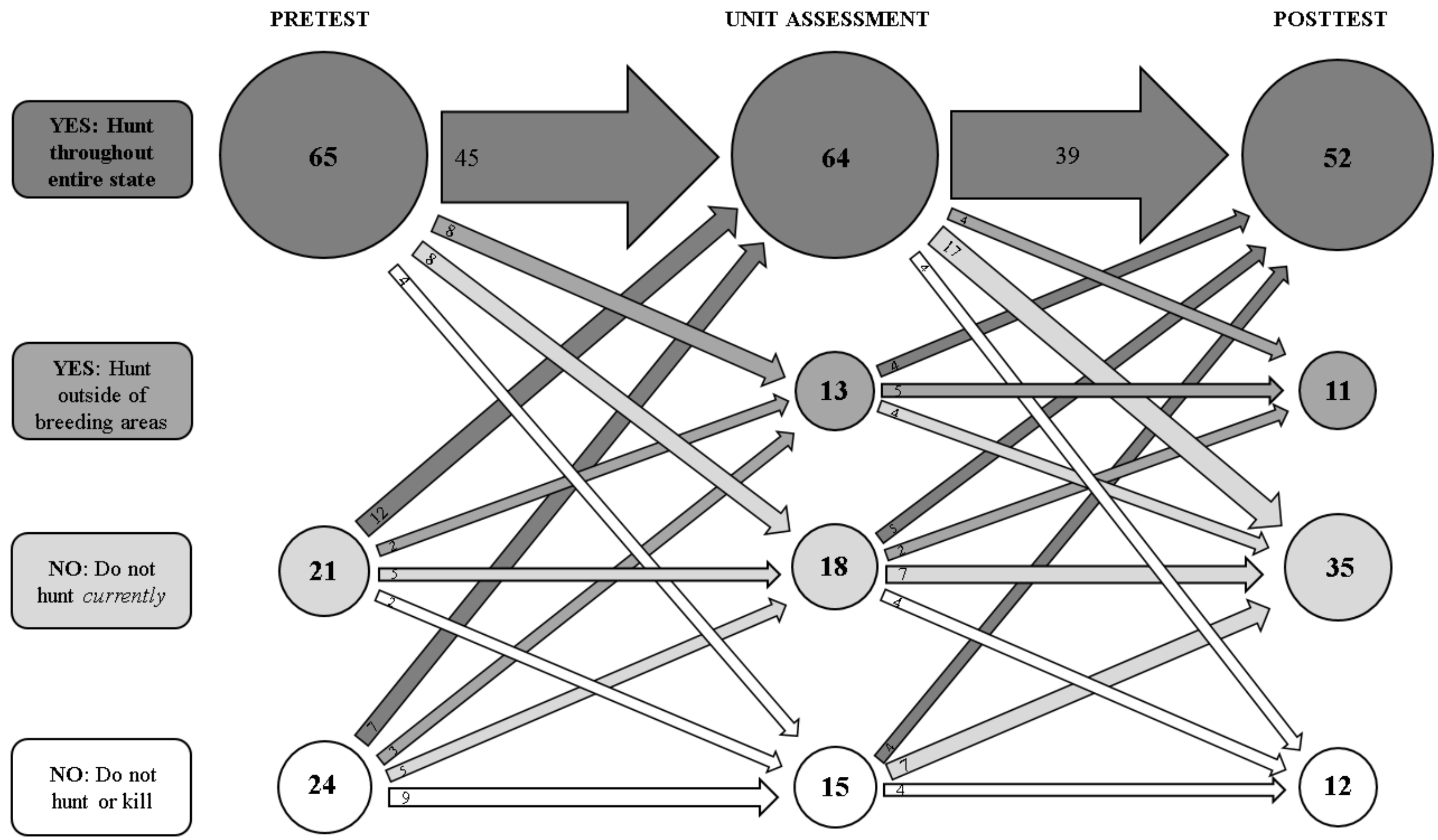


Figure 9.1. Change in decisions about mountain lion management (*n*=110)
Circles include the number of students in each management decision. Arrow size indicates the number of people who changed decision category between the Pretest and Unit Assessment and between the Unit Assessment and the Posttest.

Table 9.2. Summary of variables predicting management decisions Percent and mean scores (value orientations) of students are presented for each variable analyzed for significance in predicting management decision. Significant variables in the separate analyses performed for Pretest, Unit Assessment and Posttest are in bold (multinomial logistic regression, $p<0.1$).

Decision Format	Management Decision	Value Orientations	Gender		Rural Background		Stakeholder Group		Ecological Knowledge				
		Mean Bio-Ego Difference (mean)	Male %	Female %	Rural %	Non-rural %	Hunter %	Non-hunter %	Low Food Web Score %	High Food Web Score %	Low Small Populations Score %	High Small Populations Score %	*Total Students per Decision*
Pretest	Yes: Hunt throughout entire state	**1.13**	**76**	**51**	**70**	**45**	**73**	**48**	**65**	**57**	54	64	*65*
	Yes: Hunt outside of breeding areas	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	*0*
	No: Do not hunt currently	**1.51**	**8**	**25**	**22**	**15**	**20**	**18**	**4**	**23**	16	23	*21*
	No: Do not hunt or kill	**2.18**	**16**	**25**	**8**	**40**	**6**	**34**	**30**	**20**	30	13	*24*
Unit Assessment	Yes: Hunt throughout entire state	**1.09**	68	53	63	51	61	56	**52**	**60**	65	51	*64*
	Yes: Hunt outside of breeding areas	**1.85**	14	11	14	9	16	8	**4**	**14**	9	15	*13*
	No: Do not hunt currently	**1.88**	11	19	13	21	14	18	**13**	**17**	12	21	*18*
	No: Do not hunt or kill	**2.00**	8	16	10	19	8	18	**30**	**9**	14	13	*15*
Posttest	Yes: Hunt throughout entire state	1.05	62	40	**57**	**34**	61	36	61	44	**40**	**55**	*52*
	Yes: Hunt outside of breeding areas	1.82	8	11	**10**	**11**	10	10	4	11	**5**	**15**	*11*
	No: Do not hunt currently	1.63	19	38	**32**	**32**	27	36	17	36	**40**	**23**	*35*
	No: Do not hunt or kill	2.15	11	11	**2**	**23**	2	18	17	9	**14**	**8**	*12*
Total Variable Counts/ Total Mean VO:		*1.43±1.64*	*37*	*73*	*63*	*47*	*49*	*61*	*23*	*87*	*57*	*53*	*110*

Table 9.2.1. Value orientations "times more likely" summary

Management Decision	Value Orientations: Bio-Ego Difference Means
Yes: Hunt throughout entire state	1.11
Yes: Hunt outside breeding areas	1.85
No: Do not hunt currently	1.7
No: Do not hunt or kill	2.09
p = 0.051, 0.049	

Table 9.2.2. Demographics "times more likely" summary

Management Decision	Male/Female	X more likely
Yes: Hunt throughout entire state	male	3x
Yes: Hunt outside breeding areas	male/female	<2x
No: Do not hunt currently	female	4x
No: Do not hunt or kill	female	<2x
p = 0.029		
Management Decision	Rural/Non-rural	X more likely
Yes: Hunt throughout entire state	rural	3x
Yes: Hunt outside breeding areas	rural/non-rural	<2x
No: Do not hunt currently	rural/non-rural	<2x
No: Do not hunt or kill	non-rural	8-19x
p = 0.011, 0.031		
Management Decision	Hunter/Non-hunter	X more likely
Yes: Hunt throughout entire state	hunter	3x
Yes: Hunt outside breeding areas	hunter	<2x
No: Do not hunt currently	hunter/non-hunter	<2x
No: Do not hunt or kill	non-hunter	8x
p = 0.072		

Table 9.2.3. Food web knowledge "times more likely" summary

Management Decision	High/Low Knowledge	X more likely
Yes: Hunt throughout entire state	low/high	<2x
Yes: Hunt outside breeding areas	high	4x
No: Do not hunt currently	high	<2x-7x
No: Do not hunt or kill	low	<2x-4x

p = 0.031, 0.031

Table 9.2.4. Small populations knowledge "times more likely" summary

Management Decision	High/Low Knowledge	X more likely
Yes: Hunt throughout entire state	high/low	<2x
Yes: Hunt outside breeding areas	high	3x
No: Do not hunt currently	high/low	2x
No: Do not hunt or kill	low	2x

p = 0.047

Table 9.3.5. Non-ecological criteria. List and counts of non-ecological criteria students included in their Unit Assessment structured decision-making.

Non-ecological Criteria Descriptions	Percent of Students
Sustain or maintain mountain lion population in Nebraska	59
Human safety	55
Livestock Safety	48
Economics: Mountain lion research and conservation	14
Mountain lion health or safety	13
Maintain hunting traditions	12
Economics: State of Nebraska	10
Public opinion	9
Conservation management program sustainability	9
Economics: Nebraska Game & Parks Commission	6
Ethics (i.e., sport hunting)	5
Enactment of public education	5
Economics: Farmer/rancher profits	5
Opinion & guidance of Nebraska Game & Parks	5
Proper monitoring of mountain lion population	4
Hunter education programs	3
Economics "Vague" ("who" is making money is undetermined)	2
Maintain Nebraska culture and values	1

Table 9.4. Summary of variables predicting ecological criteria.
Percent and mean scores (value orientations) of students are presented for each variable analyzed for significance in predicting management decision. None of the variables were predictive in the separate analyses performed for Pretest, Unit Assessment and Posttest (multinomial logistic regression, $p<0.1$).

Criteria Category	Criteria Theme	Value Orientations	Gender		Hometown		Stakeholder Group		Ecological Knowledge				
		Mean Bio-Ego Difference (mean)	Male %	Female %	Rural %	Non-rural %	Hunter %	Non-hunter %	Low Food Web Score %	High Food Web Score %	Low Small Populations Score %	High Small Populations Score %	*Total Students per Criteria*
Food Webs	None	1.28	70	68	76	60	71	67	61	71	74	64	*76*
	Vague Ecosystem	1.37	8	16	11	17	8	18	13	14	12	15	*15*
	Specific Ecosystem	2.07	22	15	13	23	20	15	26	15	14	21	*19*
Small Populations	None	1.44	78	74	76	74	76	75	91	71	68	83	*83*
	Might go extinct	1.22	19	25	21	26	22	23	9	26	30	15	*25*
	Inbreeding	3.75	3	1	3	0	2	2	0	2	2	2	*2*
Total Variable Counts/Total Mean VO:		*1.43±1.64*	*37*	*73*	*63*	*47*	*49*	*61*	*23*	*87*	*57*	*53*	*110*

CHAPTER IV: FUTURE SCIENCE LITERACY GOALS

Improving and promoting science literacy may appear to be a daunting task. The world becomes more urbanized with each successive year, and the conversion of habitat to meet human needs is not slowing down in the foreseeable future. Sometimes we may feel like there is nothing we can do to make a direct impact on global environmental sustainability. However, it is important to raise awareness among students of the power they have through civic discourse and responsibilities, such as voting, to impact decisions meaningful to them at the local, state, and national level. Educators have no true barriers in continuing to strive toward continually improving students' awareness and understanding of current socioscientific issues and providing educational tools to assist with difficult decision-making tasks.

We learned from this thesis, as well as confirmed past literature, that even though educators may teach students science concepts, students may not understand or integrate the knowledge as planned. In the first study, most students neglected to connect genetic variability to conservation in a meaningful way that reflected a true understanding of how variability is important to future population-level resilience. The Next Generation Science Standards (2013) include goals for what students should know about genetic variability at the middle school and high school level, and although the percent of students who appropriately connected genetic variability to species conservation increased from middle school to high school to college, the overall percentage was surprisingly low. This research reiterates the need to continually check in with students' understanding throughout a course and address alternative conceptions accordingly. There is also a need to help students make connections between science concepts and real-life issues in a meaningful and memorable way so that they practice integrating knowledge rather than simply memorizing science concepts in isolated contexts.

This thesis also reaffirms the complexity of decision-making. Students' unstructured and structured decision-making responses highlighted challenges in addressing personal values, integrating content knowledge relevant to conservation management, and making decisions reflective of a reasoned tradeoffs analysis. A structured decision-making framework appeared to help mediate the hold of some values reflective of gender, rural background, and stakeholder identity, which is encouraging. However, educators may need to provide additional scaffolding so that students can more readily identify multiple personal values, recognize how science can aid the decision-making process, and appropriately "weigh" the values they wish to consider so that their final choice reflects reasoned decision-making. In a science literacy course such as the one in this study, students must learn a lot of content related to issues of which they may be unfamiliar, learn how to navigate a decision-making framework, as well as practice group discourse with their peers. More scaffolding and instructor guidance may help lift the stressful weight students might feel when faced with complex decision-making assignments.

The first study sends a message that content knowledge is important, while the second study claims that decision-making may be a skill useful to becoming a scientifically literate citizen. However, since content knowledge is only one consideration for informed and reasoned decision-making, the question of the importance of content knowledge remains. Content knowledge alone is a weak tool for complex decision-making—some socioscientific issues may require students to have different depths of science knowledge, and decision-making requires weighing multiple values as well. While it is unrealistic to expect all citizens to have the same scientific knowledge about any select issue, there may still be some core science concepts that are arguably more useful to everyday life than others are when considering the public, and this is where there is value in content knowledge. For example, it might not be inherently useful for the public to understand the chemical processes required to recycle plastic. Rather, it may be more useful for people to understand science related to how recycling benefits environmental sustainability at the local, state, national, and global scale. In a similar fashion, I argue that having a working knowledge of the tenets most important for species conservation may help citizens connect more deeply with conservation efforts when the time comes to vote for local initiatives, such as large predator management. If citizens lack an understanding of the basic concepts of biodiversity or genetic variability, they may be less likely to express concern for the conservation of a single species, such as mountain lions, or a local ecosystem, such as a wetland.

Rather than a traditional content knowledge acquisition whereby students memorize facts, students may benefit more from developing a working knowledge of how to apply science concepts. It may therefore be useful for students to be able to recognize when it is appropriate to seek and incorporate relevant scientific information in their decision-making about issues they may face throughout their lives. Just as it may be easy for students to forget physics lessons if other courses never address these concepts later on in their education, it is important to recognize that content knowledge integration, community discourse, and decision-making are all skills that require practice. It is therefore potentially useful to see structured decision-making practices incorporated into courses across all disciplines rather than as one isolated experience in students' undergraduate careers. Additionally, decision-making instruction is not limited to undergraduate classrooms; educators can begin teaching students decision-making at all levels of education. Using socioscientific issues to teach science, as well as other subjects, may be quite useful for educators to meet the dual challenge of teaching content knowledge and connecting it to real-world scenarios. In teaching students how to use a structured decision-making tool, educators may more readily achieve science literacy goals and contribute to influencing an engaged citizenry that works to conserve resources for the benefit of their communities.

11 References

American Association for the Advancement of Science. AAAS (1989). *Project 2061: Science for All Americans*.

Aikenhead, G. S. (1985). Collective decision making in the social context of science. *Science Education*, *69*(4), 453-475.

Arvai, J. L., Gregory, R., & McDaniels, T. L. (2001). Testing a structured decision approach: value-focused thinking for deliberative risk communication.*Risk Analysis*, *21*(6), 1065-1076.

Arvai, J. L., Campbell, V. E., Baird, A., & Rivers, L. (2004). Teaching students to make better decisions about the environment: Lessons from the decision sciences. *The Journal of Environmental Education, 36*(1), 33-44.

Beausoleil, R. A., Koehler, G. M., Maletzke, B. T., Kertson, B. N., & Wielgus, R. B. (2013). Research to regulation: Cougar social behavior as a guide for management. *Wildlife Society Bulletin*, *37*(3), 680-688.

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87*(3), 352–377.

Benson, J., & Dresdow, S. (2015). Design for Thinking: Engagement in an Innovation Project. *Decision Sciences Journal of Innovative Education*, *13*(3), 377–410.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school.* National Academy Press.

Burgess, J., Harrison, C. M., & Filius, P. (1998). Environmental communication and the cultural politics of environmental citizenship. *Environment and planning A*, *30*(8), 1445-1460.

Casey, A. L., Krausman, P. R., Shaw, W. W., & Shaw, H. G. (2005). Knowledge of and attitudes toward mountain lions: a public survey of residents adjacent to Saguaro National Park, Arizona. *Human Dimensions of Wildlife*, *10*(1), 29-38.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Curtis, M. and U. Valdez. 2009. Incorporating community education in the strategy for Harpy Eagle conservation in Panama. J. Environ. Educ. 40: 3–15.

Dauer, J. M., & Forbes, C. (2016). Making decisions about complex socioscientific issues: a multidisciplinary science course. *Science Education and Civic Engagement: An International Journal*, *8,* 5-12.

Dauer, J. M., Lute, M., & Straka, O. (2017). Indicators of informal and formal decision-making about a socioscientific issue. *International Journal of Education in Mathematics, Science and Technology*, *5*(1), 124–138.

Davidson, D. J., & Freudenberg, W. R. (1996). Gender and environmental risk concerns. Environment and Behavior, 28, 302-339.

Davenport, M. A., Nielsen, C. K., & Mangun, J. C. (2010). Attitudes toward mountain lion management in the Midwest: implications for a potentially recolonizing large predator. *Human Dimensions of Wildlife*, *15*(5), 373-388.

Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist*, *47*(3), 153–176.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601.

De Groot, J. I., & Steg, L. (2008). Value orientations to explain beliefs related to environmental significant behavior how to measure egoistic, altruistic, and biospheric value orientations. *Environment and Behavior*, *40*(3), 330-354.

Dewey, J., & Rogers, M. L. (2012). *The public and its problems: An essay in political inquiry*. Penn State Press.

Espinosa, S., & Jacobson, S. K. (2012). Human-wildlife conflict and environmental education: Evaluating a community program to protect the Andean bear in Ecuador. *The Journal of Environmental Education*, *43*(1), 55-65.

Feinstein, N. (2011). Salvaging science literacy. *Science Education*, *95*(1), 168–185.

Feinstein, N. W., Allen, S., & Jenkins, E. (2013). Outside the pipeline: Reimagining science education for nonscientists. *Science*, *340*(6130), 314-317.

Feinstein, N. W. (2015). Education, communication, and science in the public sphere. *Journal of Research in Science Teaching*, *52*(2), 145-163.

Fleming, R. (1986). Adolescent reasoning in socio-scientific issues, part I: Social cognition. *Journal of Research in Science Teaching*, *23*(8), 677–687.

Grace, M. M., & Ratcliffe, M. (2002). The science and values that young people draw upon to make decisions about biological conservation issues.*International Journal of Science Education*, *24*(11), 1157-1169.

Grace, M. (2009). Developing high quality decision-Making discussions about biological conservation in a normal classroom setting. *International Journal of Science Education*, *31*(4), 551-570.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. (2012). *Structured decision making: a practical guide to environmental management choices*. John Wiley & Sons.

Hammond, J., Keeney, R., & Raiffa, H. (2015). *Smart choices: A practical guide to making better decisions*. Harvard Business Review Press.

Hartley, L., C. W. Anderson, A. Berkowitz, J. C. Moore, J. Schramm, S. Simon. (2011, April). *Development of a Grade 6-12 Learning Progression for Biodiversity: an Overview of the Approach, Framework, and Key Findings*. Paper presented at the meeting of the National Association for Research in Science Teaching, Orlando, FL.

Hewitt, K. M. (2014). Fostering relevance in introductory biology courses: an empirical study of the effects of a socio-scientific issues-based course on student motivation through the lens of self-determination theory.

Hogan, K. (2002). Small groups' ecological reasoning while making an environmental management decision. *Journal of Research in Science Teaching*, *39*(4), 341–368.

Huffman, A. H., Van Der Werff, B. R., Henning, J. B., & Watrous-Rodriguez, K. (2014). When do recycling attitudes predict recycling? An investigation of self-reported versus observed behavior. *Journal of Environmental Psychology*,*38*, 262-270.

Hurd, P. D. (1958). Science literacy: Its meaning for American schools.*Educational leadership*, *16*(1), 13-16.

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Keeney, R. L., & McDaniels, T. L. (1992). Value-focused thinking about strategic decisions at BC Hydro. *Interfaces*, *22*(6), 94-109.

Kellert, S. R., Black, M., Rush, C. R., & Bath, A. J. (1996). Human culture and large carnivore conservation in North America. *Conservation Biology*,*10*(4), 977-990.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?.*Environmental education research*, *8*(3), 239-260.

Kolstø, S. D., Bungum, B., Arnesen, E., Isnes, A., Kristensen, T., Mathiassen, K., ... & Ulvik, M. (2006). Science students' critical examination of scientific information related to socioscientific issues. *Science Education*,*90*(4), 632-655.

Kuhn, D. (1991). *The skills of argument*. Cambridge University Press.

McComas, W. F. (2002). The ideal environmental science curriculum: I. history, rationales, misconceptions & standards. *The American Biology Teacher*, *64*(9), 665-672.

Merriam, S. B. (2009). Qualitative research: A guide to design and implementation: Revised and expanded from qualitative research and case study applications in education. *San Franscisco: Jossey-Bass*.

Morrone, J. J., Katinas, L., & Crisci, J. V. (1996). On temperate areas, basal clades and biodiversity conservation. *Oryx*, *30*(03), 187-194.

Mountain Lions in Nebraska - Nebraska Game and Parks. (2016). Retrieved June 02, 2016, from http://outdoornebraska.gov/mountainlions/.

National Research Council (Ed.). (1996). *National science education standards*. National Academy Press.

Nokes-Malach, T. J., & Mestre, J. P. (2013). Toward a model of transfer as sense-making. *Educational Psychologist*, *48*(3), 184–207.

Orams, M. B. (1996). Using interpretation to manage nature-based tourism.*Journal of sustainable tourism*, *4*(2), 81-94.

Perkins, D. N., Farady, M., & Bushey, B. (1991). Everyday reasoning and the roots of intelligence.

Ratcliffe, M. (1997). Pupil decision-making about socio-scientific issues within the science curriculum. *International Journal of Science Education*,*19*(2), 167-182.

Ripple, W. J., Larsen, E. J., Renkin, R. A., & Smith, D. W. (2001). Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. *Biological conservation*, *102*(3), 227-234.

Romanach, S. S., Lindsey, P. A., & Woodroffe, R. (2007). Determinants of attitudes towards predators in central Kenya and suggestions for increasing tolerance in livestock dominated landscapes. *Oryx*, *41*(02), 185-195.

Røskaft, E., Händel, B., Bjerke, T., & Kaltenborn, B. P. (2007). Human attitudes towards large carnivores in Norway. *Wildlife biology*, *13*(2), 172-185.

Roth, W. M., & Lee, S. (2002). Scientific literacy as collective praxis. *Public understanding of Science*, *11*(1), 33-56.

Sadler, T. D., & Zeidler, D. L. (2005). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education*, *89*(1), 71-93.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371-391.

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42.

Saunders, K. J., & Rennie, L. J. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education*,*43*(1), 253-274.

Simmons, D. A. (1991). Are we meeting the goal of responsible environmental behavior? An examination of nature and environmental education center goals. The Journal of Environmental Education, 22, 16–21.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. *Advances in experimental social psychology*, *25*, 1-65.

Slovic, P. (1995). The construction of preference. *American psychologist*,*50*(5), 364.

Sponarski, C. C., Vaske, J. J., Bath, A. J., & Loeffler, T. A. (2016). Changing attitudes and emotions toward coyotes with experiential education. *The Journal of Environmental Education*, 1-11.

Stern, P. C. (2000). New environmental theories: toward a coherent theory of environmentally significant behavior. *Journal of social issues*, *56*(3), 407-424.

Sussman, R., Lavallee, L. F., & Gifford, R. (2016). Pro-Environmental Values Matter in Competitive but Not Cooperative Commons Dilemmas. *The Journal of social psychology*, *156*(1), 43-55.

Terborgh, J., Lopez, L., Nunez, P., Rao, M., Shahabuddin, G., Orihuela, G., ... & Balbas, L. (2001). Ecological meltdown in predator-free forest fragments.*Science*, *294*(5548), 1923-1926.

Theobald, R., & Freeman, S. (2014). Is it the intervention or the students? Using linear regression to control for student characteristics in undergraduate STEM education research. *CBE-Life Sciences Education*, *13*(1), 41–48.

Thornton, C., & Quinn, M. S. (2009). Coexisting with cougars: public perceptions, attitudes, and awareness of cougars on the urban-rural fringe of Calgary, Alberta, Canada.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science, 185, 1124-1131

Tytler, R., Duggan, S., & Gott, R. (2001). Public participation in an environmental dispute: Implications for science education. *Public Understanding of Science*, *10*(4), 343–364.

Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education*, *29*(11), 1387-1410.

Wallach, A. D., Izhaki, I., Toms, J. D., Ripple, W. J., & Shanas, U. (2015). What is an apex predator?. *Oikos*, *124*(11), 1453-1461.

Wilson, R. S., & Arvai, J. L. (2006). Evaluating the quality of structured environmental management decisions. *Environmental science & technology*,*40*(16), 4831-4837.

Zeidler, D. L., & Schafer, L. E. (1984). Identifying mediating factors of moral reasoning in science education. *Journal of Research in Science Teaching*, *21*(1), 1–15.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education.*Science Education*, *89*(3), 357-377.

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education*, *21*(2), 49-58.

Zeidler, D. L., Herman, B. C., Ruzek, M., Linder, A., & Lin, S. S. (2013). Cross-cultural epistemological orientations to socioscientific issues. *Journal of Research in Science Teaching*, *50*(3), 251-283.

Zinn, H. C., & Pierce, C. L. (2002). Values, gender, and concern about potentially dangerous wildlife. *Environment and Behavior*, *34*(2), 239-256.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35–62.

APPENDIX A: CAPTIVE BREEDING INTERVIEW

Undergraduate Interview: Captive Breeding Scaffolded Questions

"Imagine you are a wildlife biologist and you want to preserve one of our endangered predators in Nebraska, the swift fox, by starting a captive breeding program and reintroducing them into the wild.

a. What is the purpose of a captive breeding program?

b. How would you select a group of swift fox for your program?

i. What characteristics would you look for?

ii. If student has not mentioned variation among individuals: How similar would the individuals be to each other? Would they be similar or variable?

c. How many swift foxes would you choose? (We are trying to get them to discuss the possibility of inbreeding.—Only use the questions below if necessary.) -[Depending on their response] Could there be anything positive about choosing too small a number? -Could there be anything negative about choosing too small a number? -Could there be anything positive about choosing too large a number? -Could there be anything negative about choosing too large a number?]"

APPENDIX B: CAPTIVE BREEDING RUBRIC

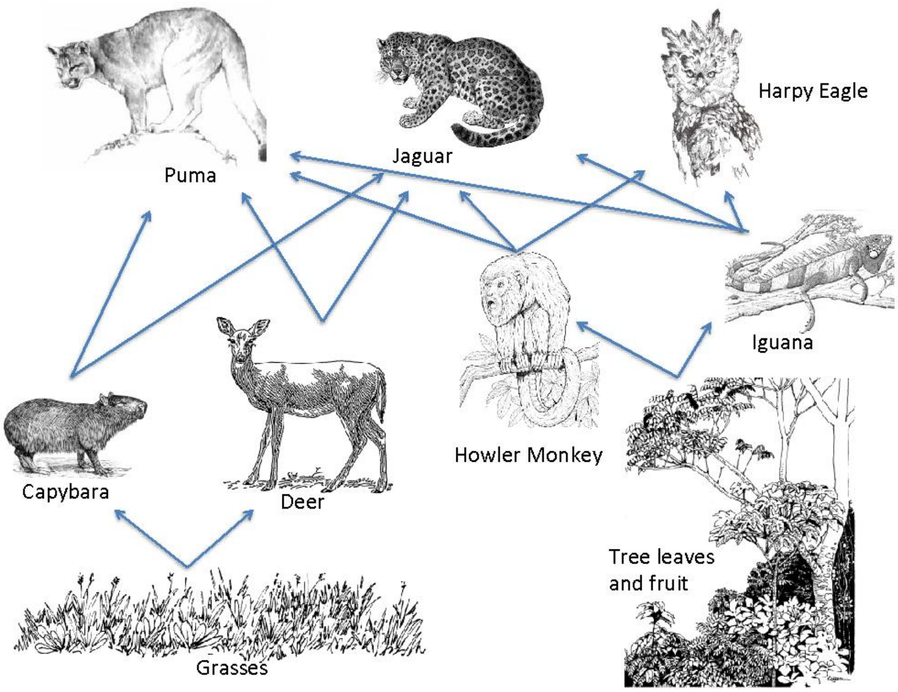
Detailed levels of sophistication for student explanations of creating a captive breeding program

	Level of Sophistication		
Coding Dimension	1: Low	2: Medium	3: High
Genetic Variability	Mentions only "male-female" variation (or implies by talking about organisms breeding/reproducing), or other type of dichotomous variation (e.g. weakest and strongest, oldest and youngest)	States or describes variability within the population as important or a positive factor (e.g., for survival), but doesn't expand on why it is important	Relates variation to being able to have traits/adaptations for a changing environment/future survival/future generations, etc."
	OR Exhibits teleological thinking in regard to variation generation within an individual; might think the species can generate its own variability	OR Mentions taking individuals from different locations without explaining why this is advantageous	OR Discusses future environment as uncertain
	OR Talks about variation in anthropocentric ways (e.g. one kind would be boring for us humans to look at, individuals need more choices)	OR Says inbreeding is negative because it is "bad" in general (but does not explain how it affects genetic resources for future generations). May say it makes genes “weaker" or creates "mutants."	OR Discusses inbreeding in terms of how it affects genetic variation for future generations or changing environments.
	OR States or implies that variation within the captive breeding population isn't important/necessary (this is different than the student not saying anything at all about variability)	OR Mentions intrinsic value of biodiversity, but does not explain why this is important ("Biodiversity is essential to an ecosystem.")	OR Links intrinsic value of biodiversity to importance in an ecosystem ("Biodiversity is essential to an ecosystem because…")
	OR Wants organisms to be the same. The students may recognize variability, but not value it in that they choose to artificially select out the variation.		OR Links sexual reproduction (could use words like “offspring” or “breeding”) to increasing genetic variation in a population for survival

Detailed levels of sophistication for student explanations of creating a captive breeding program(cont.)

	Level of Sophistication		
Coding Dimension	1: Low	2: Medium	3: High
Genetic Traits	Traits and/or instincts are not passed on genetically; they are "taught" or "learned"	Links traits (physical or behavioral) to reproductive success or survival (this indicator could also include linking individual health to the health/spread of disease to the entire population)	Describes diverse traits at the population level as important for responsiveness to a changing environment/future survival/future generations, etc.
	OR	OR	
	Basic descriptions about physical characteristics, abilities, or habitat, but does not explicitly connect these characteristics to survival or reproduction	Values "good traits" (e.g., eugenic, active, ideal, purebred, dominant) over "bad traits" (e.g., mutant)	
	OR	OR	
	Uses anthropomorphic comparisons and descriptions such as family units, compatibility, nice, behavioral problems, etc.	Traits are passed on genetically.	
Purpose of a Captive Breeding Program	Purpose is to save sick animals/help animals	Purpose is to save the species/population, but gives a eugenic reason- doesn't recognize changing environment (e.g., talks about best/strong as a static trait)	Purpose is to save species / population with description of current or future genetic diversity for a changing environment/future generations, etc.
	OR	OR	OR
	Purpose is to have animals around for human benefit	Purpose is to breed (reproduce/make babies) more animals of that species	Purpose is to breed more individuals to release into the wild
	OR	OR	
	Mentions releasing individuals, but implies that they get "freed" or they are returned to wild after rehabilitation (i.e.not thinking about population level impact of release)	Purpose of program is that the species is endangered (or "rare," "unique", etc.)	

APPENDIX C: FOOD WEB KNOWLEDGE ASSESSMENT



1. What kinds of things do you think could affect the **number of *deer*** in the rainforest?

2. Which of the following actions would affect the number of deer:

a. What kind of effect would decreasing the number of jaguar and puma have on the number of deer?

i. Positive

ii. Negative

iii. Possibly positive or negative

iv. No effect

How?

b. What kind of effect would increasing the number of capybara have on the number of deer?

i. Positive

ii. Negative

iii. Possibly positive or negative

iv. No effect

How?

c. What kind of effect would increasing the number of iguana have on the number of deer?

i. Positive

ii. Negative

iii. Possibly positive or negative

iv. No effect

How?

d. What kind of effect would increasing the number of harpy eagle have on the number of deer?

i. Positive

ii. Negative

iii. Possibly positive or negative

iv. No effect

How?

3. How would changing the number of deer influence other parts of the ecosystem?

APPENDIX D: FOOD WEB RUBRIC

FOOD WEB RUBRIC

Code	Indicator Description	Goal	Exemplar (Student Quotes)
5	Describes biotic interactions that involve at least 4 species, where at least two of the interactions are indirect effects	Can appropriately describe harpy eagle interactions	"…if the eagle numbers go up, so does the amount of prey they consume, and then the puma and jaguar might turn to consuming more deer."
4	Describes top-down biotic interactions across different habitats with one predator-mediated indirect effect	Can appropriately describe interaction between iguana/howler monkey>puma/jaguar>deer	"The iguana could become a more prominent source of prey for the three predators and give the deer more room to thrive and grow."
3	Describes top-down biotic interactions with one predator-mediated indirect effect	Can appropriately describe interaction between capybara>puma/jaguar>deer	"An increase in the number of capybara would result in less grasses for the deer to eat. It could also result in less deer being eaten by their shared predators…" "…because without predators, deer will overpopulate, and the grasses will go down."
2	Describes bottom-up biotic interactions with one food source-mediated indirect effect (i.e., competition)	Can appropriately describe competition for food interaction between capybara and deer	"An increase in the number of capybara would resultin less grasses for the deer to eat."
1	Describes biotic interactions only with direct effects	e.g., Pumas eat the deer.	"They kill the deer." "Without these predators, the deer population would begin to grow substantially."
0	Cannot make any connection with the given scenario	Cannot recognize how one species could possibly influence the other.	"Iguanas stay in trees and eat fruit while deer stay on the ground and eat grass."
NA	Simply lists things with no further explanation of how the different components are connected		"Hunting, Lack of food, New predator, Increase of predators, Disease, habitat loss"

APPENDIX E: SMALL POPULATIONS ASSESSMENT

Imagine you are a wildlife biologist and you want to preserve one of our endangered predators in Nebraska, the swift fox, by starting a captive breeding program and reintroducing them into the wild.

a. How would you select a group of swift fox for your program?

b. How many swift foxes would you choose?

Why?

APPENDIX F: PRETEST AND POSTTEST PROMPT

Should we hunt mountain lions in Nebraska? Mountain lions have recently recolonized the Pine Ridge area in the northwest corner of Nebraska. Young male mountain lions have been documented throughout Nebraska including agricultural areas where suitable habitat may be limited. Nebraska Game and Parks recently opened a mountain lion hunting season in the Pine Ridge Unit in habitat that is suitable for mountain lions and where the population is growing. Last year there was a big debate in the Nebraska legislature around hunting mountain lions including issues of animal rights, human rights, safety, biodiversity and conservation. What do you think should be done about this problem? Should we hunt mountain lions in Nebraska? Why should we do it/not do it?

APPENDIX G: SPECIFIC DECISION SUMMARY

Decision-making over time: Specific Categories % (*n*=110)	**Pretest**	**Unit Assessment**	**Posttest**
Yes: Hunt with quota throughout entire state	35	41	26
Yes: Hunt with general management plan (vague)	25	13	19
Yes: Defer management to authority	0	5	2
Yes: Hunt outside of breeding areas	0	12	10
No: Do not hunt *currently*	11	3	13
No: Kill only in defense	8	14	19
No: Alternative management plan	11	10	5
No: Do not hunt or kill	11	4	6

APPENDIX H: ECOLOGICAL CRITERIA RUBRIC

Ecological Criteria Rubric

Criteria Type.	Code	Criteria Category	Description
Concern for Food Web Interactions	2	Specific Food Web Impact	Mountain lions impact specific species or communities in the food web ("deer", "herbivores", "plant communities"; might mention trophic cascades or biodiversity).
	1	Vague Ecosystem Impact	Wants a "healthy" or "balanced" ecosystem, says mountain lions hold an important place in the ecosytem, etc., but provides no further explanation
	0	No Ecosystem	Does not make reference to food webs or environmental impact
Concern for Small Populations	2	Genetic Impacts	Expresses concern that the low mountain lion population numbers may impact variability (e.g., inbreeding)
	1	Extirpation/Extinction	Expresses concern that mountain lions could be extirpated from the state (students use the words "extirpation" interchangeably with "extinction.")
	0	No Small Populations	Does not express concern for small population numbers