ECOSYSTEM SERVICES IN ENVIRONMENTAL SCIENCE LITERACY

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ABSTRACT OF THE DISSERTATION

Ecosystem Services in Environmental Science Literacy

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Human beings depend on a set of benefits that emerge from functioning ecosystems, termed Ecosystem Services (ES), and make decisions in everyday life that affect these ES. Recent advancements in science have led to an increasingly sophisticated understanding of ES and how they can be used to inform environmental decision-making. Following suit, US science education policy makers have highlighted the importance of learning about ES in the most recent national standards: the Next Generation Science Standards. While recognized as important, science education research aimed at empirically exploring what it is one should know about ES, in order to be scientifically literate, is only beginning to gain traction. This dissertation research provides empirical evidence toward this aim. Using a set of Delphi studies, which involve iterative survey of experts in a domain until a consensus is reached, the research described in this dissertation first identified: (a) a definition of ES for non-academic audiences, (b) a set of big ideas important to connecting ES to everyday environmental decisions, (c) important questions that citizens can ask when evaluating claims and making decisions about ES, and (d) practices that citizens can use to find scientific resources (e.g. evidence, testimony) that can help them find answers to these important questions. These Delphi

Studies provided an academic expert-based postulate regarding what one needs to know about ES in order to be scientifically literate, however, research on scientific literacy cannot rely solely on the views of experts. Following a model for empirical research on scientific literacy proposed by Feinstein, I compliment these expert-based descriptions with research on authentic engagement with science to see if the knowledge postulated as important, is actually used in productive ways. The results of this research underscore the importance of the NRC Crosscutting concepts for scientific literacy writ large, provide a justification for including ES under multiple Disciplinary Core Ideas, emphasize the importance of knowledge about the nature of scientific evidence, and accentuate a need to clarify how citizens can use science practices in decision-making roles. Implications for research on scientific literacy writ large and classroom instruction on ES are discussed.

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V. Table of Contents

ABSTRACT OF THE DISSERTATION ... ii
IV. Acknowledgements ... iv
V. Table of Contents ... v
VI. List of Tables ... viii
VII. List of Figures ... ix
Chapter 1: Introduction ... 1
Theoretical Framework ... 3
Descriptions of scientific literacy rooted in domains ... 5
Descriptions of scientific literacy rooted in authentic engagement ... 6
Summary and Importance of Research ... 12
References ... 13
Chapter 2: Defining and Characterizing Ecosystem Services for Education: A Delphi Study ... 17
Abstract ... 17
Introduction ... 18
Why Ecosystem Services? An example of their importance ... 20
Using the Delphi Method to Identify Central Ideas for a Complex Science ... 21
Methods ... 24
Delphi Panel ... 25
Data Collection and Analysis ... 25
Establishing a consensus ... 29
Results ... 32
Research Question 1: How should ecosystem services be defined for a general audience? ... 32
Research Question 2: What are the big ideas about ecosystem services that can connect human decisions to changes to ecosystem services? ... 35
Discussion ... 40
ES Big Ideas and the NRC Framework for Science Education ... 40
ES and educational research on coupled human-environment systems ... 44
Limitations ... 46
Conclusions ... 47
References ... 48

Chapter 3: Engaging with ecosystem services for everyday environmental decisions: A Delphi Study ... 61
Abstract ... 61
Introduction ... 62
Integrating ecosystem services into everyday decision-making ... 64
Goals and Research Questions ... 65
Theoretical Framework ... 66
Citizen-Inquiring Questions ... 66
Citizen-Inquiring Practices ... 68
Methods ... 69
Delphi Panel ... 70
Data Collection and Analysis ... 71
Results ... 75
Instantiation of the ES Citizen Inquiring Questions and Practices: An example of inquiring to make a decision about a proposed conservation easement ... 77
Discussion ... 81
Potential Alternative Conceptions that might interfere with the Citizen-Inquiring Practices identified in this study ... 82
Summary and Implications ... 84
Limitations ... 86
References ... 87
Chapter 4: Characterizing engagement with science when evaluating authentic claims about Ecosystem Services ... 99
Abstract ... 99
Introduction ... 100
Study Context ... 104
The Setting ... 105
The Researcher ... 107
Theoretical Framework ... 107
Aims ... 109
Epistemic Ideals ... 109
Reliable processes for producing epistemic products ... 110
Epistemic Cognition Associated with Engagement with Science: a model for ES ... 111

Methods 112
Criteria for Selecting Participants 112
Interview Protocol 114
Data Reduction 115
Reliability of coding 117
Results 117
Research Question 1: Aims 117
Research Question 2: Epistemic Ideals about Epistemic Products 119
Research Question 3: Science Ideas about ES in Participants' Scientific Accounts .. 121
Qualitatively Different forms of Science Engagement 127
Discussion 134
Implications and Limitations 136
References 137
Chapter 5: Concluding Discussion 148
Conceptual Knowledge: Big Science Ideas about ES 149
Epistemic Knowledge for Engagement with Science 150
Strategic Knowledge: ES-Citizen-Inquiring Knowledge 152
Implications for Research on Science Education 153
Refining upper anchor content understandings related to ES 153
Refining the definition of competent outsider 155
Articulating domain-specific and citizen-specific practices 156
Implications for curriculum and instruction 156
Future Directions 157
References 159

VI. List of Tables

Chapter 2 ....

Table 1 Delphi Panel Participants by Disciplinary Expertise.. 57
Table 2 Structure of Delphi Study 58
Table 3 ES Core Idea Ratings.. 59
Table 4 Components of Definition of Ecosystem Services 60
Chapter 3 ....

Table 1 General and Domain-Specific Citizen-Inquiring Questions.....**Error! Bookmark not defined.**
Table 2 Delphi Panel Participants by Disciplinary Expertise.. 93
Table 3 Structure of Delphi Study 94
Table 4 Sources of Evidence for Decisions Involving ES... 95
Table 5 Everyday Decisions that can be Informed by Ecosystem Services Science....... 96
Chapter 4 ....

Table 1 Claims provided during interviews.. 1433
Table 2 Types of Ecosystem Services 1444
Table 3 Frequency of Epistemic Aims and Ideals 1455
Table 4 Frequency of ES Content Ideas 1466
Table 5 Number of Science Ideas versus Type of Engagement 1477

VII. List of Figures

Chapter 2 ....
Figure 1: Definition of Ecosystem Services..53
Figure 2: Types of Ecosystem Services 54
Figure 3: Loop Diagram for Water in Ecological Systems..55
Figure 4: Revised Model for Coupled Human-Environment Systems 56
Chapter 3 ....
Figure 1: Definition and Big Ideas about Ecosystem Services 91
Chapter 4 ....
Figure 1: Definition and Big Ideas about Ecosystem Services 140
Figure 2: Epistemic Cognition Model of Science Engagement 141
Figure 3: Two Patterns of Engagement..142

Chapter 1: Introduction

The precarious state of the world's limiting resources, and the growing demand for these resources, call attention to the current state of human interactions with the environment, and a growing need to change this relationship. To promote change, we must first draw attention to the needs of individuals and societies, the goods and services provided by natural ecosystems, and the ways in which human actions impact these ecosystems (Costanza, et al., 1997;Balmford & Bond, 2005; Balmford, et al., 2002; Berkowitz, Ford, & Brewer, 2005; Feagin, et al., 2010; Jordan, et al., 2009; Lubchenco, et al., 1991; MA, 2005; Townsend, 2007; UNESCO, 1978; Wilson, et al., 2007). Dealing with these problems requires a scientifically literate population that can engage with environmental science knowledge when making decisions related to *coupled human-environment systems* (Anderson, 2007; Covitt, Tan, Tsurusaki, & Anderson, 2009; Feinstein & Kirchglalser, 2015; Lubchenco, et al., 1991; NRC, 2012). Coupled human-environment systems, which are connections between human socio-economic systems and environmental systems, specifically include (a) human impacts to environmental systems, and (b) the flow of *ecosystem services* to humans (Anderson, 2007). Ecosystem Services (herein after ES), the subject matter for the research on scientific literacy in this dissertation, are the array of ecosystem functions that are beneficial to humans (Kremen, 2005). Some ES are responsible for the natural production of extractable goods (wood, fiber, foods, fuel, clean water, etc.). Other ES provide improved environmental conditions such as flood control, erosion control, climate regulation, and regulation of pathogens, among others (Daily, 1997; MA, 2005). Many of these ES are not incorporated into economic systems and are thus mostly hidden from public view

(Baumgärtner, 2007; Balmford, et al, 2002; Costanza, et al, 1997). While many services are hidden from public view, humans depend upon these services to support well-being and basic biological needs (e.g. clean food and water, a stable climate, etc.).

Unfortunately, ES are being lost rapidly (MA, 2005) threatening both human economies and human well-being (Wilson, 2002, pp. 106-107; Costanza, et al., 1997). This loss has led to a concerted international effort to better characterize ES, as well as identify, monitor, and valuate these ES, and expand awareness of ES in the public (Lubchenco, et al., 1997; MA, 2005). Following suit, science education researchers and policy makers have articulated ES as an important concept for scientific literacy (NRC, 2012; Gunkel, Covitt, Salinas & Anderson, 2012). The Next Generation Science Standards (NGSS) and the corresponding Framework for K-12 Science Education, include ES in the disciplinary core idea (DCI), Biodiversity and Humans (NGSS Lead States, 2013; NRC, 2012). This DCI states that, “Human beings are part of and depend upon the natural world…and benefit from ‘ecosystem services,’ such as climate stabilization, decomposition of wastes, and pollination that are provided by healthy (i.e., diverse and resilient) ecosystems” (NRC, 2012, p. 166). The DCI also describe that there are limits to human resource use and that humans can impact these ecosystems and ES through “habitat destruction, pollution of air and water, overexploitation of resources, introduction of invasive species, and climate change” (NRC, 2012, p. 166).

This inclusion of ES in the Framework is an important milestone toward developing a more complete description of environmental science literacy; however, much work remains. Though mentioned in some science education literature (e.g. Berkowitz, et al., 2005; NRC, 2012; Wilson, et al., 2007), there is relatively little research characterizing key services, what citizens should know about them, and how citizens can use this information to make informed environmental decisions. This is in part because ES is a relatively nascent domain, but likely also because scientists who study ES have struggled to communicate the relevance of ES to environmental decisions (Fisher, Turner, & Morling, 2009; WRI, 2011). That said, significant advances have been made in the fields of science studying ES that have helped inform environmental decisions.

For ES to be fully realized as an important component of scientific literacy, it is necessary to characterize a contemporary set of big science ideas related to ES, as well as types of science resources that citizens can use to inform their environmental decisions involving ES. This research can improve understanding of what one should know in order to be scientifically literate in this domain, and the research in this dissertation seeks to contribute toward this aim focused on the general research question:

What should one know in order to be scientifically literate about Ecosystem Services?

In the theoretical framework that follows, I provide a description of research on scientific literacy and outline how I approached answering this question.

Theoretical Framework

There are a number of different types of knowledge that are critical to scientific literacy (deJong & Ferguson-Hessler, 1996). In this dissertation, I explore three broad types of knowledge: *Conceptual Knowledge*, *Epistemic Knowledge*, *and Strategic Knowledge for Engagement*. I briefly discuss each in turn:

Conceptual knowledge deals with facts, principles, and concepts of a domain (deJong & Ferguson-Hessler, 1996; Greeno, 1978). The NRC Framework for K-12

Science Education articulates important conceptual knowledge in both the Crosscutting Concepts and Disciplinary Core Ideas, providing different levels of specificity in each (NRC, 2012). Conceptual knowledge is primarily static and rooted deeply in scientific theory, including such knowledge as the fact that matter and energy do not disappear but rather changes form in systems.

Epistemic Knowledge, unlike conceptual knowledge, deals with the sources of conceptual knowledge and other types of knowledge, valid and different ways of developing science knowledge, and limits of science knowledge (Muis, Bendixen, Heerle, 2006). Epistemic knowledge also includes knowing the difference between epistemic products such as observations, hypotheses, models, explanations, and inference (NRC, 2012). For example, whereas conceptual knowledge might be considered static and evaluated as right or wrong, scientific models are not viewed with the same straightforwardness (Chinn, Rinehart, & Buckland, 2014).

Strategic knowledge for engagement with science, deals with the activities that one can use to engage with science and the sequence of those activities that can be used to reach a conclusion (deJong & Ferguson-Hessler, 1996). Different from knowing the limitations or validity of these activities (i.e. epistemic knowledge), strategic knowledge is a map for engagement with science. It can include activities such as asking questions and finding relevant expertise.

Characterizing what it is one needs to know for each type of knowledge can be accomplished in two ways: (a) develop a description of what is important based upon the conceptual, epistemic, and strategic knowledge considered important, by experts, in a domain and (b) develop a description of what is important based upon what is used by citizens in everyday life. Both of these strategies are important in an empirical approach to characterizing scientific literacy for a domain (Feinstein, 2011). Here, I discuss each strategy in turn:

Descriptions of scientific literacy rooted in domains

An academic community most appropriately identifies knowledge that is central to a domain, and salient to problem solving with expertise on the subject (Osborne et al., 2003), and many descriptions of important knowledge for scientific literacy are based on the views of the academic community in a domain (Lewenstein, 2015; Stigloe, Lock, & Wilsdon, 2014; Rodriguez, 2015). A number of methods are used to develop these descriptions of important ideas such as focus groups including scientists, education researchers, and educators (Achieve, 2013; NRC, 2011), general survey of an academic community (McBride, 2011), literature review of a domain (Gunkel, et al., 2012), and a Delphi Study (Osborne, et al., 2003). Osborne and colleagues (2003), for example, used the Delphi technique to determine what a variety of relevant experts believe is important to know about the Nature of Science (NOS). They recruited academics from a variety of disciplines including natural scientists, historians, philosophers, sociologists and science educators. The Delphi method is particularly suited for identifying a central set of ideas for a domain or interdisciplinary subject. This method uses repeat survey of a panel of experts in a given domain to establish a consensus around important ideas and has been used to inform curricular aims for higher education as well as to articulate meaningful components for complex concepts such as the nature of science (Dalkey & Helmer, 1962, 1963; Murry & Hammons, 1995; Osborne, et al., 2003).

In Chapters 2 and 3, I use the Delphi technique to define ES and identify big science ideas related to ES (Chapter 2) as well as strategic knowledge for engagement, which I termed ES-Citizen-Inquiring Knowledge (Chapter 3). A Delphi panel technique is particularly powerful because it involves iterative survey of a panel of experts, not just one survey, therefore, there are built-in member checks and it is considered to have good reliability (Murry & Hammons, 1995). That being said, a Delphi Panel Technique is not used often because it is very time consuming and historically suffers from participant fatigue and ‘drop-out’.

Descriptions of scientific literacy rooted in authentic engagement

Scientific literacy is often depicted as a *useful* element of modern life, necessary to prepare the next generation of scientists, promote economic growth, and enhance engagement with science in everyday life (Anderson, 2010; Hurd, 1958; NRC, 2012; Roberts, 2007). According to Feinstein (2011), it is possible to empirically investigate whether knowledge postulated as important to scientific literacy is indeed useful in everyday life. Such empirical investigations, cannot base descriptions of scientific literacy *only* on the views of experts in a domain, like that described in the previous section. Rather, he argues, it is also necessary to compliment these logical descriptions with research, characterizing knowledge used during authentic engagement with science, to see if the knowledge postulated as important by experts is actually used in productive ways.

Engagement with science involves recognizing a role that science can play in a situation and engaging in a dialogue with, or inquiry into, relevant sources of scientific information (e.g. newspapers, science magazines, doctors, etc.) to inform decisions, actions, or one's own awareness of an issue (Feinstein, 2011; Shea, 2015). Promoting engagement with science has gained increased attention in education (e.g. NRC, 2012; Pugh, et al., 2010; Rodriguez, 2015; Ryder, 2001). The NRC Framework for K-12 Science Education expands upon the importance of engagement, calling engagement with scientific practices (e.g. questioning, arguing from evidence) central to learning and important for connecting school science to students' lived experiences (NRC, 2012). This claim is supported by a variety of research in both the fields of Science Education Research as well as Research on Public Engagement with Science (Feinstein, 2014; Luehmann, 2009; Pugh, et al., 2010; Roth & Lee, 2002; Sadler, Barab, & Scott, 2007). Describing the different ways in which citizens actually engage with science and the types of knowledge they use can inform what one needs to know in order to be scientifically literate.

Research on authentic engagement with science requires making decisions about how to identify citizens who can be considered scientifically literate. For the research in this dissertation, I adopted Feinstein's "Competent Outsiders" definition of scientifically literate citizens (Feinstein, 2011). Competent Outsiders are citizens "who have learned to recognize the moments when science has some bearing on their needs and interests, and to interact with sources of scientific expertise in ways that help them achieve their own goals" (Feinstein, 2011, pp. 13). Feinstein argued that to judge competence, it is important to find citizens that are able to arrive at an outcome that fulfills their personal needs. He also states that the researcher needs to establish a position about whether the outcome of the citizen's engagement with science is sophisticated enough (Noah Feinstein, personal communication, August 13, 2015).

For this dissertation, I did not define a set of criteria about important knowledge for competency *a priori*. Rather, I sought to characterize a set of criteria for competency by studying authentic engagement with science by individuals who I called *candidate* Competent Outsider. C*andidate* Competent Outsiders are individuals with extensive experience interacting with science from a variety of domains in the public realm. These experiences might have led them to be competent outsiders, but they are not necessarily so. In this dissertation research, I explored the *epistemic, strategic* and *conceptual knowledge* that *Candidate* Competent Outsiders used when evaluating authentic claims about ES made by policy-makers and urban planners in their community. I sought to characterize qualitatively different patterns of engagement with science to help me identify types of knowledge associated with different patterns of engagement and draw inferences about knowledge that might be important for environmental science literacy. An important outcome of this research was a refined definition of what it means to be a Competent Outsider.

When citizens evaluate scientific claims, this evaluation is guided by the epistemological beliefs that citizens hold about scientific knowledge, types of evidence, and qualities of good arguments, among others (Chinn, Buckland, & Samarapungavan, 2011; Chinn, Rinehart, & Buckland, 2014; Hoefer & Pintrich, 1997; Hogan & Maglienti, 2001; Kuhn & Weinstock, 2004). One common model of epistemological beliefs used widely in epistemology research includes, four dimensions of beliefs about knowledge and processes of knowing: (1) the certainty of knowledge, (2) the simplicity or complexity of knowledge, (3) the source of knowledge (e.g. authority), and (4) the justification of knowledge such as backing claims with evidence (Hoefer & Pintrich, 1997). The Hoefer and Pintrich (1997) framework contributed greatly to the field's thinking about epistemic cognition, however it does not fully capture cognition associated with evaluating the validity and accuracy of scientific claims.

Clark, Rinehart, and Buckland (hereinafter CRB, 2014) refined the Hoefer and Pintrich (1997) framework in order to more fully capture cognition associated with evaluating the validity and accuracy of scientific claims. They argued that a holistic framework was needed that contains not only dimensions of belief, but also cognitive activities such as setting aims (e.g. explanation, understanding) and carrying out reliable inquiring processes (Mohan, Chen, & Anderson, 2009; CRB, 2014). Adopting the umbrella term *epistemic cognition,* which is used to describe a host of thinking processes and understandings related to acquiring knowledge and other epistemic products (e.g. models), the CRB (2014) framework contains three independent dimensions: (a) personal aims or targets of epistemic cognition, (b) ideals about the types of information that must be acquired in order to achieve an epistemic aim, and (c) reliable processes that can be used to achieve their epistemic aims. CRB (2014) summarized these dimensions of epistemic cognition as Aims, Ideals, and Reliable Processes (AIR). For the research described in this dissertation, I adopted this model of Epistemic Cognition to analyze authentic engagement with science and draw inferences about important epistemic, strategic, and conceptual knowledge. In the sections that follow, I explain each component of the AIR framework in turn.

Aims

Aims are goals that drive cognition and action; these aims can be both epistemic and non-epistemic (CRB, 2014). *Epistemic Aims* are goals that drive epistemic practices such as evaluating the accuracy or truthfulness of a claim as well as seeking more knowledge. For example, if a citizen with the epistemic aim of *questioning the accuracy of information* comes across the claim, “recycling saves the environment”, he or she might question the claim: “Are there other tradeoffs associated with recycling such as needing a greater amount of energy in manufacturing?”

Unlike epistemic aims, *Non-Epistemic Aims* are values that are not directly associated with epistemic practices. They include aims like the pursuit of pleasure, a desire to help out and ‘save the environment', protecting one's image, or outperforming others. For example, consider an individual who has a *non-epistemic aim* characterized by a desire to save 'the environment'. This person may not immediately investigate the accuracy of the claim “recycling saves the environment” because the claim itself aligns with his or her non-epistemic aim. In cases like this, non-epistemic aims may prevent a citizen from fully evaluating a claim.

On the other hand, non-epistemic aims can also augment the use of epistemic aims. For example, consider an individual who also holds a non-epistemic aim that is associated with *saving the environment*, but also holds an epistemic aim that is concerned with *evaluating the accuracy of claims*. This person’s non-epistemic aim is likely to add motivation to his or her epistemic aim. For example, if this person were to encounter the claim that “recycling is more expensive than using raw materials and does not save the environment”, he or she is likely to investigate the claim, not draw the conclusion to stop recycling because it is bad for the environment. This connection between non-epistemic aims and epistemic aims is important because the extent to which individuals let non-epistemic aims guide their epistemic processes, may have a significant impact on how they evaluate the accuracy of scientific claims. In Chapter 4 of this dissertation, I explore this interaction between epistemic and non-epistemic aims looking for epistemic knowledge that is important to know in relation to ES.

Epistemic Ideals

Epistemic Ideals are the criteria or standards that people use to judge whether the epistemic products that they have accumulated have achieved their epistemic aims (CRB, 2014). These ideals more closely map on to the original framework by Hoefer and Pintrich (1997). They include but are not limited to: (a) ideals about the sufficient complexity of epistemic products such as scientific accounts, and (b) the validity of different types of scientific resources (e.g. models, case studies). For example, an individual may view ideal scientific models as having limitations, but nonetheless as having the capacity to inform how one interprets a claim. In Chapter 4 of this dissertation, I explore different epistemic ideals of *Candidate* Competent Outsiders.

Reliable processes for acquiring and generating suitable epistemic products

Processes are activities (e.g. inquiries) that individuals use to acquire or generate epistemic products (e.g. scientific models, explanations) in route to achieving their epistemic aim, and some of these processes are more reliable than others (CRB, 2014). When citizens engage with science, some of these reliable processes may include: (a) developing scientific accounts based upon their prior understanding of a subject (a personally-generated epistemic product), or (b) carrying out a personal inquiry, during which they accumulate epistemic products from scientists or those near the field (Feinstein, 2014; Mohan, 2009). *Science accounts* are explanations of natural or social systems, or phenomena based on conceptual knowledge in a domain (NRC, 2012). These accounts are used to link observations to scientific theory. For example, consider a hypothetical situation in which a citizen is engaging with science to help her town restore a stream damaged by industrial activity. This person may develop a personal *science account* that includes the conceptual idea that, *local ecosystems are embedded within a changing environment*. This conceptual idea prompts him/her to ask new questions about how to restore the local ecosystem in a way that can allow it to continue to thrive and adapt to changes.

Citizens can engage in *personal inquiry* to find potential answers to their questions and fill gaps in their understanding. For example, Feinstein tracked the parents of children with autism and found that they (a) iteratively asked questions (e.g. *is this a normal behavior?*), and (b) engaged in personal inquiry to find answers to these questions using a variety of near science resources (e.g. newspapers, science magazines, science teachers) and science resources (e.g. Academic articles, scientists) (Feinstein, 2014). In Chapter 4, I identify the conceptual knowledge that *Candidate* Competent Outsiders use when developing scientific accounts when evaluating authentic claims about ES. I also identify the strategic knowledge about the types of questions that they ask.

Summary and Importance of Research

In summary, In Chapters 2 and 3 of this dissertation, I use the views of experts on ES to develop a putative description of important conceptual and strategic knowledge for scientific literacy on ES. In Chapter 4 of this dissertation, I examine this putative description, looking at authentic engagement with science by *candidate* competent outsiders. I specifically analyzed their epistemic cognition in order to identify important conceptual, epistemic, and strategic knowledge used while engaging with science.

This comprehensive approach to characterizing important knowledge using both domain expertise and authentic engagement with science is unique and represents an important step toward establishing a more empirical basis to research on *useful* scientific literacy. This research will not only help inform what is important to know about ES, but also help to refine criteria for identifying the "competency" of outsiders. Thus, the results of this dissertation provide important implications for research on environmental science literacy and scientific literacy writ large.

References

Anderson, C.W. (2007). Environmental literacy learning progressions. Paper presented at the Knowledge Sharing Institute of the Center for Curriculum Studies in Science, Washington, D.C., July 22-25, 2007.

Anderson, C.W. (2010). Learning progressions for environmental science literacy. Paper presented to the NRC National Standards Framework Committee, March, 2010.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., & Turner, R.K. (2002). Economic reasons for conserving wild nature. Science, 297, 950-953.

Balmford, A. & Bond, W. (2005). Trends in the state of nature and their implications for human well-being. Ecology Letters, 8, 1218-1234.

Baumgärtner, S. (2007). The insurance value of biodiversity in the provision of ecosystem services. Natural Resource Modeling, 20, 87-127.

Berkowitz, A.R., Ford, M.E., & Brewer, C.A. (2005). A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education. In: Johnson, E.A. and Mappin, M.J. (Eds), Environmental Education and Advocacy: Changing Perspectives of Ecology and Education (pp. 227-266). Cambridge, UK: Cambridge University Press.

Chinn, C.A., Buckland, L.A., Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. Educational Psychologist, 46(3), 141-167.

Chinn, C.A., Rinehart, R.W., Buckland, L.A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D. Rapp and J. Braasch (Eds.), Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences (pp. 425-453). Cambridge, MA: MIT Press.

Costanza, R., d'Arge, R., Groot, R.d., Farber, S., Grasso, M.,Hannon, B. et al.. (1997). The value of the world's ecosystem services and natural capital. Nature, 387, 253–260.

Daily, G.C. (1997). Introduction: what are ecosystem services? In: Daily, G.C.(Ed.), Nature's Services: Societal Dependence on Natural Ecosystems (pp. 93-112). Washington, DC: Island Press.

Dalkey, N., & Helmer, O. (1962). An experimental application of the Delphi method to the use of experts. Management Science, 9, 458-467.

deJong, T., Ferguson-Hessler M.G.M (1996). Types and qualities of knowledge. Educational Psychologists, 35, 105-113.

Feagin, R.A., Martinez, M.L., Mendoza-Gonzales, G., Costanza, R. (2010). Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. Ecology and Society, 15(4), 14. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art14/

Feinstein, N. (2011). Salvaging scientific literacy. Science Education, 95, 168-185.

Feinstein, N. (2014). Making sense of autism: progressive engagement with science among parents of young, recently diagnosed autistic children. Public Understanding of Science, 23, 592-609.

Feinstein, N.W., & Kirchglalser, K.L. (2015). Sustainability in science education? How the Next Generation Science Standards approach sustainability, and why it matters. Science Education, 99, 121-144.

Fisher, B., Turner, R.K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics, 68, 643-653.

Greeno, J.G. (1978). Understanding and procedural knowledge in mathematics instruction. Educational Psychologist, 12, 262-283.

Gunkel, K.L., Covitt, B.A., Salinas, I., Anderson, C.W. (2012). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching, 49(7), 843-868.

Hoefer, B.K., & Pintrich, P.R. (2002). Personal epistemology: the psychology of beliefs about knowledge and knowing, Mahwah, NJ: Lawrence Erlbaum Associates.

Hogan, K. & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. Journal of Research in Science Teaching, 38, 6, 663-687.

Hurd, P. D. (1958). Science literacy: it's meaning for American schools. Educational Leadership, 16(13–16), 52.

Jordan, R., F. Singer, J. Vaughan, and A. Berkowitz. 2009. What should every citizen know about ecology? Frontiers in Ecology and the Environment, 7, 495-500.

Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology? Ecology Letters, 8, 468-479.

Luehmann, A. (2009). Accessing resources for identifying development by urban students and teachers: Foregrounding context. Cultural Studies of Science Education, 4(1), 51-66.

Lewenstein, B.V. (2015). Identifying what matters: science education, science communication, and democracy. Journal of Research in Science Education, 52, 253-262.

Lubchenco, J. (1978). Plant species diversity in a marine intertidal community: importance of herbivore food preference and algal competitive abilities. American Naturalist, 112, 23-39.

[MA] Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis, Washington, DC: Island Press.

McBride, B.B. (2011). Essential elements of ecological literacy and the pathways to achieve it: perspectives of ecologists. (Doctoral Dissertation). The University of Montana.

Mohan, L., Chen, J., & Anderson, C.W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46, 675-698.

Muis, K.R., Bendixen, L.D., Haerle, F.C. (2006). Domain-generality and domain-specificity in personal epistemology research: philosophical and empirical reflections in the development of a theoretical framework. Educational Psychology Review, 18, 3-54.

Murry, J.W. Jr. & Hammons, J.O. (1995). Delphi: A versatile methodology for conducting qualitative research. Review of Higher Education, 18, 423–436.

NGSS Lead States (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

[NRC] National Research Council (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea. Washington, DC: National Academies Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschle, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. Journal of Research in Science Teaching, 40, 692-720.

Pugh, K.J., Linnenbrick-Garcia, L., Koskey, K.L., Steward, V.C., Manzey, C. (2010). Motivation, learning, and transformative experience: a study of deep engagement in science. Science Education, 94, 1-28.

Rodriguez, A.J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the Next Generation Science Standards. Journal of Research in Science Teaching, 52(4), 448-460.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research in science education (pp. 729–779). Mahwah, NJ: Erlbaum.

Roth, W-M. & Lee, S. (2002). Scientific literacy as collective praxis. Public Engagement with Science, 11, 33-56.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. Studies in Science Education, 36, 1-44.

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

Shea, N.A. (2015). Examining the nexus of science communication and science education: a content analysis of genetics news articles. Journal of Research in Science Teaching, 52, 397-409.

Wilson, C.D., Tsurusaki, B., Wilke, B., Zesaguli, J., & Anderson, C.W. (2007). The development of an environmental literacy learning progression: biological diversity and change over time in environmental systems. Paper presented at the Center for Curriculum Materials in Science Knowledge Sharing Institute.

Wilson, E.O. (2002). The Future of Life. New York, NY: Vintage Books.

[WRI] World Resource Institute. (2012). Available online http://docs.wri.org/share/eiasurvey/survey_summary.pdf

Chapter 2: Defining and Characterizing Ecosystem Services for Education: A Delphi Study

Abstract

Recent advancements in science have led to an increasingly sophisticated understanding of the many ways in which humans benefit from environmental systems. These benefits, termed *Ecosystem Services*, are sparsely characterized in education literature, but have been included in the most recent iteration of US national science standards: the Next Generation Science Standards (NGSS). In this paper, we introduce the concept of Ecosystem Services and discuss why it is emerging as an important idea to teach. This study presents a definition and set of big ideas about ecosystem services developed using a Delphi technique: a method that uses repeat survey of a panel of experts in a domain, to reach a consensus about important ideas. Using the central ideas that emerged during this study, we provide a refined model of coupled human-environment systems that articulates multiple human populations as embedded within ecosystems, connected to these ecosystems near and far, and benefitting from the resources and conditions provisioned by these ecosystems. We discuss the implications of this model to future education research, as well as to future revisions of Disciplinary Core Ideas in the National Research Council Framework for Science Education.

Keywords: ecosystems, ecology, economics, scientific literacy, environmental education, standards, environment, ecosystem services

Introduction

Humans, today, face a complex set of environmental problems including climate change, pollution, native habitat destruction, and an accelerated loss of biodiversity (MA, 2005). These problems have important implications for the well-being of all humans, and dealing with these problems requires an educated public that can engage with environmental knowledge (Covitt, Tan, Tsurusaki, & Anderson, 2009; Feinstein, 2011; Lubchenco, et al., 1991; NRC, 2011). Environmental knowledge is highly diverse, varying by location, history, and culture; however, it is possible to frame this knowledge in a way that promotes productive reasoning.

One model for framing environmental reasoning is the coupled human-environment systems loop diagram developed by Anderson (Anderson, 2007). This model contains four dimensions; (a) environmental systems, (b) human social and economic systems, (c) human impacts to environmental systems and (d) ecosystem services. The study described in this paper focuses on defining and characterizing the last dimension of this model: *Ecosystem Services* (herein after ES) or benefits that humans gain from functioning ecosystems. ES promote human well-being and include easily recognized connections (e.g. ecosystem functioning that is necessary for sustainable provisions of goods like food and clean water) as well as others that are less tangible connections (e.g. regulating nutrient loads in ecosystems that could otherwise become highly concentrated and toxic). Managing these services is an important and critical goal for sustainable human development (MA, 2005).

ES have been adopted as an important topic to teach, present in both policy documents and education literature (NGSS Lead States, 2013; Anderson, 2010; NRC, 2011). The Next Generation Science Standards (NGSS) and the corresponding framework, contain ES in the disciplinary core idea (DCI), Biodiversity and Humans (NGSS Lead States, 2013; NRC, 2011). This DCI articulates that humans rely on the natural world and upon the benefits "from 'ecosystem services,' such as climate stabilization, decomposition of wastes, and pollination that are provided by healthy (i.e., diverse and resilient) ecosystems" (NRC, 2011, p. 166). The DCI also includes the idea that there are limitations of resources in ecosystems and that humans can also impact these ecosystems and their provision of ES through "habitat destruction, pollution of air and water, overexploitation of resources, introduction of invasive species, and climate change" (NRC, 2011, p. 166).

This inclusion of ES in the Framework is an important milestone towards developing a more comprehensive description of environmental science literacy; however, much work remains. Though mentioned in some science education literature (Berkowitz, et al., 2005; NRC, 2012; Wilson, et al., 2007), there is relatively little research characterizing key services, what citizens should know about them, and how citizens can use this information to make informed environmental decisions. This is, in part, because ES is a relatively nascent domain, but likely also because scientists who study ES have struggled to communicate how to connect ES to environmental decisions (Fisher, Turner, & Morling, 2009; WRI, 2011). Despite this struggle, a principle aim of research on ES is to more clearly articulate human-environment systems. In the section that follows this introduction, I provide an example of how ES provide a more comprehensive picture of human-environment systems, discussing ES in the Mississippi watershed.

For ES to be fully realized as an important component of scientific literacy, it is necessary to articulate a contemporary definition of ES that fits new understandings in this rapidly evolving field, a definition that can be understood by a general audience of environmental decision-makers. Research is also needed to identify key science ideas about ES that citizens can use to connect ES to everyday environmental decisions. In accordance with these needs, this paper presents the findings of an empirical study using the Delphi technique to answer two research questions:

1) How should Ecosystem Services be defined for a general audience?
2) What are the big ideas about Ecosystem Services that can connect human decisions to changes to Ecosystem Services?

These questions aim to articulate ES in a manner that can be understood and used in a practical way by all citizens.

Why Ecosystem Services? An example of their importance

The ES provided by the vast coastal wetlands that once surrounded the mouth of the Mississippi River are critical to the economic and social well-being of New Orleans. These wetlands provide a variety of ES, including acting as a buffer against the violent waters of the Gulf of Mexico during hurricanes, as well as providing nutrient cycling services that remove soluble nitrogen from river water and maintaining nutrient levels conducive to active fisheries. Scientists have observed a steady erosion of these coastal wetlands as a result of larger regional impacts upstream (Templet & Meyer-Arendt, 1988). For example, upstream farmers have built levees to control flooding and allow for a greater provisioning of food (a good). Though resulting in a lower risk to food for this single farmer, there are tradeoffs associated with these actions; these levees alter water flow rates forcing water to flow faster downstream. When enough of these levees are built, by the time water reaches the mouth of the river at the Gulf of Mexico, it is moving too quickly to deposit enough silt to maintain the coastal wetlands (Gergerl, Carpenter, & Stanley, 2005; Templet & Meyer-Arendt, 1988; Walker & Salt, 2006). Coastal wetlands require a continuous depositing of silt to provide the raw materials for land in the ecosystem. With low siltation rates, there is a slow erosion of coastal wetlands and the ES that they provision. Thus, while levees are directly beneficial at a local level, at the regional level, they indirectly impact the regenerative capacity of an important wetland ecosystem.

As downstream residents have lost ES and been made aware of some of these losses, they have had a greater incentive to promote a multifaceted watershed management plan. The organizations "American Rivers" and "Earth Economics" are working with citizens around the watershed on such a multifaceted management plan. Their hope is to select and prioritize projects that are both cost effective and maximize ES that the basin provides (Earth Economics, 2013). Such projects rely on an informed citizenry that can recognize a loss of ES, rally to protect these ES, and gain enough political clout to promote these multifaceted environmental management plans.

Using the Delphi Method to Identify Central Ideas for a Complex Science

The academic community that studies information central to a domain and salient to problem solving, most appropriately identifies it (Osborne, et al., 2003). Scientists from various disciplines including ecology, environmental science, and economics, among others, study ES. These scientists bring with them discipline-specific methodology, as well as biases related to their parent discipline. While the bodies of knowledge for each of their parent disciplines are complex on their own, together, they make knowledge about ES highly complex and context-dependent, based upon the information available for specific human social systems and ecosystems being studied. The scientists who study ES pursue research such as characterizing and developing incentives to preserve native ecosystems, as well as evaluating the tradeoffs of ecological restoration in urban systems. Despite the large range of topics that ES scientists research, we make the assumption that those who study ES share a central set of ideas that frame their thinking about ES.

The Delphi method is particularly suited for identifying a central set of ideas. This method uses repeat survey of a panel of experts in a given domain to establish a consensus around important ideas (Dalkey & Helmer, 1962; 1963). The Delphi Method has been used to inform curricular aims for higher education as well as to articulate meaningful components for complex concepts such as the nature of science (Dalkey & Helmer, 1962, 1963; Murry & Hammons, 1995; Osborne, et al, 2003). Delphi methods are particularly powerful because they use an iterative survey process that has built-in member checks that lead to reliable results.

Defining expertise is an important component of the Delphi process. In their Delphi study on important components of *nature of science knowledge,* Osborne and others (2003) defined experts in science practices as those individuals "with acknowledged expertise in communicating, using, or researching the processes and practices of science" (Osborne, et al., 2003, p. 698). For this research, we defined experts in ES as *individuals who have published peer-reviewed academic research seeking to improve scientific knowledge about coupled human-environment systems, or improve* *methods of communicating about and teaching this relationship*. This includes individuals who: (a) study the role of ecosystem structure in functioning that contributes to ES, (b) explore economic variables affected by changes to ecosystem functioning, (c) develop ways to include ES in urban planning, and (d) design spaces to promote ES in engineered systems.

The size of a Delphi panel can vary between 10-30 members (Brooks, 1979; Cochran, 1983; Delbecq, Van de Ven, & Gustafson, 1975; Osborne, et al., 2003). As panel size increases, the reliability and error reduces; however, Delbecq (1975) and Brooks (1979) found that little improvement in results are seen once group size exceeds 25 – 30 members.

The members of a Delphi panel, answer questions, as well as rate and comment on ideas independently without face-to-face interaction that may result in deferment to domineering group members, tangential thinking, and band-wagoning (Martorella, 1995; Murry & Hammons, 1995). The Delphi method allows participants to remain anonymous in an effort to ensure more honest participation for controversial topics and rests on two assumptions: (a) a group consensus provides a more valid decision than those made by a single person, and (b) various problems can arise when experts meet face-to-face, some of which we mentioned above (Murry & Hammons, 1995).

Researchers approach the initial phases of Delphi studies in different ways. Some begin with a review of literature to provide an initial set of answers that the Delphi Panel can respond to and help edit (Murry & Hammons, 1995). Others begin with a set of open-ended questions from which the Delphi researcher identifies a set of ideas (Osborne, et al., 2003). In subsequent rounds of study, the expert panel is asked to rate and comment on each idea and the researcher uses responses to modify the ideas until a consensus is reached. Researchers typically use a Likert questionnaire to provide quantitative values on the consensus among participants. Brooks described a consensus as “a gathering of individual evaluations around a median response, with minimal divergence” and that little, if any, further shifting of positions will occur (Brooks, 1979, p. 378). For controversial issues, a median response is one that is amenable to most of the Delphi panel with a low standard error (minimal divergence). Similarly, for curricular aims, a consensus is achieved when there is a high rating of importance for a given idea or aim with a low standard error (Osborne, et al., 2003). When a consensus is achieved, the Delphi process is complete. For this study, we defined a consensus on a specific big idea or clause of the definition of ES as a point when the importance of ideas and clauses was rated as highly important (average of rating above important factoring in standard error) and where recommendations to revisions were not based upon the idea itself, but particular word choices (e.g. “ecosystem services in human-engineered systems should be stated as ecosystem services in human-dominated systems”). It is important to note that we did accept these word choice changes when the word was critiqued by at least two participants. In the example above, five members of the expert panel explicitly cited the word “engineered” as a questionable word choice.

Methods

As noted above, a Delphi study involves iterative survey of an expert panel. For this study, we conducted four rounds of survey, and in this section, we describe the (a) expert panel that participated in this study, (b) data collection procedures, (c) data analysis, and (d) establishing a consensus.

Delphi Panel

Forty-six academic experts in ES provided input for this Delphi study at some point during the four rounds of survey. To help ensure sufficient participation throughout this study, we modified a traditional Delphi approach by allowing any invited expert to contribute in any round. This was done to reduce problems associated with participant fatigue and attrition (Osborne et al., 2003) and allowed us to maintain a larger panel size per round of survey and perform more rounds of survey than might have otherwise been possible with a single set of experts throughout. Two experts participated in all four rounds, one participated in three rounds, and seven participated in two rounds. It is also important to note that we had independent discussions with some experts to better understand their comments and better represent their ideas in the findings of this study. Table 1 contains the disciplinary training of the expert panel for this study based upon the doctoral programs from which they graduated.

Data Collection and Analysis

Table 2 contains an outline of the general methodological structure used to collect data for this Delphi study as well as the outcome of this data collection. Like many Delphi studies, we began this study with a set of open-ended questions:

1. How should ecosystem services be defined for a general audience?
2. What ecosystem services or properties of them do you think are important for high school graduates to know?
3. What ecosystem components, interactions, and properties are necessary to construct scientific explanations, arguments, or models related to the ecosystem services that you have listed?

Five experts in ecosystem services contributed their opinions during this initial round of study.

To supplement the expert responses from the first round of survey and provide a richer array of ideas for later rounds of survey, we also reviewed 50 peer-reviewed articles published in the journals listed in Table 1. A number of criteria were used to select articles for inclusion. First, we wanted to obtain ideas from a wide array of academic disciplines that study ES. The journals that we selected represent an approximation of the various fields of science that inform ES, and the articles that we selected within these journals included topics such as (a) valuations of specific services like water flow regulation (Guo, Xiao & Li, 2000), (b) biodiversity preservation through ecosystem service mapping (Chan, et al., 2006), (c) the effects of global change on ecosystem services like those of salt water marshes (Brown & Ulgiati, 1999; Feagin, Martinez, Gonzalez, & Costanza, 2010), among others.

We also selected articles that were both theoretical and practical. Of the practical articles, we selected articles to capture a variety of ecosystems and different types of ES. For the theoretical articles, we looked for articles with different perspectives on classifying ES than the standard model developed as a part of the Millennium Ecosystem Assessment process that took place in 2003. The model developed as part of the Millennium Ecosystem Assessment (MA, 2005) categorizes ES into 4 types (provisioning, regulating, cultural, and supporting services). Theoretical articles were included only past 2005, when the Millennium Ecosystem Assessment framework was widely distributed. For example, Fisher, Turner, and Morling (2009) lumped the Millennium Assessment categories into two categories based upon types of ecosystem functioning that contribute to human well-being (intermediate and final services); they then added another novel category, *benefits,* the identification of which involves *translating an ecosystem function into a direct benefit*, such as the cleaning of water (service) that can be used as *drinking water* (benefit). They developed this category scheme to more clearly connect services to humans because some, such as nutrient cycling, are not clearly a benefit in everyone's minds.

Analysis for Big Ideas about ES

For each of the questions in the first round of survey and for each participant comment in subsequent rounds of survey, we used a propositional analysis (Frederiksen, 1975; Kintsch & van Dijk, 1978) to identify each unique idea in the definitions of ES provided by participants during the first round of survey. From participant responses, we identified any proposition that contained a mechanistic connection between ecosystems and human life, including human benefits from ecosystems, impacts to ecosystems, and reciprocal impacts of human alteration of ecosystems on human well-being. For example, one participant described networks of interdependent organisms and their environment as critical to the persistence of ES:

> "Interactions between networks of interdependent organism and between them and their environment are at the heart of ecosystem services….Even single pollinators (e.g. honey bees) depden[sic], in turn, on a network of other organisms that enable them to persist and perform their pollination function."

We used this same approach to analyze the 50 journal articles during the initial phase of this study. We identified all propositions present in the paragraph defining ecosystem services in an academic article. These propositions included ideas such as (a)

ES have a limited flow rate in provision, (b) provisions of ES are governed by the structure of an ecosystem, and (c) the components of functioning systems, among others. For some ideas, there were multiple perspectives. For example, the term ecosystem was used varyingly to refer to “wild nature” (Balmford, et al., 2002), constructed wetlands (Yang, et al., 2008), and also urban ecosystems (Bolund & Hunhammar, 1999). We discuss the process for establishing consensus on ideas with multiple perspectives below.

We were also interested in how academic experts categorize ES and how they articulate human relationships to them. We used a combination of participant responses and peer-reviewed literature to identify these categories and relationships. We identified any unique way in which various services were categorized and connected to human life. In the propositional analysis, we maintained all categories proposed in addition to the Millennium Ecosystem Assessment categories (e.g. the benefits category describe by Fisher et al. (2009) above). We analyzed all 50 articles to identify any unique idea and conceptual category of ES. While we analyzed all 50, no new ideas emerged after about 25 articles.

Repeat Survey

With an initial list of important ideas for a definition of ES, as well as important properties of ES and ecosystems, we distributed a second survey to the expert panel. In this survey, 22 experts rated the importance of each idea generated during the first round of survey in relation to two questions:

a) How important is this idea for the definition of ecosystem services?
b) What are the components, interactions, and properties of an ecosystem services model that are necessary for citizens to mechanistically connect everyday

personal, political, or business decisions to the well-being of socio-ecological systems?

These ratings were on a five-point Likert scale that ranged from "Not Important" to "Very Important". The survey also contained space for comment next to each idea and encouraged participants to provide input at any point in the survey. Of the 26 potentially important ideas from the first round of this Delphi study, 17 were rated as important or higher. These 17 ideas were given to participants twice more for language refinement in rounds three and four of this Delphi study. In the third round of survey, a few participants argued that one of the original 17 ideas, negative feedback loops, had multiple ideas: one related to resilience and one to sudden change and should be further articulated. Therefore, 18 ideas were provided for final rating and language refinement in the third and fourth rounds of survey (Table 3).

Establishing a consensus

Some ideas about ES had multiple perspectives present both in literature and in participant responses to the first survey. To deal with these issues when they arose, we asked participants to select one of the divergent perspectives or a combination of these perspectives (if a combination was possible). For example, we asked participants to select between three perspectives regarding the *benefits from ecosystems*. The first two perspectives emerged from participant ideas and the literature review. The third, we developed by melding together the ideas of the first two in an attempt to achieve consensus on divergent perspectives:

> **Choice 1**: Ecosystem services are only the ecosystem functioning that can be conceived of as a benefit, and listed as a *valuable unit.*

> **Choice 2**: Ecosystem services are, in general, the *extensive array of ecosystem functioning* that supports human well-being, the ecology and size of which is intangible, making it such that the existence of functioning ecosystems themselves are a benefit.

> **Choice 3**: Fully perceiving ecosystem services requires *both* translating specific ecosystem functioning into specific ecosystem services as well as recognizing the complexity of ecosystems and their indefinitely long array of benefits that make whole functioning ecosystems important to human well-being (note this choice was selected by majority of participants).

All ideas that initially had divergent perspectives were easily resolved; over two-thirds of participants selected each divergent perspective that we moved forward with for future rounds of survey. Once divergent perspectives were resolved, in future rounds of survey, those remaining ideas with an average rating score as important (3 out of 5) or higher, were selected as central ideas (Table 3) or ideas to include in the definition of ES (Table 4).

We also used surveys to establish a consensus with regard to the level of understanding citizens should have with regard to a topic. Using the responses from the first set of questions and survey of literature, we listed all ideas, regardless of complexity, in the second survey. For the sake of brevity, we describe the process for establishing a consensus on the elimination of one of these ideas here: the complex systems concept of 'emergence'. Emergence deals with patterns that appear at higher levels-of-organization in systems as a result of the behaviors or positioning of structures at a lower level of organization (for more information on emergence presented for educators, see Wilensky and Resnik, 1999). After finding the concept of emergence in the literature review, we included the concept in the second round of survey as a component idea associated with "functioning in complex systems". We specifically asked participants to rate the importance of the following clause of ideas associated with functioning in ecosystems:

> *"The functioning of ecosystems responsible for ES is "emergent" because these functions are not the primary roles of components in the ecosystems. For example, leaves on trees exist as sites for photosynthesis (primary role), but have emergent buffering and regulating functions at the ecosystem-level intercepting rain and sunlight. Thus the ecosystem functioning that provisions ES is an emergent phenomenon."*

Few participants rated this idea as important (average rating of 2.44 of 5). One fourth of participants rated this idea as not important altogether. In response to this idea, participants made comments such as, "*emergence is excessive…outcomes [of ecosystem processes] can be either directly or indirectly related to human well-being… modifying the word "function" just seems unnecessary*" (Participant 13). Participants often provided short explanatory arguments for their ratings like the example presented here. We concluded that a consensus was reached to drop an idea when ideas were consistently rated with a low importance and to which the comments associated with the low rating were not about needing better phrasing. It is important to note that we are not arguing against including the concept of *emergence* as an important target of scientific literacy; rather, we are presenting the results based upon expert (in ES) views on the most important conceptual ideas related specifically to ES. The final list presented in Tables 4 and 5, contain only those ideas rated as important or higher, including standard deviation.

Results

We divide this section into two parts corresponding to each research question. Based on participant comments in four rounds of survey, we provide: (a) a definition of ES for a general audience, and (b) a list of six big ideas about ES.

Research Question 1: How should ecosystem services be defined for a general audience?

Figure 1 contains the final definition of ES generated during this study. The definition was developed from ideas that had an average rating of important (3 of 5, including standard error) or higher. There are 14 ideas that were included in this definition (Table 4). Here we describe the component ideas underlying each sentence of the definition; sentences of definition are *italicized*.

Ecosystem Services (ES) are a vast array of direct and indirect, market and non-market, as well as perceived and intangible benefits that humans gain as a result of being connected to functioning ecosystems, native or modified. Humans benefit from ecosystems in many ways. Some benefits are easily perceived, such as clean water, shade, or a visually appealing landscape. Others are less tangible ecosystem-processes, such as nitrogen-fixing bacteria enriching the soil. Functioning ecosystems require an array of components that interact to move materials and energy through the system rather than pool in a spot, which could otherwise lead to toxic conditions or leave a resource unavailable to an organism. These functioning ecosystems exist not only in 'wild nature' but also in urban areas dominated by humans.

We can articulate some specific ES, but the total number of benefits gained from functioning ecosystems is beyond human comprehension. When thinking about ES, it is important to consider two perspectives simultaneously while reasoning about ES. The first perspective is a logical, scientific perspective. It involves characterizing *specific benefits* from an ecosystem, such as regulating services or resource-provisioning services. The second perspective is more of a wisdom that involves thinking about the functioning system as a whole and the countless ES that may be there but are intangible. It is important to reason using each of these perspectives independently because they each yield different outcomes. The first perspective affords an economic view of ES: they can be thought of in specific, valuable, and tradeable ways. On the other hand the second perspective provides the understanding that, *any accounting system developed to include ES will NOT include them all.*

Some ES result in resources that can be actively extracted as goods and traded, while others require no human effort to obtain, and human activity alters the provisioning of different ES by changing ecosystems. ES are *not* goods, such as clean water and food, but are responsible for the *provisioning* of these goods. Without functioning ecosystems, many goods will decline. Changing the functioning of ecosystems to promote only the provisioning of one type of good can lead to the loss of those other ES, such as flood regulating services that do not require human effort to obtain.

The ES that provision resources, do so at a limited rate that changes depending upon the flow of matter and energy to that extractable resource, the flow rate of which is dynamic. One of the key ideas about ES is this idea of *flows*. Flows are responsible for the functioning connections in an ecosystem. Without flows, an ecosystem is static and cannot provision anything, but these flows only occur at a certain rate that places limitations on what an ecosystem provisions. This rate of flow, changes, depending upon environmental conditions, time of year, etc. These changes are important to reasoning about the limitations of ecosystems and their services.

Including ES in decision-making can provide incentives to conserve native ecosystems or restore functioning ecosystems. Despite a limited capacity to identify and quantify all ES, including them in decision-making can expand the number of tradeoffs considered when making environmental decisions. By articulating value to services not traditionally included in economic markets, it is possible to create incentives to conserve or restore ecosystems. The caution, as articulated earlier, is that any assignment of economic value when analyzing tradeoffs, has significant limitations that should be considered.

Controversy that led to this iteration of the definition

Most of the ideas in the definition were not controversial; however, it is important to highlight one controversy that led us to specifically describe two ways of thinking about ES as a specifically identifiable list of benefits and a wisdom of vast benefits that grounds economic valuation of them. Though ES are commonly thought of as a list of benefits, some participants expressed concern over the extent to which research on ES can inform policy given the incomplete knowledge we have of this complex construct. The following statements highlight this view:

> P1: *"Bottom line--the whole ecosystems services concept is of dubious value if the idea is to attempt to price or value those services. Evaluation is a mug's game to begin with -- since the goal is to make allegedly efficient 'trade-offs'-- but one cannot legitimately play the game at all if we cannot identify the things to be traded off in the first place."*

P2: *"The important point about ecosystem services is the sheer magnitude of the list."*

P3: *"beyond the obvious [services], we don't even know what they are. The vast majority of the vital functions of nature are invisible until they are threatened or destroyed."*

The views of the scientists (quoted above) are fundamentally distinct from that of the economists' views of ES, who believe that having a list of services from which tradeoffs can be identified and valuated is critical to sustainable human economies. Despite the limitations of the ES concept to transform human economies, many economists are, in fact, attempting to assign an economic value to ES.

To rectify this controversial gap, we included the uncertainty in ecological and economic sciences from which ES knowledge emerges in this definition of ES. Those trying to develop accounting procedures recognize this limitation, but view ES as a powerful tool to conserve functioning ecosystems. Nonetheless, the uncertainty of scientific knowledge is important because it communicates the caution necessary when enacting any ES policy.

Research Question 2: What are the big ideas about ecosystem services that can connect human decisions to changes to ecosystem services?

Using the top 18 ideas that emerged during this study, we constructed descriptions of six big ideas about ES. Table 3 contains these big ideas with the highly rated component ideas used to generate these big ideas. Here, we provide these big ideas that the expert panel deemed as important to know by all citizens in *italics*. We also provide a more detailed description of these big ideas for teachers and education researchers.

Big Idea 1: *Humans are embedded within ecosystems and benefit from them in many, if not countless ways, directly and indirectly, actively and passively, and many of these benefits are not a part of traditional markets.* Humans benefit from functioning ecosystems in many ways. As described above, there are both easily identifiable ES and those that are less tangible. Some benefits are a part of economic markets, but many of them are not a part of traditional markets for one of two reasons: (a) they are *non-excludable* (i.e. ownership is impossible because some ES are dispersed across property and political lines and it is not possible to exclude others from use or enjoyment) or (b) they are *non-rival* (i.e. passive enjoyment of some ES does not reduce the ES available to others). While it is possible to place a value on these types of services, these valuations are limited making it problematic if a decision-maker uses this information when reasoning about a "bottom-line". This is problematic because attempting to squeeze a desired set of services from ecosystems as efficiently as possible can create a condition in which the functioning of that ecosystem becomes tenuous (See Big Idea 5).

When thinking about ES, it is useful to divide them into categories. There are two broad categories that are helpful ways of thinking about ES: (a) resource-provisioning services, and (b) conditions-enhancing services. Conditions-enhancing services also has a number of sub-categories including, (a) ecosystem-enhancing and supporting services, (b) regulating services, and (c) cultural services. We provide examples of each category in Figure 2. These categories help to articulate the importance of looking at multiple services. Importantly, however, there are *tradeoffs associated with selecting one service over another:* this usually leads to a decline of other services.

Big Idea 2: *Ecosystems from which humans benefit have interactions at local, regional, and global scales that embed human populations in ecosystems close-by as well as far-away.* The boundaries between ecosystems are not easily delineated. This is partly because ecosystems can be perceived at multiple scales (e.g. local, regional, and global scales) but also because the interactions in ecosystems are not restricted to any location or scale. For example, benefits such as flood regulation can depend upon the presence of trees in a distant forest that slow water movement downstream. There are two important messages from this big idea: (1) humans are embedded in ecosystems even when it seems like they are remote, and (2) there are multiple human populations living in local ecosystems connected through trade of resources.

Big Idea 3: *Ecosystems from which humans benefit can only process wastes and provision resources at limited rates. If humans extract resources or dump wastes at a rate that exceeds an ecosystem's capacity, that ecosystem will become over-exploited or polluted. This places constraint upon the human population.* Because native ecosystems have a limited capacity to provision direct human resources (e.g. food and water), as the human population grows, the bounty of these direct resources decreases per-capita. Therefore, it is sometimes necessary to transform ecosystems to meet these basic needs and increase flows of matter and energy to a specific resource (e.g. food). Because there are limits to the provision of ES, such transformations usually yield a reduction in other ES. Similarly, as the human population and resource consumption grows, we increase the rate at which wastes flow into ecosystems, and ecosystems have a limited capacity to metabolize these wastes. Use of either provisioning or waste processing ES at a rate faster than they are provisioned in ecosystems, will result in over-exploitation or pollution.

Big Idea 4: *Ecosystem functioning depends upon the flows of matter and energy through the system and this functioning is important for the provision of some Ecosystem Services, such as resource-provisioning and waste-processing services.* Matter and energy are transformed in ecosystems from one form to another, and flow through well-functioning ecosystems. The types of flows in an ecosystem will determine the type of services it provides. For example, in wetlands, organic nitrogen is converted to atmospheric nitrogen removing potential toxic wastes that contribute to dead zones in coastal fisheries.

Different organisms in ecosystems have different metabolisms and contribute to different flows of matter and energy in ecosystems. Therefore, when looking at ecosystems, biodiversity is often considered important because having biodiversity is often associated with a diverse array of flows and a greater number of ecosystem services associated with these flows.

Big Idea 5: *Ecosystems often change rapidly and unexpectedly but resilient systems are less likely to experience a dramatic change in ecosystem function.*

Stability in ecosystems is regulated by negative feedbacks. Negative feedbacks keep the condition in a system in a state of "dynamic equilibrium" or "homeostasis" (word choice depending upon domain of science). Predator-prey relationships, for example, follow a negative feedback pattern in ecosystems; when predators eat prey and expand their population, fewer prey become available, keeping the size of the predator population in check (i.e. stabilizing the sizes of their populations). In complex ecosystems, there are many interlocking feedback relationships (e.g. many predator-prey relationships, among others). Interlocking feedback relationships help maintain the functioning of an ecosystem over time and the provisioning of ES. Feedbacks also play an important role in the resilience of an ecosystem. Resilience is the capacity of an ecosystem to absorb disturbances and reorganize while maintaining the current functioning.

Thresholds are points at which an ecosystem no longer has the specific feedbacks that are important to maintaining current functioning. For example, removing a single keystone species eliminates important feedbacks and leads an ecosystem to a threshold state. Once thresholds are reached, the positive feedbacks in a system cause a rapid change to a new state. For humans, the transition to a new state can be problematic if the new state has fewer ES or different types of ES (e.g. ES from a forest versus a desert). The point at which a system will reach a threshold is hard to predict because of limitations of scientific knowledge that make it difficult to forecast how changes to ecosystems will affect the provision of ES. Given this difficulty in forecasting and because environmental conditions are always changing, if ecological networks are too rigid, they are considered less resilient and more likely to enter a threshold state.

Big Idea 6: *Humans make everyday decisions as individuals and as groups that alter ecosystem structure and functioning at multiple scales.* Humans make decisions every day that alter ecosystem structure and the ES that they can provision. Whether it is through the purchase of goods or business transactions, almost all human actions have some impact on ecosystems, either to increase or decrease specific ES. For example, farmers alter land to provision food (a resource-provisioning ES), while reducing other ES such as water flow regulation. Because humans trade goods across the world, the impact that the extraction of goods has on a local ecosystem, may not be seen by the consumer population purchasing these goods, affecting perception of the impacts of decisions. Not all human actions are the same, however. Humans can reduce impacts to native ecosystem structure or improve ecological functioning through restoration.

Discussion

This paper presents a set of contemporary central ideas about ES that academic experts in the field believe are necessary to connect ES to everyday environmental decisions. These central ideas are a baseline for education research on ES. In this discussion, we compare the findings of this study to the Framework for Science Education from the National Research Council and the standards that followed (NGSS Lead States, 2013; NRC, 2011), as well as to education research on coupled human-environment systems (Anderson, 2010; Covitt, Tan, Tsurusaki, & Anderson, 2009; Gunkel, Covitt, Salinas, & Anderson, 2013). We specifically highlight that, shifting focus to ES does not significantly add more content to national standards; rather, it involves reframing current standards to include ES under multiple disciplinary core ideas.

ES Big Ideas and the NRC Framework for Science Education

Recently, a committee of the National Research Council developed a set of disciplinary core ideas (DCIs) across the Life, Earth, and Physical Sciences (NRC, 2011). Some of the DCIs articulated by this committee overlap with the results of the study described in this paper. These include, (a) *Biodiversity and Humans*, (b) *Ecosystems:*

Interactions, Energy and Dynamics, and (c) *Earth and Human Activity*. The condensation of the large array of science concepts into such a discrete list of DCIs represents a major intellectual achievement by the committee, and the results of this study do not significantly add to the current articulation. Rather, they recommend explicit connection of ecosystem services to the already existing ideas in the DCIs, *Ecosystems: Interactions, Energy, and Dynamics* and *Earth and Human Activity.* There are two important reasons for doing so that are based upon the results of the study described in this paper: (a) ES are benefits from ecosystems at many scales (i.e. local, regional, and global), not just biodiversity and (b) ES are more than natural resources and expand this narrow anthropocentrism. These distinctions highlight important ways of thinking about ES and coupled human-environment systems that were identified as central by the panel of experts in this study.

ES are benefits from ecosystem functioning not only biodiversity.

ES are currently described, rather eloquently, under the core idea *Biodiversity and Humans* in the Framework for Science Education developed by a committee of the National Research Council (NRC, 2011). This description includes a variety of ecosystem-level ideas associated with ES, but their current iteration in the Biodiversity core idea makes it such that, the role of these ecosystem-level processes is less clear.

Though biodiversity is sometimes used as one indicator of ecosystem functioning (e.g. Baumgärtner, 2007; Tilman, 1997), the participants of this Delphi study argued that biodiversity alone is an insufficient predictor of the ES that might emerge from an ecosystem (none of the participants selected this view over that of ecosystem-level structure and functioning). Biodiversity is insufficient because at the ecosystem level-of-organization, biological organisms spring into a functional role, and some of these functional roles are important ES (see examples provided for Big Idea 4 above). Ecosystem functioning is brought to bear in the NRC DCI, *Ecosystems: Interactions, Energy, and Dynamics*; however, this functioning is not directly connected to humans or ES. These functioning relationships are important elements of scientific arguments for conserving biodiversity and native ecosystems. Functional relationships give organisms importance beyond that of direct human benefit (i.e. resources) because organisms are not only important to humans but to other organisms and ecosystem functioning upon which humans depend.

This is particularly salient when considering research on how students prioritize organisms for preservation. Palmer (2003) surveyed learners in grade 9, to determine their views on the importance of various species in an ecological system. He found that 44% selected only specific species as playing a role in ecosystems. In another similar study, when asked about the importance of actively preserving specific species, few participants (grades 6 and 10) selected all species as important to preservation (Palmer, 1997). They selected importance, not based on ecological role (ecosystem-level of organization), but on features such as attractiveness, uniqueness, and their role economically for humans. In another study by Fox-Parrish and Jurin (2008), learners were given an activity about the important roles that muskrats, a keystone species, played in ecosystem functioning, but at the conclusion of the activity still believed that other organisms were more important for conservation. It was clear from these studies that understanding the role of organisms in ecosystems did not afford them with a perspective of the importance of those roles or the functioning of the ecosystems themselves. It is possible that knowing ES associated with these roles may help promote reasoning aligned with conservation of a wider array of organisms.

In light of the findings presented in these studies and the opinion of this expert panel, we recommend including ES with their related ideas in the Ecosystems: Interactions, Energy, and Dynamics Disciplinary Core Idea as revisions of the NRC Framework for K-12 Science Education take place (NRC, 2012).

ES widen anthropocentrism.

Promoting "anti-anthropocentrism" has been viewed as an important goal of environmental education (e.g. Dunlap & VanLiere, 2008; Manoli, Johnson, & Dunlap, 2009). Anti-anthropocentrism is a part of a worldview that rejects consumer economy and the idea that natural resources exist for consumption by humans, with no real value beyond human use (Manoli, Johnson & Dunlap, 2009). This push against anthropocentrism has been driven by research linking it to lower positive environmental attitudes (Kilbourne & Polonsky, 2002; Manoli, Johnson, & Dunlap, 2009).

While ES are anthropocentric, there is a difference between traditional western anthropocentrism and the type of anthropocentrism espoused in the Big Ideas about ES. Traditional western anthropocentrism has a narrow view of economy, recognizing benefits primarily from natural resources that can be extracted from ecosystems and traded on markets as goods (Daly & Farley, 2010; Kilbourne & Polonsky, 2002; Pirages & Ehrlich, 1984; Rennie, 2008). Resources commonly refer to the components of ecosystems that are consumed by an organism (Tilman, 1982). ES shift the traditional narrow anthropocentric lens to include a broader set of benefits including less tangible ones such as flood regulation and wetland regenerating services (i.e. those discussed in the Mississippi example earlier in this paper). ES are not resources themselves (Big Idea 1), but are the ecosystem functioning responsible for the provisioning of such resources as well as regulating "our" environment, supporting ecological networks, and enhancing living conditions within and surrounding human settlement.

The findings of this study recommend including ES in the Earth and Humans DCI in the next iteration of the NRC Framework for K-12 Science Education. In the current version of the Framework, the DCIs associated with Earth and Human Activity focus primarily on natural resources espousing a traditional western anthropocentric lens. Even though the Framework discusses sustainable management and conservation of these resources, focusing on natural resources as central, yields an incomplete view of the benefits that humans gain from functioning ecosystems. Including ES in the DCIs associated with Earth and Human Activity may better connect resource consumption to potential changes in the larger array of ES, and widen the traditionally narrow anthropocentric lens.

ES and educational research on coupled human-environment systems

Research on coupled human-environment systems is ongoing in education (Anderson, 2010; Covitt, Tan, Tsurusaki, & Anderson; Gunkel, Covitt, Salinas, & Anderson, 2013; Mohan, Chen, & Anderson, 2009). This research uses what they call the 'loop-diagram of coupled human-environment systems' to frame target understandings about these relationships (Figure 3, reproduced from Covitt and colleagues, 2009). This "loop model" depicts ES as flowing from environmental systems to human systems, and the ES discussed in education literature typically focus on human resources such as water (Covitt, Tan, Tsurusaki, & Anderson, 2009), food, and fuel (Mohan, Chen, & Anderson, 2009).

While the "loop model" provides a useful frame for thinking about flows between human and environmental systems, the separation of humans and the environment into discrete compartments, conflicts with the cognitive view of coupled human-environment systems developed during the study described in this paper. The second big idea articulates that humans are embedded within environmental systems at multiple overlapping scales and that ecosystem functioning is integral to human well-being. This implies that human populations are not single units separate from the environment; therefore, we revised this diagram representing coupled human-environment systems with humans embedded in local, regional and global ecosystems (Figure 4).

There are six important clarifications to the "loop model" that are depicted in Figure 4: (a) humans are embedded within environmental systems at various scales, (b) there are multiple human populations, (c) between these local human systems, there is trading of resources, (d) there is a flow of ES from both local and regional/global environmental systems, (e) ES are vast including more than resources, and (f) there are human impacts to environmental systems (depicted in red) that can affect the provision of ES to local as well as other human populations. These were all ideas articulated by the Delphi Panel of our study as important to ideas about ES.

Though different in the visual portrayal of ideas, many of the ideas are already considered important in education research on coupled human-environment systems. For example, many target understandings developed for this domain include *perception at various scales* such as local, regional and global scales in addition to a few others discussed in the literature (Gunkel, et al., 2012; Mohan, et al., 2009). Similarly, researchers in this domain discuss different types of ecosystem services (Wilson, et al., 2007).

The framework developed in this study, therefore, adds only one real new idea: *there are multiple human populations, between which there is a trade of resources*. This new idea has ecological grounding (populations interact across landscapes in ecological systems), but primarily emerges from the social sciences side of ES research. The fact that humans trade resources and move them around the world plays a strong role in how we perceive the impacts of human actions. For example, when citizens of the United States purchase products that have rare earth metals from a mine in Asia where environmental regulations are not as strict, they are unlikely to see the environmental consequences of this action. These consequences are felt primarily by the local populations in this distant location. This example makes it clear that ES is at the intersection of the natural and social sciences, and a future task articulated in the NRC Framework on Science Education is integrating social sciences into this framework (2011, pp. 13-14). The research in this dissertation provides information toward that aim.

Limitations

It is important to explicitly articulate the difference between this study and a traditional Delphi design; this study used an open participation panel rather than a confined Delphi panel. Delphi studies have often been characterized as difficult, particularly as a result of participant attrition during the survey process (Osborne, et al., 2003). To overcome this difficulty, we modified the traditional method in an attempt to increase the number of individuals participating at any point in the study. Thus, participants who put forth ideas in early rounds may not have been around in later rounds to argue the importance of their idea. That being said, having a larger number of participants than might have otherwise been possible, makes it such that the results presented here reflect a larger population of experts on ES.

Conclusions

As a result of this study, we have developed a set of six big ideas that are central to understanding a complex topic that rests at the nexus of the natural and social sciences: ES. This simplification represents a significant intellectual milestone in education research on coupled human-environment systems. More importantly, the big ideas articulated herein do not require adding to an already large list of core science ideas that are the focus of education research. Rather, they recommend articulating ES in two other locations within the NRC DCIs, bringing to the forefront the role that functioning ecosystems play in human well-being. For example, adding ES to the Earth and Human Activity DCIs will promote an education that focuses not only on natural resources but a larger array of services important for human well-being.

Articulating DCIs in a way that more clearly articulates human connections to ecosystems can have major implications for the ideas that we attend to in classrooms and in research. For example, in their study characterizing students' use of knowledge and scientific practices when making environmental decisions, Covitt and colleagues (2009) provided a transcript for one learner, Selena, who initially had a solidly formed opinion about allowing a water bottling company to drill a well near a sensitive ecosystem with trout and other fish in the river. Selena initially supported the well-drilling stating anthropocentric reasons, such as "I think I might agree with them to build the well …

because we need water just like the fish does" (p. 34). During the interview, Selena was given various bits of information about the impacts of wells on fish, and by the end of the interview, Selena had changed her mind about the well, offering the following reason for her change of opinion: "Ahh, cuz I, the fish is very important because sometimes you have to eat fish to survive too" (p. 34). In this response, Selena expanded her view to include benefits from fish, not just water, looking at the water as a contributing component to the functioning of the fish's ecosystem. Selena maintained focus on human resources; however, her expansion of potential benefits to include fish in the water led her to consider a larger set of ecological issues. The ES big ideas presented in this paper, legitimize such reasoning and call to a greater examination of how including ES in instruction can affect how learners reason about coupled human-environment systems.

While Selena made the link between fish and humans on her own, teachers can help learners identify different ES, particularly guiding them to investigate ES not directly linked to resources. Then, learners can be guided through the situation (e.g. whether to drill a well for water bottles), looking at the situation through a lens of each big idea about ES. For example, an instructor might provide learners with an activity in which they look at the effects of drilling a well at local and regional scales, taking into account Big Idea 2.

References

Anderson, C.W. (2007). Environmental literacy learning progressions. Paper presented at the Knowledge Sharing Institute of the Center for Curriculum Studies in Science Washington, D. C., July 22-5, 2007

Anderson, C.W. (2010). Learning progressions for environmental science literacy. Paper presented to the NRC National Standards Framework Committee, March, 2010.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola,

J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., & Turner, R.K. (2002). Economic reasons for conserving wild nature. Science, 297, 950-953.
Baumgärtner, S. (2007). The insurance value of biodiversity in the provision of ecosystem services. Natural Resource Modeling, 20, 87-127.
Bolund, P. & Hunhammar, S. (1999). Ecosystem services in urban areas. Ecological Economics, 29, 293-301.
Brooks, K. W. (1979). Delphi technique: expanding applications. North Central Association Quarterly, 53(3), 377-385.
Brown, M.T., & Ulgiati, S. (1999). Emergy evaluation of the biosphere and natural capital. AMBIO, 28, 486-493.
Chan, K.M.A., Shaw, M.R., Cameroon, D.R., Underwood, E.C., & Daily, G.C. (2006). Conservation planning for ecosystem services. PLOS Biology, 4, 2138-2152.
Cochran, S.W. (1983). The Delphi method: formulating and refining group judgments. Journal of the Human Sciences, 2, 111–117.
Covitt, B.A., Tan, E.,Tsurusaki B.K., & Anderson, C.W. (2009). Students' use of scientific knowledge when making decisions in citizens' roles. Paper presented at the Annual Conference of the National Association for Research in Science Teaching, Garden Grove, April 7-21.
Dalkey, N., & Helmer, O. (1962). An experimental application of the Delphi method to the use of experts. Management Science, 9, 458-467.
Daly, H.E., & Farley, J. (2011). Ecological Economics: principles and applications. Island Press, Washington, DC.
Delbecq, A.L., Van de Ven, A.H., & Gustafson, D.H. (1975). Group techniques for program planning. Scott Forman, Glenview, IL.
Dunlap, R.E., & Van Liere, K.D. (2008): The "New Environmental Paradigm". The Journal of Environmental Education, 40, 19-28
Earth Economics (2013). Available online http://www.eartheconomics.org/Page116.aspx.
[ESA] Ecological Society of America. (1996). The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications, 6, 665-691.
Feagin, R.A., Martinez, M.L., Mendoza-Gonzales, G., & Costanza, R. (2010). Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. Ecology and Society, 15(4), 14.
Feinstein, N. (2010). Salvaging scientific literacy. Science Education, 95, 168-185.
Fisher, B., Turner, R.K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics, 68, 643-653.
Fox-Parrish, L., & Jurin, R.R. (2008). Students' Perceptions of a Highly Controversial yet Keystone Species, the Black-Tailed Prairie Dog: A Case Study. The Journal of Environmental Education, 39, 3-14.
Frederiksen, C. H. (1975). Representing logical and semantic structure of knowledge acquired from discourse. Cognitive Psychology, 7, 371-458.
Gergerl, S.E., Carpenter, S.R, & Stanley, E.H. (2005). Do dams and levees impact nitrogen cycling? Simulating the effect of flood alterations on floodplain denitrification. Global Change Biology, 11, 1352-1367.

Gunkel, K.L., Covitt, B.A., Salinas, I., & Anderson, C.W. (2013). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching, 49, 843-868.

Guo, Z., Xiao, X., & Li, D. (2000). An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecological Applications, 10, 925-936.

Kilbourne, W.E., Polonsky, M.J. (2002). Environmental attitudes and their relation to the Dominant Social Paradigm among university students in New Zealand and Australia. Australasian Marketing Journal, 13, 37-48.

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. Psychological Review, 85, 363-394.

Lubchenco, J., Olson, A.M., Brubaker, L.B., Carpenter, S.R., Holland, M.M., Hubbell, S.P., Levin, S.A., MacMahon, J.A., Maston, P.A., Melillo, J.M., Mooney, H.A., Peterson, C.H., Pulliam, H.R., Real, L.A., Regal, P.J., & Risser, P.G. (1991). The sustainable biosphere initiative: an ecological research agenda: a report from the Ecological Society of America. Ecology, 72, 371-412.

Martorella, P. (1991). Consensus building among social educators: a Delphi study. Theory and Research in Social Education, 19, 83–94.

[MA] Millennium Ecosystem Assessment Board. (2005).Ecosystems and Human Well-being: Synthesis, Island Press, Washington DC.

Mohan, L., Chen, J. & Anderson, C.W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46, 675-698.

Murry, J.W. Jr. & Hammons, J.O. (1995). Delphi: A versatile methodology for conducting qualitative research. Review of Higher Education, 18, 423–436.

NGSS Lead States (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

[NRC] National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea. National Academies Press, Washington DC.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschle, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. Journal of Research in Science Teaching, 40, 692-720.

Palmer, D.H. (1997). Students' application of the concept of interdependence to the issue of preservation of species: observations of the ability to generalize. Journal of Research in Science Teaching, 34, 837-850.

Palmer, D.H. (2003). Investigating the relationship between refutational text and conceptual change. Science Education, 87, 663-684.

Pirages, D.C. & Ehrlich, P.R. (1974). Ark II: Social Response to Environmental Imperatives. W.H. Freeman, San Francisco, CA.

Rennie, S. (2008). Toward a 21st-Century understanding of humans' relation to nature: two hats? Journal of Environmental Education, 40, 55-61.

Templet, P. H. & Meyer-Arendt, K.J. (1988). Louisiana wetland loss: a regional water management approach to the problem. Environmental Management, 12, 181-192.

Tilman, D. (1997). Biodiversity and ecosystem functioning. In. G.C. Daly (Ed.), Nature's Services: Societal Dependence on Natural Ecosystems, Island Press, Washington, DC.

Tilman, D. (1982). Resource Competition and Community Structure. Princeton University Press, Princeton, NJ.

Tsurusaki, B.K. & Anderson, C.W. (2010). Students' understanding of connections between human engineered and natural environmental systems.

Walker, B. & Salt, D. (2006). Resilience Thinking: Sustaining Ecosystems and People in a Changing World, Washington, DC: Island Press.

Wilensky, U. & Resnick, M. (1999). Thinking in levels: a dynamic systems approach to making sense of the world. Journal of Science Education and Technology, 8, 3-19.

Wilson, C. D., Tsurusaki, B., Wilke, B., Zesaguli, J., & Anderson, C. W. (2007). The development of an environmental literacy learning progression: Biological diversity and change over time in environmental systems. Paper presented at the Knowledge Sharing Institute, AAAS, Washington, D.C.

[WRI] World Resource Institute. (2012). Available online http://docs.wri.org/share/eiasurvey/survey_summary.pdf

Yang, W., Chang, J., Xu, B., Peng, C. & Ge, Y. (2008). Ecosystem service value assessment for constructed wetlands: a case study in Hangzhou, China. Ecological Economics, 68, 116-125.

Figure Legends

Figure 1: Definition of Ecosystem Services

Figure 2: Types of Ecosystem Services

Figure 3: Loop Model of Coupled Human Environmental Systems reproduced from Covit, Tan Tsurusaki, and Anderson (2009).

Figure 4: New Ecosystem Services Model of Coupled Human-Environmental Systems developed to visualize findings of this study.

Definition of Ecosystem Services

Ecosystem Services (ES) are a vast array of direct and indirect, market and non-market, as well as perceived and intangible benefits that humans gain as a result of being connected to functioning ecosystems, native or modified. We can articulate some specific ES, but the total number of benefits gained from functioning ecosystems is beyond human comprehension; therefore, any accounting system developed to include ES will *not* include them all. Some ES result in resources that can be actively extracted as goods and traded, while others require no human effort to obtain and human activity alters the provisioning of these different ES by changing ecosystem structure. The ES that provision resources do so at a limited rate that changes depending upon the flow of matter and energy to that extractable resource, the rate of which is dynamic. Including ES in decision-making can provide incentives to conserve native ecosystems or restore functioning to ecosystems.

Figure 1 Definition of Ecosystem Services

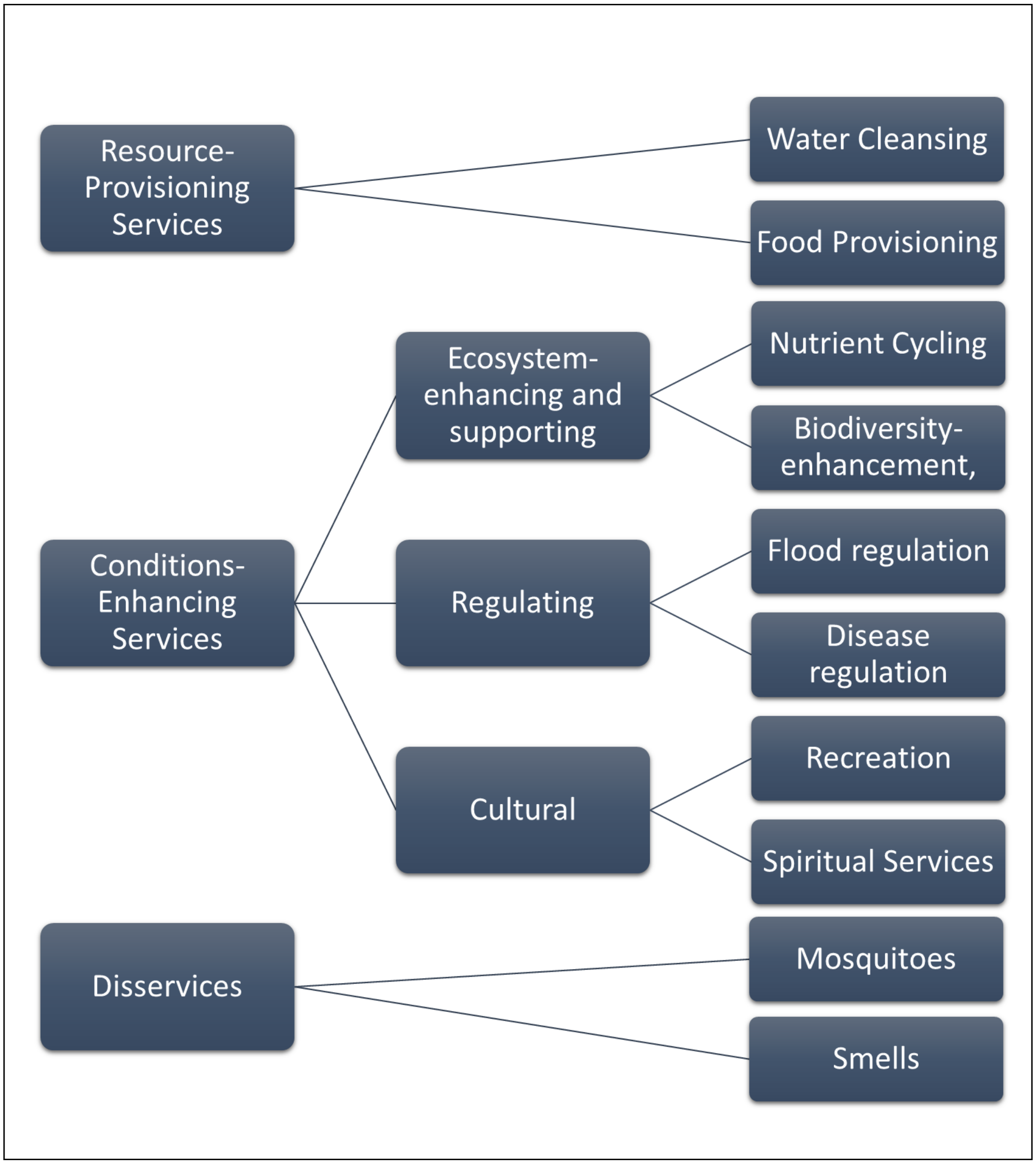

Figure 2: Types of Ecosystem Services

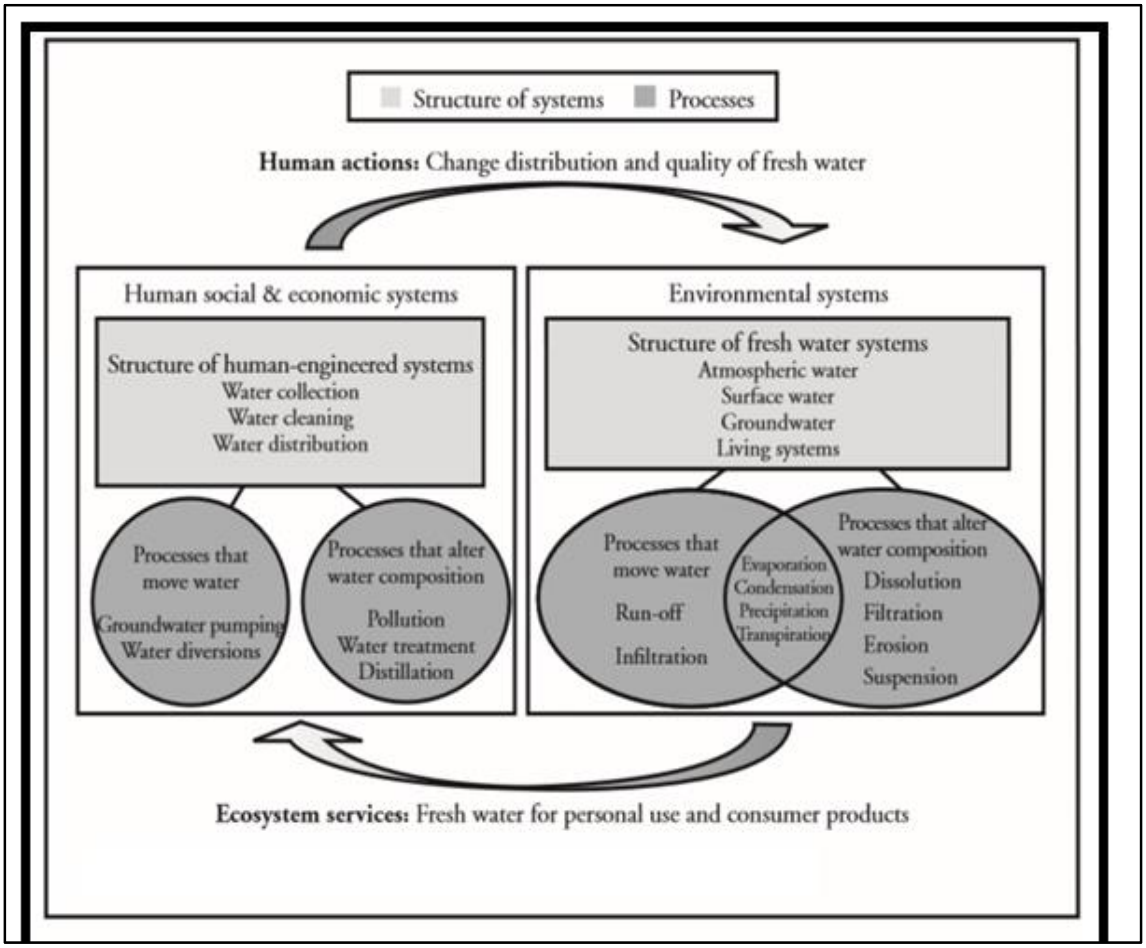

Figure 3: Loop Model of Coupled Human Environmental Systems reproduced from Covit, Tan Tsurusaki, and Anderson (2009).

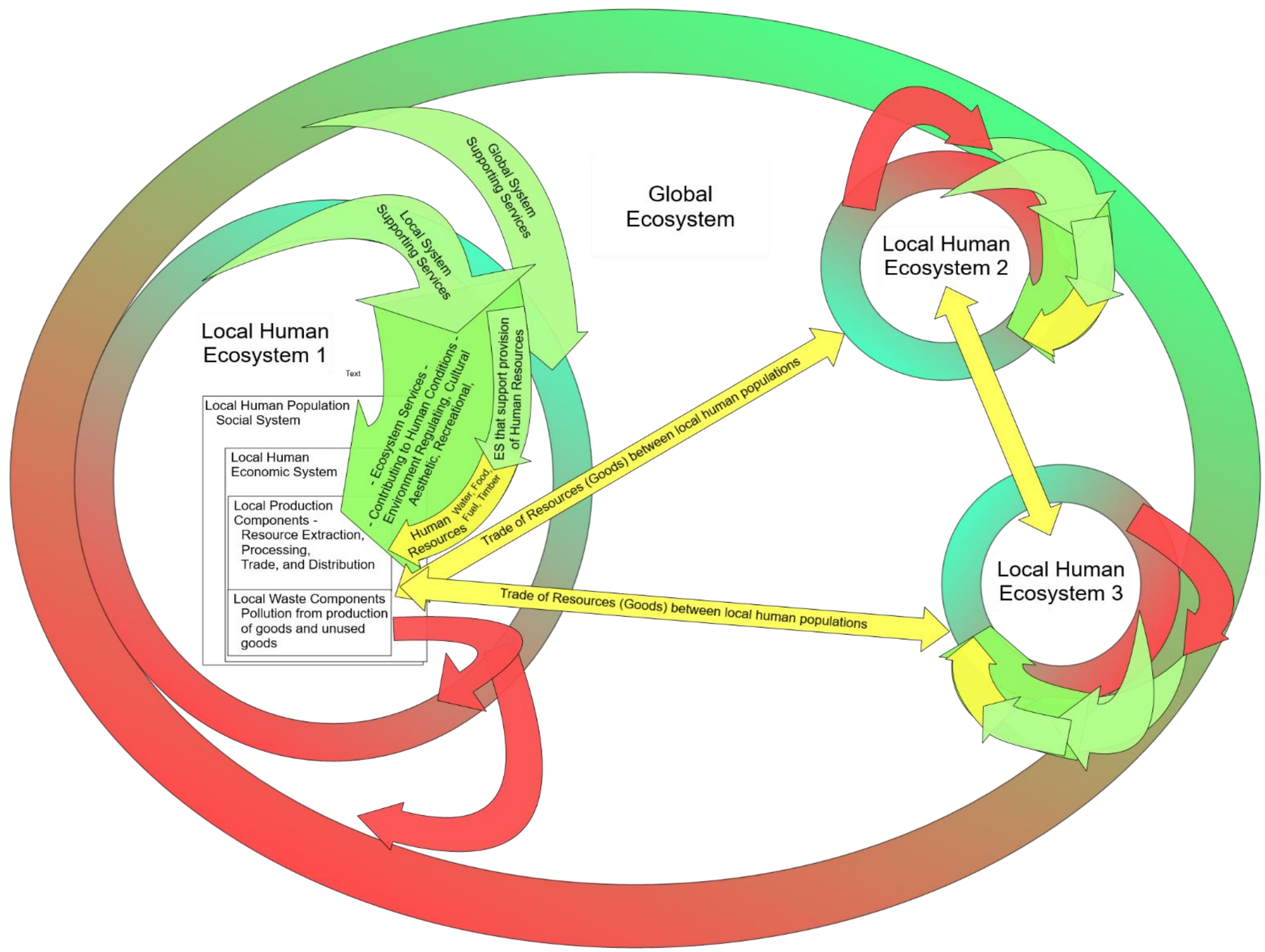

Figure 4: New Ecosystem Services Model of Coupled Human-Environmental Systems developed to visualize findings of this study.

Table 1
Delphi Panel Participants by Disciplinary Expertise

Discipline of PhD Program	Number of Participants
Ecology	18
Education in the Environment	9
Economics	8
Agronomy	2
Environmental Science	2
Natural Resource Management	2
Remote Sensing and Landscape Ecology	2
Climate	1
Landscape Architecture	1
Urban Planning	1

<u>Journals Used in Literature Review</u>

Ecological Economics, Ecology, Frontiers in Ecology, Proceedings of the National Academy of Sciences, Ecology Letters, Science, Trends in Ecology and Evolution, Natural Resource Modeling, Ecological Indicators, AMBIO, PLOS Biology, Nature, Ecology & Society, Ecological Applications

Table 2
Structure of Delphi Study

Round	Purpose of Round	Questions of Round	Outcome of Round	# of Participants
1	Open-ended questionnaire to identify potential ideas using a propositional analysis	How should ES be defined? What ecosystem services or properties of them do you think are important for high school graduates to know? What ecosystem components, interactions, and ecosystem properties are necessary to construct scientific explanations, arguments and models related to the ecosystem services that you have listed?	26 potentially important ideas	5 participants 50 paper literature review
2	Rate the importance of the 26 ideas. Resolve divergent perspectives Refine language	How important is this idea for the definition of Ecosystem Services? How important is this idea to an ecosystem services model that can be used by citizens to connect everyday political, personal, or business decisions to the well-being of socio-ecological systems?	17 important ideas All divergent perspectives resolved	23 participants
3	Refine language	Please provide modifications that you feel are necessary or general comments on the proposed disciplinary core ideas listed here.	18 important ideas refined	21 participants
4	Final rating of ideas and refine language	Please rate the importance of each clause/idea. Please comment on any of the ideas presented here.	*Definition* – 14 important ideas arranged into 5 thematic sets *Central Ideas* – 18 important Ideas organized into 6 idea categories	14 participants

Table 3
ES Core Idea Ratings

Big Idea 1 ES and Humans	Average Rating *3-important*	Standard Error
Active extraction and marketable as well as passive enjoyment	4.07	0.2
Humans depend upon ecosystems for survival, well-being and economic activity	4.94	0.05
Some benefits direct and many indirect	3.31	0.31
Limited perception of ES list	4.06	0.18
Big Idea 2 - Interactions at Local, Regional, & Global Scales		
Benefits differ across space	4.19	0.21
Humans embedded in ecosystems	4.63	0.15
Scale is important	3.25	0.29
Big Idea 3 - Ecosystems have limited flows		
Limited provision	4.56	0.13
Human population constraints	3.83	0.22
Big Idea 4 - Components & connections in ecosystems		
Supporting systems of organisms require resources and conditions for survival	3.81	0.28
Ecosystem structure important to functioning includes diverse biotic and abiotic components as well as network interactions	3.88	0.17
Big Idea 5 - Ecosystems change rapidly and unexpectedly		
Thresholds and non-linear change	4.06	0.26
Negative feedbacks in systems govern resilience	4.19	0.22
Big Idea 6 - Human decisions		
Everyday human behaviors (e.g. resource use, wastes generated) directly impact provision of ES by modifying ecosystems	4.13	0.26
Decisions that alter ecosystem are individual, institutional, and economic	4.24	0.2
Modifying ecosystems to increase one ES tradeoff to loss of others	4.38	0.15
ES can emerge from modified ecosystems by restoring ecosystem structure.	3.94	0.15
Small actions like changes in consumer behavior have significant changes to local ES and those experienced by other distant human populations	4.56	0.11

Table 4
Components of Definition of Ecosystem Services

Sentence 1 Components	Average Rating	Standard Error
Tangible and intangible	3.4	0.28
Functioning ecosystems	3.6	0.38
Native or modified	3.7	0.28
Human benefits	4.4	0.25
Connected to ecosystem functioning	3	0.35
Sentences 2 Components		
Uncertainty of ES array size and mechanisms of action	3.4	0.3
Sentence 3 Components		
Extracted as goods	3.44	0.28
Traded on markets	3	0.28
Non-market services	3.1	0.35
Active & passive	3.2	0.3
Human activity alters services	3.8	0.3
Sentence 4 Components		
Limited flow	3.7	0.25
Dynamic flow	3.4	0.38
Sentence 5 Components		
Incentive to conserve	3.7	0.3

Chapter 3: Engaging with ecosystem services for everyday environmental decisions: A Delphi Study

Abstract

Human beings depend on a set of benefits derived from environmental systems, termed Ecosystem Services (ES), and make decisions in everyday life that affect these ES. Recent advancements in the scientific understanding of ES have helped researchers articulate claims about the important role that functioning ecosystems play in human well-being. These claims provide decision-makers with a large and complex set of tradeoffs to consider. Using a Delphi technique, involving repeated survey of a panel of experts on ES, this study developed a list of (a) everyday decisions that are opportunities for citizens to engage with ES, (b) key questions (specific to these decisions) that citizens can ask related to ES, and (c) inquiring practices that citizens can use to find answers to these questions. Alternative conceptions that may impede citizens' use of these questions and inquiring practices are also discussed, as well as implications for other domains of science and for education.

Keywords: ecosystems, ecology, economics, scientific literacy, environmental education, standards, environment, ecosystem services (ES), Delphi study

Introduction

Humans, over the last century, have brought about a variety of environmental problems including climate change, resource depletion, biodiversity loss, and habitat destruction, among others. Combating these problems requires a citizenry capable of identifying when everyday decisions may have environmental consequences and then engaging with relevant scientific knowledge when making such decisions (Anderson, 2010; Tsurusaki & Anderson, 2010). Making decisions involves using knowledge and values that extend beyond science and may include ethics, justice, financial considerations, and politics, among others. Though these other dimensions of knowledge and values are important contributors to decision-making, in this paper, we are concerned only with the science that can inform decisions related to coupled human-environment systems (Anderson, 2007).

Coupled human-environment systems are connections between human socio-economic systems and environmental systems and specifically include (a) human impacts to environmental systems, and (b) the flow of *ecosystem services* to humans (Anderson, 2007). Ecosystem Services (hereinafter ES) are an array of benefits that humans experience as a result of living within functioning ecosystems, both native and modified (Authors, 2014), (Figure 1). These ES are extensive and include, mitigating the severity of natural disturbances (e.g. floods, hurricanes), regulating the atmosphere and climate, and supporting the functioning of ecosystems necessary for continued provisioning of goods (e.g. food, clean water), among others (Costanza, et al., 1997). ES are essential for human well-being, and the continued provisioning of ES hinges on the presence of functioning ecosystems globally (MA, 2005). Unfortunately, there has been a reduction in the functioning of ecosystems that contribute to ES (MA, 2005). These reductions are not often driven by single actors or single decisions, but are a product of the collective decisions of individuals and social institutions. For example, farmers living along the banks of the Mississippi River, as well as local governments, have built levees that have altered vast areas of floodplain ecosystems. Floodplains historically absorbed water in heavy rain events and slowed water flow downstream. Constructing levees provides farmers and river-side towns with less frequent local flooding, but these levees have also had numerous effects downstream including:

- greater incidence of downstream flooding (Poff, et al. 1997),
- lower rate of nutrient cycling that can increase nutrient concentrations to toxic levels (Gergerl, Carpenter, & Stanley, 2005), which can result in fishery losses downstream,
- reduced siltation rate at the Mouth of the river, necessary for maintaining coastal wetlands (Templet & Meyer-Arendt ,1988), which are integral to sustaining fisheries (Boesch & Turner, 1984) and protecting coastal cities from tropical weather.

It is clear that simple actions, such as constructing levees, can have long-reaching effects on entire watersheds. This underscores the importance of recognizing tradeoffs of altering ecosystems to prioritize specific ES.

Articulating potential impacts of altering ecosystems and how they can be integrated into human decision-making is a principle target for scientists who study ES. Guo, Xiao, and Lee (2000), for example, used an ES-based analysis of the Yangtze River watershed in China to convince a hydroelectric utility company that it would be financially beneficial to purchase conservation easements that would protect these forested hillsides from logging. They noted that if logging continued at its current rate, future decreases in forested area would lead to larger variations in flows through the hydroelectric plant. At times, the water flows would be so low that the power company would not be able to generate the needed electricity. Guo and his team concluded that it was financially beneficial for the power company to purchase conservation easements protecting the forests and their ES.

Integrating ecosystem services into everyday decision-making

When making everyday decisions, citizens rarely involve themselves in the rigorous, empirical procedures of creating new scientific evidence (Feinstein, 2014). Rather, when citizens face decisions related to ES, and other human-environment systems, they can engage in two “citizenship practices” that guide their decision-making: (a) *developing accounts of scientific phenomena relevant to a decision* and (b) *inquiring to test and expand their understanding of science that can inform a decision* (Mohan, Chen, & Anderson, 2009). In earlier research, we focused on the first citizenship practice, identifying conceptual, scientific *accounts* that citizens should be able to construct about ES (Authors, 2015). Here, we focus on the second citizenship practice: identifying how citizens should *inquire* about ES related to a decision at hand.

We argue that when inquiring about ES related to a decision, citizens need to know (a) that a decision merits inquiring about ES, (b) specific C*itizen-Inquiring Questions* to ask, and (c) *Citizen-Inquiring Practices* that can be used to find *sources of scientific expertise* about ES and potential answers to those questions. We will henceforth refer to this set of knowledge as *ES-specific Citizen-Inquiring Knowledge*

(ES-CIK). This ES-CIK is a quality of knowledge about ES that can help a citizen find and comprehend relevant scientific resources. We base this concept of ES-CIK on what Feinstein (2010) calls *competent outsiders*: "people who have learned to recognize the moments when science has some bearing on their needs and interests and to interact with sources of scientific expertise in ways that help them achieve their own goals" (Feinstein, 2011, p. 13). Competent outsiders iteratively question and find scientific resources as they weave together a sophisticated understanding of a system and connect science to their everyday decisions (Feinstein, 2014).

Goals and Research Questions

In this study, we provide an analysis of academic expert opinion about the ES-CIK that citizens should know in order to integrate ES into their everyday decision-making. As applied scientists who work to connect ES into decision-making, these scientists may often consider the role that ES play in decisions outside of their specific research, including everyday decisions. This makes academic experts on ES, a group particularly well suited to offer answers to the following research questions:

1) What kinds of everyday decisions are opportunities for citizens to engage with science resources involving ES?
2) If citizens are inquiring about ES related to a specific decision, what key questions are important to ask?
3) What inquiring practices can citizens employ to find scientific resources that can address their questions?

The answers provided in this paper provide targets of learning based on the views of academic experts on ES. The instantiation of this ES-CIK for decision-making may be hindered by prior conceptions that citizens might have about the environment. Therefore, to illustrate the potential importance of these alternative conceptions as well as the need for further research in this domain, we characterize select conceptions in the discussion of this study.

Theoretical Framework

In the introduction, we presented a construct that we call Ecosystem Services-specific Citizen-Inquiring Knowledge (ES-CIK). ES-CIK guides citizen-inquiry related to decision-making that can involve Ecosystem Services (ES). Though articulated as a construct specific to ES, relating it to research on authentic public engagement with science in other domains can increase the generalizability of the findings of this study. We focus on each dimension of the ES-CIK framework in turn: (a) Citizen-Inquiring Questions, and (b) Citizen-Inquiring Practices for finding scientific resources.

Citizen-Inquiring Questions

Citizens infrequently ask questions associated with gaining a better understanding of detailed causal mechanisms, like understanding the underlying molecular genetics of Down’s Syndrome (Layton, Jenkins, Macgill, & Davey, 1993). Rather, citizens commonly focus on questions such as *what is normal? How do I treat or fix this? What are the risks of different treatments? How do I know if this treatment is working as it should?* (Feinstein, 2014; Layton, et al., 1993). The questions here, specifically focus on health sciences, but can be generalized to a set of general *Citizen-Inquiring Questions* (henceforth CIQ) that are applicable to multiple domains. Identifying CIQs, therefore requires looking at the questions citizens ask when engaging with science from different domains.

We articulate five domain-general CIQs using the results described in two influential studies on Public Engagement with Science; one study in the health sciences (Feinstein, 2014) and one in the environmental sciences (Roth & Lee, 2002). These CIQs include:

1) What system or phenomenon are we inquiring about?
2) What is considered normal/healthy for the system or phenomenon of interest?
3) What are potential impacts that can change the system or phenomenon of interest?
4) Are any data available monitoring indicators (e.g. symptoms, water quality) that can be used to determine if these potential impacts indeed have effects on the system or phenomenon of interest?
5) What information, if any, is available about the limits of a system's ability to withstand an impact factor without repercussion?

We developed these CIQs by drawing comparisons between the inquiring questions in the qualitative data presented from both studies: Feinstein's study about how parents of children with autism inquire about science (Feinstein, 2014), and Roth and Lee's Study about how a community inquired about science when making decisions about how to restore a stream so that it can provide better trout habitat (Table 1). Table 1 depicts the CIQs above and exemplar questions obtained from the results sections of these studies from which these questions were developed. We used CIQs as a guide to articulate ES-specific citizen-inquiring questions specific to different decisions involving ES.

Citizen-Inquiring Practices

When citizens search for answers to their questions, they primarily use near-science resources (Feinstein, 2014). Near-Science Resources include science teachers, doctors, and environmental educators, among others who are “near the social world of science without belonging to it” as well as science websites, news reports, and popular science magazines, which are written by people near the social world of science (Feinstein, 2014, p. 7). Thus, citizen-inquiring practices involve finding answers to questions using existing science and near-science resources. This is in contrast to ES *Academic Practices*: those practices used by academic scientists to answer novel empirical questions. Academic practices involve finding and evaluating existing scientific resources (e.g. peer reviewed literature) as well as synthesizing new resources (e.g. through data collection, model development, etc.) that can be used to inform business and policy decisions involving ES. Though differing in the types of resources used (i.e. science resources vs. primarily near science resources), a central aim of both ES Citizen and Academic Practices is *finding resources to inform a decision*.

Near-science resources rely upon the information emerging from academic practices; therefore, near-science resources can only provide information that academic practices are empirically capable of producing. Therefore, it is important to characterize the types of resources developed by valid academic practices seeking to inform decisions involving ES. It is then possible to articulate candidate Citizen-Inquiring Practices that citizens can use to find such valid resources.

When developing Citizen-Inquiring Practices, it is important to keep in mind that not all science resources from academic practices can be fruitful for communicating the role of ES in everyday environmental decisions (Feinstein, 2011; Roth & Lee, 2004). Research, therefore, should identify *candidate* Citizen-Inquiring Practices that have a logical connection to the Citizen-Inquiring Questions that we articulated in the previous section (Table 1). We call these Citizen-Inquiring Practices *candidates* because there are a number of limitations associated with transcribing Academic-Inquiring Practices into Citizen-Inquiring Practices. For example, using a consensus of academic experts as a source of data may be logically valid (Feinstein, 2011), but may not reflect the science actually used in everyday life (Feinstein, 2011; Layton et al., 1993; Roth & Lee, 2004). That being said, characterizing academic practices can help articulate what to look for when studying authentic engagement with science.

Methods

The study described in this paper used a Delphi method, which is an empirical approach to establishing a consensus among experts for a variety of aims such as articulating higher education curricula, identifying central ideas about the Nature of Science, and building forecasting methods to inform business decision-making (Osborne, et al., 2003; Murray & Hammons, 1995; Basu & Schroeder, 1977). The Delphi method consists of repeat survey and comment on a set of questions by a panel of experts in a given domain until a consensus is reached (Dalkey & Helmer, 1962, 1963).

The members of a Delphi panel participate anonymously without face-to-face interaction that can otherwise result in deferment to domineering group members, tangential thinking, and band-wagonning (Martorella, 1991; Murray & Hammons, 1995). The Delphi method rests on two assumptions: (a) a group consensus provides a more valid decision than that made by a single person and (b) numerous problems can arise when experts meet face-to-face, some of which are mentioned above (Murray & Hammons, 1995). The following sections outline (a) the panel of experts that contributed responses during this Delphi study and (b) the structure of the surveys used to provide answers to the research questions.

Delphi Panel

Selecting a panel of experts is an important part in the process of conducting a Delphi study, and this requires defining expertise. In their Delphi study of core ideas about the *nature of science*, Osborne and others (2003) defined experts in science practices as those individuals "with acknowledged expertise in communicating, using, or researching the processes and practices of science" (Osborne, et al., 2003, p. 698). For this study, we define experts as *academics who focus on improving ecological and economic knowledge about coupled human-environment systems or who seek to improve science education related to these relationships*.

The size of a Delphi panel typically varies between 10-30 members (Brooks, 1979; Delbecq, Van de Ven, & Gustafson, 1975; Cochran, 1983; Parenté & Anderson-Parenté, 1987). As panel size increases, the reliability increases and error reduces; however, Delbecq (1975) and Brooks (1979) found that little improvement in results is seen once group size exceeds 25 – 30 participants. For the study described in this paper, 46 experts provided input in at least one of four surveys (see specific academic expertise in Table 2). To reduce problems traditionally encountered with Delphi studies including attrition and difficulty finding participants (Osborne, et al., 2003), we invited a large pool of ES experts to provide input at any time during the iterative process. This afforded maintaining a larger panel size in each round of survey and perform more iterations of survey than might have been possible with a single, smaller panel of experts. Following an initial survey of five experts on ES, each remaining round of survey consistently had a participation level that is known to provide reliable data for a Delphi Study: greater than 13 individuals (Cochran, 1983). A total of two experts participated in all four surveys, one participated in three surveys, and seven participated in two surveys.

Data Collection and Analysis

Delphi studies often begin with a set of open-ended questions from which the researcher articulates a set of ideas representative of participant responses (Murry & Hammons, 1995; Osborne, et al., 2003). Once this initial set of ideas is articulated, Delphi researchers proceed through an iterative process of data collection and analysis to refine this set of ideas. This involves asking members of the Delphi Panel to repeatedly rate and comment on the evolving set of ideas until a stable consensus is achieved. Brooks described a consensus as "a gathering of individual evaluations around a median response, with minimal divergence" and that little, if any, further shifting of positions will occur (Brooks, 1979, p. 378). For this study, we defined a stable consensus as achieved, when there is a high rating of importance for a given idea or aim with a low standard error. When a stable consensus is achieved, the Delphi process is complete (Brooks, 1979).

When using a Delphi method, data collection is based upon data analysis; therefore, in the next sections of this paper, we simultaneously discuss the survey format with data analysis and findings. We break this discussion into two sections. First, we describe methods for obtaining data for the first research question: What kinds of *everyday decisions* are opportunities for citizens to engage with evidence about ES? The second section is aimed at the second research aim: identifying the *ES-specific Citizen-Inquiring Knowledge* (ES-CIK) that can guide citizens as they inquire about the role that ES might play in everyday decision-making.

Everyday decisions that are opportunities to engage with ES

We began with an initial survey of five experts on ES in which we asked the question: *If a citizen is interested in promoting the sustainable management of ecosystem services, what are opportunities to take action*? Many of the opportunities mentioned by the experts, involved decisions. We identified 20 candidate decisions following this round of survey (see Table 3 for an outline of data collection and analysis).

With a list of 20 candidate decisions articulated, the aim of the second survey was to reduce the number of decisions on this list and better articulate those decisions most closely related to ES. Twenty-three experts on ES provided suggestions including merging some candidate decisions, that were really the same idea, and to remove other candidate decisions, that were not directly connected to ES. Before eliminating or merging decisions, we contacted participants who had initially articulated the decision. We asked them to respond to the critique of their claim. If they agreed with the critique, the candidate decision that they proposed was removed or integrated into others. After this process, 15 candidate decisions remained.

During the next round of survey, 18 participants rated each of these 15 candidate decisions on a five-point Likert scale (1-unimportant, 3-important, 5-essential). This final survey also contained open comment boxes for each decision and for the list as a whole. Participants were asked to recommend any decisions that they felt were absent as well as comment on the wording of any specific decision.

A total of seven decisions were rated as important or higher by at least 75% of the participants surveyed. These seven decisions also had an average rating of important or higher including standard error, fulfilling the requirement for “minimal divergence” (Brooks, 1979). We provide these seven decisions in Table 5.

Ecosystem Services-Specific Citizen-Inquiring Knowledge

One of the goals for this study was to characterize *Ecosystem Services-specific Citizen-Inquiring Knowledge* (ES-CIK). As we articulated earlier, a core component of ES-CIK are the *Citizen-Inquiring Practices* that citizens can use to find near science and science resources about ES. In order to identify these Citizen-Inquiring Practices, we first built a model of key Academic Practices that scientists use to find and synthesize evidence that can inform decisions involving ES using survey of the Delphi Panel. We specifically asked expert to respond to the prompt: *Any good explanation that involves ecosystems services should use the following evidence to support that explanation.* Using a propositional analysis (Frederiksen, 1975; Kintsch & van Dijk, 1978), we identified three types of evidence from survey responses: (a) case studies detailing conditions of a specific location, (b) data for indicators of ES over time (e.g. changes in water quality over time), and (c) output of socio-ecological models that can be used to predict ecosystem dynamics and changes in ES.

We next analyzed 50 peer-reviewed articles from journals that are common outlets for publications on ES (listed in Table 2) in order to identify Academic Science Practices used to synthesize these different types of evidence. Using a literature review to supplement the first round of a Delphi Study is common practice (Murry & Hammons, 1995). We selected journal articles in order to capture examples of research practices that generated each of the evidence-types described above. The articles that we selected had research aims such as (a) identifying the value of specific services like water flow regulation (Guo, Xiao & Li, 2000), (b) preserving biodiversity through ecosystem service mapping (Chan, et al., 2006), and (c) identifying impacts of large-scaled phenomena, like climate change, on ecosystem services (Brown & Ulgiati, 1999, Feagin, Martinez, Gonzalez, & Costanza, 2010). We selected both highly cited articles (in the hundreds, thousands, and even some in the tens of thousands) and less cited articles (in the tens) in an attempt to sufficiently capture a wide array of inquiring practices. Fifty articles offered a large enough sample, with few new scientific practices appearing after approximately 30 articles.

Eight Academic Practices emerged from the literature review, which we sought to connect to the Citizen-Inquiring Questions (CIQs) that we identified in Table 1. To help make these connections, we used a survey of the Delphi panel seeking to find those practices that experts believed all citizens should be able to do and what types of information they should look for when engaging in these practices. This survey instrument had two parts. The first part provided the panel with the academic practices, instructing participants to, *rate the importance of citizens being able to engage in this practice when making everyday decisions that impact ES*. This rating was on a five-point Likert scale (1-unimportant to 5-essential) with 3 indicating important. Participants were informed that any practice with an average rating of three or higher including standard error would be included. We used this part of the survey to identify those Academic Practices that could most clearly inform the citizen-inquiring questions and decisions involving ES (Table 4).

The second part of the survey contained a series of "boundary statements" including lists of conceptual considerations that might be important for citizens when engaging in a citizen-inquiring practice. We asked the Delphi Panel to rate the sophistication of each boundary statement and used the outcome of this rating to adapt the academic practice to a form that can more clearly inform Citizen-Inquiring Questions and everyday decisions involving ES. For example, for the last practice in Table 4, *identifying levels of flows that a specific ecosystem can sustain without affecting its resilience*, one of the boundary statements was, *citizens should find information in relation to the size of ecosystems and their ability to handle impacts.* This information was included in the Citizen-Inquiring Practice as important qualifier information that citizens should seek out when engaging in this practice.

Results

At the conclusion of this Delphi Study, seven decisions were rated as important opportunities to engage with ES by at least 75% of the experts surveyed. We provide these seven decisions in Table 5 with the corresponding percent of the Delphi Panel rating the decision as important or higher. Table 5 also contains five essential inquiring questions for each decision based upon one of general ES questions including:

1) What type of ecosystem are we inquiring about?
2) For the type of ecosystem of interest, what does a healthy, resilient ecosystem look like and what ES would such a healthy system provision?
3) What are potential impacts to the continued functioning of this ecosystem?

4) Is evidence available that has tracked changes in indicators of ecosystem functioning over time, suggesting that these impacts are indeed having an effect on ES?
5) What information, if any, is available about the limited rate at which an ecosystem can absorb or process an impact without repercussion?

These general ES questions were adapted from the General Citizen-Inquiring Questions listed in Table 1.

A total of six Academic Practices were also rated, as important, by the expert panel for adaptation to Citizen-Inquiring Practices. These include:

1) Identifying flows of materials or energy through ecosystems including human ecosystems,
2) Identifying indicators of ecosystem functioning or ES,
3) Testing the reliability of indicators to detect changes in ecosystem functioning and ES,
4) Identifying potential impacts to ecosystem functioning such as human wastes, land-use change, ecological dynamics, etc.,
5) Monitoring changes in ecosystem structure over time, and,
6) Identifying the components of wastes and their impact on components of ecosystems.

In Table 4, as described previously, we provide the adaptations of these Academic Practices organizing them by the Citizen-Inquiring Question that they most suitably inform. We next discuss how all of this information fits together using an instantiation of the first decision: consumer product choice.

Instantiation of the ES Citizen Inquiring Questions and Practices: An example of inquiring to make a decision about a proposed conservation easement

Public ballots fairly regularly contain yes/no votes on funding for conservation easements, and citizens interested in ES can participate in decision-making at the local level as decisions are made about where to allocate financial resources for these conservation easements. In this section, we provide a description of how citizens and communities can use the ES Citizen-Inquiring Questions and Practices to inform a decision about whether to move forward with a specific conservation easement. The example provided here is necessarily decontextualized, but is articulated with relevant hypothetical detail in order to clearly illustrate how one might instantiate the ES Citizen-Inquiring Questions and Practices. We discuss each ES Citizen-Inquiring Question and its associated Practices related to this decision in turn.

ES-CIQ1: What kind of ecosystems are in the policy boundaries and are downstream of the site?

In order to make any decisions, it is first important to identify the context. Answering the first Citizen-Inquiring Question (CIQ) gives perspective on the different types of ecosystems that might be considered for conservation and knowing all ecosystems is important because there are always limited funds available for conservation easements. For example, lets imagine a situation in which a citizen has joined a local conservation board in a town along the Appalachian Mountains of the United States. The conservation board is considering the most suitable location to spend money for conservation. If not already done, first this citizen can look at a map of the policy district and delineate different ecosystems in the policy boundaries. Next, the citizen can trace boundaries of watersheds in the policy district and also map out ecosystems downstream of the policy boundaries by tracing the flows of water (CIP1-1, Table 4).

ES-CIQ2: For the type of ecosystems in the political boundary, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision?

With all relevant ecosystem identified, the next step is to identify the ES associated with these ecosystems. Using an Internet search to identify ES provisioned by forests, one might find a new *EnviroAtlas* tool developed by the US Environmental Protection Agency (Pickard, et al., 2015). This web-interface provides detailed information about the ES that come from these different ecosystems. For example, healthy forests provision ES such as Clean Air, Aesthetics & Engagement with Nature, Water Hazard Mitigation, Recreation & Physical Activity, and Clean Water.

When seeking information for what a healthy ecosystem might look like (the second part of CIQ2, Table 5), a citizen can *find information that depicts indicators of ES* (CIP 3, Table 4). A web search for "indicators of healthy forests" returns work by the US Forest Service that provides multiple indicators of healthy forests such as, the presence of certain types of Lichens (an Algae, Fungi symbiont that grows on the surfaces of rocks, trees etc.). With a set of indicators of a healthy system identified, a citizen and fellow board members can go out into the ecosystems around town and assess the health of the ecosystems.

ES-CIQ3: What are potential impacts to the health of the ecosystems in the region?

When deciding on which locations may be best for conservation, it is also helpful to identify potential impacts to the health of that ecosystem. One way to do this is to characterize pollution sources, future land use around potential sites for conservation, and others. For pollution sources, it is also important to *identify the type of pollution and any toxicological effects that this pollution can have if emitted into different ecosystems* (CIP 3.2). Undergoing Citizen-Inquiring Practice 3.2 (Table 4) can help a conservation board consider more potential impacts and provide more information to consider when prioritizing different sites for conservation.

ES-CIQ4: Is there any evidence available documenting changes in indicators of ecosystem functioning over time for this local system (or similar systems) from which conclusions can be drawn about connections between land-use and ecosystem functioning?

With some indicators identified from earlier, the citizen can next *look for monitoring data for some of these indicators to assess the health of the mapped ecosystems* (CIP 4.1, Table 4). For example, the US Forest Service also offers a GIS (Geographic Information Site) that contains indicator data for various locations around the US, and the site of interest might be in the data set (NACSE, 2015). If no such data are available, the same US Forest Services site contains a guide that the conservation board can use to set up their own monitoring effort.

As an alternative, members of the conservation board might also *look for long-term data from similar ecosystems where connections have been linked to different human impacts such as land-use change* (CIP 4.2, Table 4). A web search for "indicators of forests degradation" returns PowerPoint slides by Haymell and colleagues (2011) in which they present indicators associated with productive functioning and forest degradation (Haymell, et al., 2011). Indicators of degradation associated with land-use include fragmentation of landscape, road density, and abundance of certain invasive species, among others. It is clear from this example that there are a lot of indicators that can be used to get a sense of the extent of impacts that might affect an ecosystem, and using these indicators, it is possible to draw inferences about the possible long-term health of the ecosystem without collecting long-term data.

ES-CIQ5: Is information available about a relationship between the size of a forest and its ability to maintain functioning and provide ES in spite of pollutants?

For some of the potential impacts identified, one can *search for information about the level of flows that a specific ecosystem can sustain without significantly affecting its resilience* (CIP 5.1, Table 4). Resilience is the capacity of the ecosystem to maintain functioning through reorganization and this continued functioning is important for the sustained provision of ES. For this, one might look for data connecting different amounts of a specific waste going into forests of different sizes and draw inferences about the specific limits of these ecosystems. For example, consider a situation in which one source pollutant in the forest is outflows from a sewage treatment plant. In its current state, there is enough forested and other downstream ecosystems that process the residual wastes and make it such that trout are able to live in the streams (a biodiversity ES), the presence of which is enjoyed by local fishers (a provisioning ES). Carrying out CIP 5.1, one might find data that tracked how reductions in the size of similar forested area led to reduced water quality, and the conservation board might use this as evidence to decide that a certain amount of land will be necessary to sustain the trout and water cleansing ES.

In summary, the Citizen-Inquiring Questions and Practices articulated in Tables 4 and 5 each, can inform prioritization of different areas for conservation, an authentic and difficult problem given a limited pot of funding. Going through this entire inquiring process is not easy, and the greater investment one has in achieving a more informed decision, the more likely they will carry out practices to answer each question.

Discussion

In this study, we articulated a set of Citizen-Inquiring Questions and Practices that can connect ES to everyday decisions in a way that can guide inquiry in everyday life. Based upon the views of the ES experts surveyed in this study, knowing the specific questions and practices articulated in this paper, which we have called *ES-specific Citizen-Inquiring Knowledge* (ES-CIK), may be an important component of scientific literacy. While we cannot state that this knowledge is necessary or sufficient for individuals engaging in authentic decision-making, we are arguing that the questions and practices articulated in this study provide clear connections between ES and everyday decisions. We have paid specific attention to the types of questions that citizens have been shown to ask (Feinstein, 2014; Layton, Jenkins, Macgill, & Davey, 1993; Roth & Lee, 2002) when developing this set of ES-specific Citizen-Inquiring Questions. This study has built upon this previous research to articulate questions and inquiries that citizens can use, and which are based upon the views of academic experts on ES, likely to yield fruitful scientific information to support everyday decisions involving ES.

When instantiating this ES-CIK in real life, difficulties may arise for a number of reasons such as (a) considering many tradeoffs in authentic situations yields an extensive set of scientific resources to consider, (b) the availability of near-science resources is relatively sparse in this domain, but growing, (c) interpreting this information in ways that align with scientific understandings of ES. As stated at the end of the introduction, alternative conceptions related to ES concepts may affect engagement. When investigating how parents of children with autism engaged with science, Feinstein (2014) found that some of these parents had conceptions of science that interfered with their engagement. Because of the importance that alternative conceptions of science might play in how citizens engage with science, we provide a few examples of those related to making decisions about ES. Articulating these alternative conceptions is important to developing appropriate scaffolds that can help learners productively engage with science when making decisions involving ES.

Potential Alternative Conceptions that might interfere with the Citizen-Inquiring Practices identified in this study

In the introduction, we noted that we would expand the discussion to include some key conjectures about ways in which alternative conceptions might interfere with the ES Citizen-Inquiring Practices (CIP) developed as a result of this study. This discussion can inform limitations of the CIP identified here as well as future directions for education research.

There are many alternative conceptions known about students' views of ecosystems that might be relevant to how citizens engage with science when making decisions involving ES. A full review of these conceptions is outside of the scope of this discussion. In the following, we focus on alternative conceptions associated with (a) ecological limits, as well as (b) change and stability. These are ideas situated within the citizen-inquiring practices associated with identifying potential impacts to ecosystems and ES and evaluating the importance of these potential impacts. Other alternative conceptions are also likely important such as conceptions of scale (Jones & Taylor, 2009;

Trettor, et al., 2006) and systems thinking (Grotzer & Bell-Basca, 2003; Hmelo-Silver, Maranthe, & Liu, 2007; Wikensy & Resnick, 1999) are some other relevant conceptions, to which we cite here as reference for the reader.

Alternative conceptions related to *limits* in ecosystems

Citizen-Inquiring Practice 5.1 in Table 4 requires that citizens identify the amount of an impact, such as the amount of a biodegradable waste that is being emitted into an ecosystem. Organisms in ecosystems can only metabolize a limited amount of these biodegradable wastes in a given amount of time. Anything beyond this rate can have significant impacts on ecosystem structure. In contrast to the scientific view, a common view of biodegradable wastes is that they are not pollution because they will break down (Brody, 1991). For example, Mohan and colleagues (2009) found that learners often describe matter as going into and out of existence and thus do not view ecosystems as having a limited amount of matter and energy. It would make sense under this conception of matter, that a biodegradable bag will essentially disappear once it is placed in ‘the environment’.

Another conception associated with *limits* is called the *dissipation effect* (White, 1997). This is the view that the further one gets from a location, the less the effect will be. This is not necessarily the case; many wastes are carried by water downstream where they converge with wastes from other locations. Thus, in reality, human wastes have “actions at a distance”. The importance of actions at a distance was highlighted in the example provided in the introduction to this paper (levees along the Mississippi River). Having strong views of dissipation can result in constrained, localized reasoning that omits the possibility of larger regional and global impacts and viewing science related to these impacts as a "hoax" (re: views of climate change research).

Alternative conceptions with regard to *change in ecosystem*s

Citizen-Inquiring Practice 4.1 in Table 4 requires that citizens find information about long term trajectories of change that might indicate a trend toward a new state of an ecosystem. Citizens may struggle with this practice if they have a common view that nature will always rebound. This view is based upon a few alternative conceptions. For example, the notion that nature exists in *balance* and that it will continue to do so without major human destruction (Sander, Jelemenská, & Kattman, 2006). Another conception is that ecosystems are *centrally organized and controlled* (Jacobson & Wilensky, 2006) such that a *vital force or agent* prevents the collapse of an ecosystem (Inagaki & Hitano, 2006). Hovardas and Korfiatis (2010) argue that an outcome of viewing ecosystems as balanced or centrally controlled is attempting to keep ecosystems stable rather than allowing them to reorganize to fit the changing circumstances around them. If decisions are made that restrict an ecosystems ability to change, it is possible to push ecosystems into alternative states that may yield significant changes to the ES provisioned in these systems (Walker & Salt, 2006; Holling, 2010).

Summary and Implications

The benefits of integrating Ecosystem Services into environmental decision-making cannot be understated. Many of the environmental calamities humans face today (e.g. water quality problems, biodiversity loss, etc.) are a result of misunderstanding coupled human-environment systems. Though ES scientists have struggled to articulate ES in a way that can be applied to decision-making (WRI, 2011; Fisher, Turner, &

Morling, 2008), we have made use of their expertise on ES, in concert with education theory, to construct a framework for such integration which we call Ecosystem Services-Specific Citizen Inquiring Knowledge (ES-CIK). This framework aligns with prior research on citizen engagement with science (Feinstein, 2014) and captures the resources that experts in this domain believe citizens should be able to interact with. We have highlighted some potential barriers to this interaction: alternative conceptions. It is important to identify other alternative conceptions that might be associated with central ideas about ES (Table1), (Authors, 2015) and might interfere with the ES Citizen-Inquiring Practices.

The ES-CIK presented in this paper adapts the scientific practices described in the NRC Framework to citizenship-practices specific to the domain of ES. This domain-specific and citizen-specific adaptation is important in light of prevailing evidence that domain-specific knowledge plays an important role in scientific practices (McNeil & Krajcik, 2009; Muis, Bendixen, & Haerle, 2006; NRC, 2012; Penner & Klahr, 1996; Sandoval & Millwood, 2005). This adaptation is also important in light of evidence that citizens engage with science in different ways than do experts (Layton, Jenkins, MacGill, & Davey, 1993; Feinstein, 2014). Future research on the “useful” dimension of scientific literacy should develop adaptations of practices for multiple domains and refine these practices over time as more becomes known about citizens’ use of these practices when engaging with science to solve meaningful problems and make informed decisions.

The findings of this study, while not yet verified by research on authentic engagement with science when making decisions involving ES, are a step toward a science curriculum that is more integrated with use of science in everyday life and one that may help promote engagement with ES later in life. As articulated, the Citizen-Inquiring Questions and Practices that we developed here can be useful classroom activities for teaching about ES. For example, learners can be asked to investigate answers to the Citizen-Inquiring Questions (CIQ) in relation to authentic environmental problems in their local town. Classroom activities can scaffold their use of Citizen-Inquiring Practices associated with each CIQ keeping in mind alternative conceptions associated with limits and change.

Limitations

This study used the opinions of academic experts on ES to identify the types of questions and practices that citizens can use to integrate ES into everyday decision-making. As we articulated in the introduction and theoretical framework, these are logical arguments based upon the reasoned judgment of experts, not empirical findings on actual citizen engagement with science. Further research is necessary to empirically determine if, in fact, citizens in authentic circumstances use the ES-CIK that we have identified.

It is also important to highlight that in order to maintain participation levels conducive to reliable data in this study, we strayed from the normative Delphi approach allowing any recruited expert on ES to participate in any round of study that they could. Attrition and participant fatigue is a common issue in Delphi Studies (Osborne, et al., 2003) and we sought to avoid this problem. We argue, that this modification does not impact the quality of the findings of this study because all participants were experts in ES and, in fact, 46 experts provided input at some point, which adds confidence to the claims that we have made here. While we acknowledge these limitations, we believe that the work presented here provides a relatively concise model that can guide engagement with science when making decisions involving ES, a model that we argue can lead citizens to key science resources that can inform their decision-making.

References

Anderson, C.W. (2007). Environmental literacy learning progressions. Paper presented at the Knowledge Sharing Institute of the Center for Curriculum Studies in Science, Washington, D.C., July 22-25, 2007.

Anderson, C.W. (2010). Learning progressions for environmental science literacy. Paper presented to the NRC National Standards Framework Committee, March, 2010.

Basu, S., & Schroder, RG. (1977). Incorporating judgments in sales forecasts: application of the Delphi Method at American Hoist & Derrick. Interfaces, 7(3), 18-27.

Boesch, D.F., & Turner, R.E. (1984). Dependency of fishery species on salt marshes: the role of food and refuge. Estuaries, 7, 460-468.

Brody, M.J. (1991). Understanding of pollution among 4th, 8th, and 11th grade students. Journal of Environmental Education, 22, 24-33

Brooks, K. W. (1979). Delphi technique: expanding applications. North Central Association Quarterly, 53, 377-385.

Brown, M.T., & Ulgiati, S. (1999). Emergy evaluation of the biosphere and natural capital. AMBIO, 28, 486-493.

Chan, K.M.A., Shaw, M.R., Cameroon, D.R., Underwood, E.C., & Daily, G.C. (2006). Conservation planning for ecosystem services. PLOS Biology, 4, 2138-2152.

Cochran, S.W. (1983). The Delphi method: Formulating and refining group judgments. Journal of the Human Sciences, 2, 111–117.

Costanza, R., d'Arge, R., Groot, R.d., Farber, S., Grasso, M.,Hannon, B. et al.. (1997). The value of the world's ecosystem services and natural capital. Nature, 387, 253–260.

Dalkey, N., & Helmer, O. (1962). An experimental application of the Delphi method to the use of experts. Management Science, 9, 458-467.

Delbecq, A.L., Van de Ven, A.H., & Gustafson, D.H. (1975). Group techniques for program planning. Glenview, IL: Scott Forman.

Feagin, R.A., Martinez, M.L., Mendoza-Gonzales, G., & Costanza, R. (2010). Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. Ecology and Society, 15, 14[online].

Feinstein, N. (2014). Making sense of autism: progressive engagement with science among parents of young, recently diagnosed autistic children. Public Understanding of Science, 23, 592-609.

Feinstein, N. (2010). Salvaging scientific literacy. Science Education, 95, 168-185.

Fisher, B., Turner, R.K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics, 68, 643-653.

Frederiksen, C. H. (1975). Representing logical and semantic structure of knowledge acquired from discourse. Cognitive Psychology, 7, 371-458.

Gergerl, S.E., Carpenter, S.R, & Stanley, E.H. (2005). Do dams and levees impact nitrogen cycling? Simulating the effect of flood alterations on floodplain denitrification. Global Change Biology, 11, 1352-1367.

Grotzer, T.A., Bell-Basca, B. (2003). How does grasping the underlying causal structures of ecosystems impact students' understanding? Journal of Biology Education, 38, 16-29.

Guo, Z., Xiao, X., & Li, D. (2000). An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecological Applications, 10, 925-936.

Haymell, V., Thompson, I., Loyche-Wilkie, M., Kleine, M., Okabe, K., Nasi, R., Maginnis, S., Guaraguata, M., & Kapos, V. (2011). Forest degradation and proposed indicators. Paper presented at the Collaborative Partnership on Forests Conference, Tokyo, Japan, March, 2011

Hmelo-Silver, C.E., Maranthe, S., Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: expert-novice understandings of complex systems. Journal of the Learning Sciences, 16, 307-331.

Holling, C.W. (2010). Engineering Resilience of Terrestrial Ecosystems. In: Gunderson, L. H., Allen, C.R., and Holling, C.S (Eds.), Foundations of Ecological Resilience, (pp. 51-66). Washington, DC: Island Press

Hovardas, T. & Korfiatis, K. (2010). Towards a critical re-appraisal of ecology education: scheduling an educational intervention to revisit the 'balance of nature' metaphor. Science and Education, Online First™, 30 November 2010.

Hug, J. (1977). Two hats. In J.L. Aldrich & A.A. George (Eds.), The report of the North American Regional Seminar on Environmental Education for the Real World (p. 73). Columbus, OH: SMEAC Information Reference Center.

Hungerford, H.R. (2010). Environmental Education (EE) for the 21st Century: Where Have We Been? Where Are We Now? Where Are We Headed? Journal of Environmental Education, 41, 1-6.

Inagaki, K., & Hatano, G. (2006). Young children's conception of the biological world. Current Directions in Psychological Science, 15, 177–181.

Jacobson, M.J. & Wilensky, U. (2006). Complex systems in education: scientific and educational importance and implications for the learning sciences. Journal of the Learning Sciences, 15, 11-34.

Jones, G.M., Taylor, A.R. (2009). Developing a sense of scale: looking backward. Journal of Research in Science Teaching, 46, 460-475.

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. Psychological Review, 85(5), 363-394.

Layton D, Jenkins E, Macgill S and Davey A (1993) Inarticulate Science? Perspectives on the Public Understanding of Science and Some Implications for Science Education. Driffield: Studies in Education.

Martorella, P. (1991). Consensus building among social educators: a Delphi study. Theory and Research in Social Education, 19, 83–94.

[MA] Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis, Washington, DC: Island Press.

McNeil, K.L., Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena. Journal of the Learning Sciences, 18, 416-460.

Mohan, L., Chen, J., & Anderson, C.W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46, 675-698.

Muis, K.R., Bendixen, L.D., Haerle, F.C. (2006). Domain-generality and domain-specificity in personal epistemology research: philosophical and empirical reflections in the development of a theoretical framework. Educational Psychology Review, 18, 3-54.

Murry, J.W. Jr. & Hammons, J.O. (1995). Delphi: A versatile methodology for conducting qualitative research. Review of Higher Education, 18, 423–436.

[NACSE] Northwest Alliance for Computational Science & Engineering (2015). Retrieved from http://gis.nacse.org/lichenair/

[NRC] National Research Council (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea. Washington, DC: National Academies Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschle, R. (2003). What "ideas-about-science" should be taught in school science? A delphi study of the expert community. Journal of Research in Science Teaching, 40, 692-720.

Parenté, F.J., & Anderson-Parenté, J. (1987). Delphi inquiry systems. In G Wight & P Ayton (Eds.) Judgmental Forecasting (129-156). New York: John Wiley & Sons.

Penner, D.E., Klahr, D. (1996). The interaction of domain-specific knowledge and domain-general discovery strategies: a study with sinking objects. Child Development, 67, 2709-2727.

Pickard, B.R., Daniel, J., Mehaffey, M., Jackson, L.E., Neale, A. (2015). EnviroAtlas: a new geospatial tool to foster ecosystem services science and resource management. Ecosystem Services, 14, 45-55.

Poff, N.L., Allan, D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., & Stromberg, J.C. (1997). The natural flow regime. BioScience, 47, 769-784.

Roth, W-M. & Lee, S. (2002). Scientific literacy as collective praxis. Public Engagement with Science, 11, 33-56.

Roth, W-M. & Lee, S. (2004). Rethinking Scientific Literacy. New York: Routledge Falmer.

Ruppert, J. R. & Duncan, R.G. (2014). Defining and Identifying Disciplinary Core Ideas about Ecosystem Services using a Delphi Study. Paper to be presented at the International Conference for the National Association for Research in Science Teaching, Pittsburg, PA, March 30-April 2, 2014.

Sander, E., Jelemenská, P., & Kattmann, U. (2006). Towards a better understanding of ecology. Journal of Biology Education, 40, 119-123.

Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations. Cognition and Instruction, 23, 23-55.

Templet, P.H. & Arendt, K.J.M. (1988). Louisiana wetland loss: a regional water management approach to the problem. Environmental Management, 12, 181-192.

Tsurusaki, B.K., & Anderson, C.W. (2010). Students' understanding of connections between human engineered and natural environmental systems. International Journal of Environmental Education, 5, 407-433.

Walker, B. & Salt, D. (2006). Resilience Thinking: Sustaining Ecosystems and People in a Changing World, Washington, DC: Island Press.

White, P.A. (1997). Naïve ecology: causal judgments about simple ecosystems. British Journal of Psychology, 88, 219-233.

[WRI] World Resource Institute. (2012). Available online http://docs.wri.org/share/eiasurvey/survey_summary.pdf

Definition and Big Ideas about Ecosystem Services as articulated by Authors, 2015

Ecosystem Services (ES) are a vast array of direct and indirect, market and non-market, as well as perceived and intangible benefits that humans gain as a result of being connected to functioning ecosystems, native or modified. We can articulate some specific ES, but the total number of benefits gained from functioning ecosystems is beyond human comprehension; therefore, any accounting system developed to include ES will *not* include them all. Some ES result in resources that can be actively extracted as goods and traded, while others require no human effort to obtain and human activity alters the provisioning of these different ES by changing ecosystem structure. The ES that provision resources do so at a limited rate that changes depending upon the flow of matter and energy to that extractable resource, the rate of which is dynamic. Including ES in decision-making can provide incentives to conserve native ecosystems or restore functioning to ecosystems.

Big Idea 1*:* Humans are embedded within ecosystems and benefit from them in many, if not countless ways, directly and indirectly, actively and passively, and many of these benefits are not a part of traditional markets.

Big Idea 2: Ecosystems from which humans benefit have interactions at local, regional, and global scales that embed human populations in ecosystems close-by as well as far-away.

Big Idea 3: Ecosystems from which humans benefit can only process wastes and provision resources at limited rate. If humans extract resources or dump wastes at a rate that exceeds an ecosystem's capacity, that ecosystem will become over-exploited or polluted. This places constraint upon the human population.

Big Idea 4: Ecosystem functioning depends upon the flows of matter and energy through the system and this functioning is important for the provision of some Ecosystem Services, such as resource-provisioning and waste-processing services.

Big Idea 5: Ecosystems often change rapidly and unexpectedly as a result of thresholds and the breakdown of feedback loops, but resilient systems are less likely to reach a threshold.

Figure 1: Definition and Big Ideas about Ecosystem Services as articulated by Authors, 2015

Table 1
General and Domain-Specific Citizen-Inquiring Questions

		CIQ 1	CIQ 2	CIQ 3	CIQ 4	CIQ 5
General Citizen-Inquiring Questions		*What system or phenomenon are we inquiring about?*	*What is considered normal/healthy for the system or phenomenon of interest?*	*What are potential impacts that can change the system or phenomenon of interest?*	*Is any data available monitoring indicators that can be used to determine if these potential impacts indeed have effects on the system or phenomenon of interest?*	*What information, if any, is available about the limits of a system's ability to withstand respond to an impact factor without repercussion?*
Environment-Specific Questions	Examples from Roth and Lee (2002)	A group is interested in restoring a stream for trout habitat. During a discussion about the quality of the water in the stream, members of the group take an interest in the surrounding ecosystem. *What ecosystems surround the stream and what is unique about these systems?* (paraphrased from page 40)	As a group traverses they discuss what is normal for trout habitat. *What are normal oxygen levels for trout habitat? Could the trout spawn here?*(paraphrased from page 38-39)	Two individuals discuss why water quality goes up and down to identify potential impacts. *What are farmers doing that might be causing water quality in the stream to spike? (*paraphrased from page 40)	A group uses long-term data for one indicator, oxygen level, to try to piece meal which of the identified impacts to trout habitat seem to be most important. *Are the oxygen levels better or worse in any area, particularly after different farms? (*paraphrased from page 39)	A group discusses the limits to changes in oxygen levels before it affects trout ability to use area as habitat. They find during their investigation that the trout are pretty resilient *Even though oxygen levels are real low her, are there still fish there?* (paraphrased from page 39)
Health-Specific Questions	Examples from Feinstein (2014)	A parent notices a behavior, that her child writes her name backward and asks: *"Is this dyslexia?* (paraphrased from page 599)	For another parent that notices her child being aggressive toward his sister asks if the behavior is normal. *"Is this aggressive behavior normal for children with ASDs?"* (pp. 602)	The parent seeks to identify a number of potential impacts that exacerbate the problem behavior. Are *there things in his life that may be impacting his behavior?* (paraphrased from page 602)	The parent seeks to monitor potential impacts over time to see if they appear to be valid impacts. *Are there variations in his schedule? "I'm trying to find out how I can narrow it down"* (pp. 602).	The parent seeks to know if son's medications are too high and having indirect impacts. *Are particular aspects of Alex's treatment regime exacerbating his behavior.* (paraphrased from page 602)

Table 2
Delphi Panel Participants by Disciplinary Expertise

Discipline of PhD Program	Number of Participants
Ecology	18
Education in the Environment	9
Economics	8
Agronomy	2
Environmental Science	2
Natural Resource Management	2
Remote Sensing and Landscape Ecology	2
Climate	1
Landscape Architecture	1
Urban Planning	1

Journals Used in Literature Review

Ecological Economics, Ecology, Frontiers in Ecology, Proceedings of the National Academy of Sciences, Ecology Letters, Science, Trends in Ecology and Evolution, Natural Resource Modeling, Ecological Indicators, AMBIO, PLOS Biology, Nature, Ecology & Society, Ecological Applications

Table 3

Structure of Delphi Study

Survey	Purpose of Round	Questions of Round	Outcome of Round	# of Participants
1	Open-ended questionnaire to identify potential ideas using a propositional analysis	1. If a citizen is interested in promoting the sustainable management of ecosystem services, what are opportunities to take action? 2. Any good explanation that involves ecosystems services should use the following resources to support that explanation.	20 Decisions 8 Citizen-Inquiring Practices	5
2	Provide non-quantitative arguments about draft list of decisions developed from responses to pilot survey.	Please add any decisions to this list that you feel are missing and also provide categories if you feel that some decisions can be grouped together.	15 Decisions	23 surveys completed 2 follow up conversations
3	Refine a list of Citizen-Inquiring Practices identified in literature review and pilot survey and obtain quantitative data about the degree of consensus around the importance of each.	1. Rate the importance of citizens being able to engage in this practice when making everyday decisions that impact ES. 2. Rank the boundary statement of expectation from insufficient to overly ambitious and unnecessary.	Consensus achieved in one round on seven Citizen-Inquiring Practices in survey. Two Citizen-Inquiring practices dropped, not being rated as important by more than 25% of participants. Post-hoc practice identified through personal communication with three of 21 participants in this round who felt strongly that we should consider both resource and waste flows in ecosystems.	21 surveys completed 3 follow-up conversations.
4	Refine list of everyday decisions and obtain quantitative data about the degree of consensus around the importance of each.	1. With what common decisions can citizens engage with science for ecosystem services?	7 Everyday Decisions (Table 5)	14 surveys completed

*Note: Review of decisions and survey of evidence-generating practices was split up among rounds of survey because each survey also contained questions for a larger study seeking to characterize information for the citizenship practice: explain ecological problem at hand in a way that compliments central ideas about ES. This information was published separately in Ruppert and colleagues (unpublished data).

Table 4
Sources of Evidence for Decisions Involving ES

Reliable Citizen-Inquiring Practices (CIP) and Questions (CIQ)		Percent of respondents selecting practice as important or higher
Ecosystem and Services-Identifying Inquiring Practices		
ES-CIQ 1: *What type of ecosystem are we inquiring about?*		
CIP 1.1	Trace the flows of matter and energy (e.g. water, wastes) through a region to identify ecosystems that are within the boundaries of the problem or decision at hand.	88%
ES-CIQ 2: *For the type of ecosystem of interest, what does a healthy, resilient ecosystem look like and what ES would such a healthy system provision?*		
CIP 2.1	Find information that depicts indicators of ES that allow citizen to identify what a healthy, resilient ecosystem looks like. There are many indicators and Biodiversity alone is insufficient. Other indicators might include vertical density, which is the amount of vertical space filled that will intercept rain and slow flows of water downstream (i.e. water flow regulation services).	94%
Impact-Identifying Inquiring Practices		
ES-CIQ 3: *What are potential impacts to the continued functioning of this ecosystem?*		
CIP 3.2	Identify components used either in manufacturing or delivery of products OR in one's individual or town's waste stream and toxicological effects that these components can have if emitted into ecosystems.	100%
ES-CIQ 4: *Is evidence available that has tracked changes in indicators over time, suggesting that these impacts are indeed having an effect on ES?*		
CIP 4.1	Begin a monitoring effort tracking *multiple* key indicators over time to determine if the health of the ecosystem(s) have changed.	94%
CIP 4.2	Find information amassed from long-term monitoring of ecosystem structure for a managed ecosystems. Make sure to consult any implications discussed in relation to, changes resulting from the extraction of resources, land-use change, and natural dynamics.	88%
ES-CIQ 5: *What information, if any, is available about the limited rate at which an ecosystem can absorb or process an impact without repercussion?*		
CIP 5.1	Identify high flow components in the ecosystem (e.g. biodegradable waste flows, water flows, etc.) and search for information about the level of flows that a specific ecosystem types can sustain without significantly affecting its resilience. This information will contain qualifiers that are important to consider (e.g. the size of the ecosystem, the health of the ecosystem, random and unaccounted variables, etc.)	88%

Table 5

Everyday Decisions that can be Informed by Ecosystem Services Science

Everyday Decision	**Percent of participants rating engagement with ES for decision as important or higher**	**Essential Citizen Inquiring Questions and Decision-Specific Notes**				
		Ecosystems and Services-Identifying Questions		***Impact-Identifying and Prioritizing Questions***		
		CIQ 1	CIQ 2	CIQ 3	CIQ 4	CIQ 5
		What type of ecosystem are we inquiring about?	*For the type of ecosystem of interest, what does a healthy, resilient ecosystem look like and what ES would such a healthy system provision?*	*What are potential impacts to the continued functioning of this ecosystem?*	*Is evidence available that has tracked changes in indicators over time, suggesting that these impacts are indeed having an effect on ES?*	*What information, if any, is available about the limited rate at which an ecosystem can absorb or process an impact without repercussion?*
Consumer Product Choice (Home maintenance and construction choice)	94%	What are the raw materials that are needed both to make goods and deliver them to consumers and from what ecosystems do the manufacturers of this product get them?	For the type of ecosystem of interest, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision?	In the manufacturing and delivery of these products, what are potential ways in which companies might impact healthy ecosystems, by either modifying them or emitting harmful wastes?	For the ecosystem identified as the source of raw materials, is there any data available about changes in key indicators of ES since the start of manufacturing?	Is any information available indicating that a waste is biodegradable, and if so does the company producing wastes make claims that it monitors the local ecosystem to ensure that it can handle the volume of wastes emitted?
Personal Waste Generation and Disposal (How much to buy, travel/transport decisions, etc.)	100%	Through what ecosystems do my wastes flow after I dispose of it down the drain, on the street, or in a refuse container?	For the type of ecosystem of interest, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision?	What are wastes that I generate *(e.g. Carbon Dioxide from manufacturing, electricity, & transportation; household chemical wastes; food; water; etc.)* and do any of these wastes pose a threat to ecosystem functioning?	For the ecosystems identified as the receivers of my wastes, is there any data available that has monitored key indicators over time in areas that receive the types of wastes that I generate? What else has been going on in these areas?	Is any information available about the rate at which these wastes can be metabolized in a system, and if so is my town/region as a whole releasing more wastes into local ecosystems than can be processed by them?

Choice of Living Location	94%	In what regional-level biome is the town located and what ecosystems are within town?	For the types of ecosystems and biome of interest, what does a healthy and resilient ecosystem look like and what ES would such healthy systems provision? Do the ecosystems and biome fit these characteristic indicators?	What is the status of land-use and zoning policy both locally and in the surrounding watershed/region? Are there industries in town and up-stream that might impact the local/regional ecosystem?	For the local and regional ecosystems as well as the urban system is any evidence available that has documented change in indicators of ES. Can any projections be made about impact factors associated with these trends?	Are there areas of town or the surrounding region poised for growth and development that might exceed the ecosystems' capacities to maintain functioning and resilience?
Reproductive Decisions	75%	N/A	N/A	*See all other impacts. There are no specific impacts associated with this decision.*	How have indicators of local, regional, and global ecosystem functioning changed in comparison with population growth?	Is there information available about the rate at which humans consume resources or deposit wastes in to systems relative to population size? Do these variables change per-capita as population grows?
Voting and Business Decisions: Land-use decisions such as for conservation easements (Common decision on public ballots).	100%	What kind of ecosystems are in the policy boundaries and are downstream of the site?	For the type of ecosystems in the political boundary, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision? Do the boundaries in the conservation areas encompass healthy ecosystems?	What are potential impacts to the health of the ecosystems in the region? Using indicators of impacts do any of the ecosystems show signs of stress?	Is there any evidence available documenting changes in indicators of ecosystem functioning over time for this local system (or similar systems) from which conclusions can be drawn about connections between land-use and ecosystem functioning?	Is information available about a relationship between the size of a forest and its ability to maintain functioning and provide ES in spite of pollutants?

Activist Decisions: Altering ecosystems to increase the provision of a good or restore/add ecosystem structure	100%	What kind of ecosystems are in the policy boundaries or were historically present in these boundaries?	For the type of ecosystems in restoration/ transformation plan, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision? Do the restoration/ transformation plans have these characteristic indicators built in to the design?	What are potential impacts to the restored ecosystem that prevent them from fully functioning (e.g. pollution, global change, random natural disasters) and are these potential impacts factored in to the design?	Is any evidence available documenting the trajectories of key indicators of ecosystem functioning in restored sites? In cases where functioning was not restored, what was discussed as potential causes of failure? Are these issues being considered?	Is information available about the capacity of similar restored systems to handle the types of impacts identified? Did designers explicitly model the restored ecosystem's capacity to handle the amount of wastes and other flows that will pass through the system?
Activist Decisions: Pollution Regulating (Particularly at local level).	85%	What kind of ecosystems are in the policy boundaries?	For the type of ecosystems in the political boundary, what does a healthy and resilient ecosystem look like and what ES would such a healthy system provision? What ecosystem services would we have to gain from increasing pollution regulation?	What are components of air pollution locally? What do these pollutants impact in the local ecosystem including humans and other components of the local ecosystem?	Is any evidence available showing a relationship between different types of pollution regulations and indicators of ecosystem functioning in similar systems? What are the successes and failures of these different regulations?	Is any information available about the rate at which these pollutants can be metabolized in similar ecosystems, and if so is the pollution regulation appropriate to this level?

Chapter 4: Characterizing engagement with science when evaluating authentic claims about Ecosystem Services

Abstract

Science education has long focused on identifying what one should know in order to be scientifically literate. More recently, this attention has expanded to also investigate what literate engagement with science looks like. In this study, I investigated both of these research aims characterizing engagement with science by members of an authentic community. Specifically, I focused on their engagement with claims about benefits that humans might gain from a green infrastructure system proposed in their town. These benefits, termed Ecosystem Services, are an emerging component of scientific literacy. Using an authentic context, in which claims about ecosystem services were being conveyed to a local community, I interviewed members of this community to characterize their engagement with science and the knowledge that they used. Two types of engagement with science emerged from this characterization, that I call the *questioning cycle* and the *definitive-justification* patterns. A questioning cycle involves iteratively questioning a claim, rather than arriving at a definitive conclusion while a definitive-justification involves taking a stand and justifying that stand. All individuals used both of these types of engagement depending upon the specific claim that they were evaluating indicating an important role that knowledge might play in engagement. Findings are discussed with regard to their implications for what it is one needs to know in order to be scientifically literate about ecosystem services as well.

Keywords: ecology, economics, scientific literacy, environmental education, standards, ecosystem services (ES), competent outsider

Introduction

Scientific literacy is considered an essential element of modern life - necessary to prepare the next generation of scientists, promote economic growth, and enhance engagement with science in everyday life (Anderson, 2010; Hurd, 1958; Roberts, 2007). Education researchers and policy makers have developed educational aims that can promote scientific literacy for all citizens. Much of their research (Roberts, 2007) focuses on answering the question: *What does one need to know in order to be scientifically literate?* A common method for answering this question is to use an analysis of science disciplines and establish an expert consensus about important ideas in science disciplines (Lewenstein, 2015; Stigloe, Lock, & Wilsdon, 2014; Rodriguez, 2015). As a field, we have developed targets for learning that are based on these discipline analyses (Mohan, Chen, & Anderson, 2009; Gunkel, Covitt, Salinas, & Anderson, 2012). These upper anchors are *prescriptions* of what is important in order to be scientifically literate as articulated by domain experts, and are quite reliable at characterizing important ideas for scientists. That said, an important question that is relatively unanswered by science education research at this time is, are these upper anchors representative of what citizens use when engaging with science in everyday life? Answering this question involves research that describes authentic engagement with science, specifically targeting the knowledge used by citizens when engaging with science (Feinstein, 2011). In this study, I adopt this alternative method for identifying important knowledge for scientific literacy, describing authentic engagement with science by citizens in everyday life.

Research on *Public Engagement with Science* offers a glimpse at how citizens engage with science in everyday life. This research has focused on the sources of expertise in communities (McCallie, et al., 2009; Stigloe, Lock, & Wilson, 2014; Roth and Lee, 2002), as well as the types of questions and scientific resources with which individuals interact (Feinstein, 2014; Layton, Jenkins, MacGill, & Davey, 1993). A key finding regarding sources of expertise indicates that there is an important role of sharing knowledge, and that engagement with science can be best described as an iterative process of asking questions, finding scientific resources that can be used to construct answers to these questions, developing scientific accounts based on these findings, and asking new questions (Feinstein, 2014; Mohan, et al., 2009). This cycle of questioning leads citizens to develop an increasingly sophisticated understanding of a topic at hand (Feinstein, 2014). For example, Feinstein (2014) tracked parents of children with autism as they engaged with science, finding that some, but not all, parents progressively engaged with science, continuing to ask new questions as they discovered new information and as new situations arose.

Feinstein calls citizens capacity to engage in this cycle of questioning, "Competent Outsiders"; citizens "who have learned to recognize the moments when science has some bearing on their needs and interests and to interact with sources of scientific expertise in ways that help them achieve their own goals" (Feinstein, 2011, pp. 13). It is important to note, however, that not all citizens in his study on Autism questioned in this way (Feinstein, 2014). Some citizens were more concerned with questions about the availability of services than the science. One citizen articulated a distrust of mainstream science. These citizens, it seemed, had alternative goals of their questioning and ideas about what counts as good knowledge. Feinstein did not design his analysis to explore this dimension of participants' cognition; therefore, research is needed to further explore beliefs about knowledge and types of knowledge that support or inhibit engagement with science.

In order to identify the knowledge and beliefs about knowledge that competent outsiders bring to a situation, and then use when engaging with science, it is necessary to first select a situation that we would expect citizens to realistically encounter. One common situation is making environmental decisions. Some of these decisions are personal, such as product choice and where to live, while others are local-level community decisions such as those related to land preservation and 'green infrastructure' (Authors, 2015b; Krasny, Russ, Tidball, & Elmqvist, 2014; Pickett, Cadenasso, & Grove, 2004; Roth & Lee, 2002). Many of these decisions impact what ecologists call *Ecosystem Services,* and when making environmental decisions, citizens are increasingly confronted with claims about these services (Anderson & Doherty, 2014; Authors, 2015a, 2015b; Covitt, Tan, Tsurusaki, & Anderson, 2009; Krasny, et al., 2014; NRC, 2012; Pickett, et al., 2004).

Ecosystem Services (henceforth ES) are benefits that humans gain as a result of being connected to the functioning of ecosystems, native or modified (Authors, 2015a). Functioning ecosystems can include anything from "Green Infrastructure" in an urban center to a National Preservation, among many others, and all of these ecosystems generate an array of services that improve human well-being such as cleaning water, regulating climate, and provisioning resources. Given the extensive impacts that humans have on the environment, claims about ES are becoming more prominent raising the question: what knowledge about ES do competent outsiders commonly use to critically evaluate these claims?

In earlier research, my colleagues and I asked academics who specialize in ES to characterize what literate citizens need to know in order to critically evaluate claims about ES (Authors, 2015a). This research identified a set of ‘big ideas’ about ES (Figure 1). In this study, I explored whether these big ideas are used by citizens when critically evaluating authentic claims about ES? Specifically, I investigated the knowledge used by members of a local community seeking to improve ES following a recent catastrophic flooding event as these individuals evaluated authentic claims about ES made by environmental and urban planners. In addition, in response to the findings that some citizens do not engage with science discussed earlier (Feinstein, 2014), this study also explored factors that might affect how citizens engaged with science, such as the goals that they establish as aims of their evaluation and their beliefs about good knowledge.

At the time of this study, a team of urban and environmental planners had recently presented a green infrastructure proposal to the city’s community at a public forum. I interviewed highly active members of this city’s community, whom I refer to as candidate competent outsiders, in the weeks immediately following this presentation. I consider these individuals *candidate* competent outsiders because, though they all had a long-standing and active role engaging with science in their community, the extent of their actual competence was unknown. From this data set, I sought to answer the following research questions aimed at characterizing engagement with science when evaluating claims about ES:

1. What do candidate competent outsiders establish as goals of their engagement with science when evaluating authentic claims about ES from green infrastructure?
2. What do candidate competent outsiders view as types of information needed in order to fully evaluate a claim about ES from green infrastructure?
3. What science ideas about ES do candidate competent outsiders use while engaging with science to evaluate authentic claims about ES from green infrastructure?
4. What role do these different goals, science ideas, and views of ideal sources of information play in the outcome of engagement with science?

Although these research questions are specific to a single circumstance, the findings of this study can inform what engaging with claims about ES might look like more broadly, as well as offer additional insights about factors affecting engagement with a socio-scientific knowledge as a competent outsider. Moreover, refining what it means to be a Competent Outsider can also provide a methodological tool for future research on scientific literacy writ large.

Study Context

I provide a thorough description of the study context prior to the theoretical framework section in order to contextualize some of the examples that follow. Towards this end, I describe the approach used to describe the community, their problem, and the proposed solution to their problem. This description was used to design an interview protocol that simulates important features of this authentic context. I specifically focused on claims being made about ES.

Three sources of data were used to develop this description: document analysis, observations of public meetings, and conversations with team designers. For this document analysis, I collected relevant articles from the town newspaper and used these to draw a story of the environmental and political context, by recording claims and stakeholder dissents that were documented by the reporters. This document analysis provided me with an initial description of the setting.

The Setting

The data for this study was collected in a riverine city that had recently suffered a major flooding event as a result of storm surge from a hurricane. This town has a very active citizenry involved in all aspects of local policy including organizations devoted to park space, quality of life, and small businesses, among others. The town also suffers from a chronic flood problem as, like New Orleans, much of it sits below sea level because of its development history. In the aftermath of the major flooding resulting from the hurricane event, city policy makers made a commitment to solve this flooding problem.

The town policy makers entered a competition for federal funds and appointed a team of professionals that consisted of urban planners, landscape architects, economists, and engineers, among others. This project team was charged with developing a solution to the town's flooding problem. At the time that this study was conducted, the project team presented a plan for transforming the town's infrastructure at an open public forum attended by political leaders and many community members.

One feature of the proposal was a "terraced wetland system" in a protected alcove along the riverbank. The "terraced wetland system" was to consist of a small band of wetlands that would sit in the tidal area of the river in combination with a series of wetlands that would snake through a terraced landscape. The project team stated that the wetland system was included to add more ES to the town and surrounding region, including, cleaning water entering the river from a sewage treatment plant, mitigating coastal erosion, improving the riverine ecosystem, and adding economic value to that area of town. When citizens asked questions about how this wetland design would yield this array of ES, the designers made some of the following claims (among others):

1. *You know we could think of the wetland as a way of improving our relationship with the river. .....the engineered wetlands along the river will help enhance the estuary ecosystem, particularly as more of these are built throughout the region. It does so by providing breeding ground for fish, processing natural wastes from the river, providing a sanctuary for birds and other wildlife, etc.*
2. *The wetland component will act as a "living wall" that could clean water. Effluent from the town's sewage treatment plant will be pumped to the top of the terraced wetland system, which will then meander through the levels of the wetlands inside of the terraces so that by the time the water would enter the river it will be cleaner.* At the presentation, the design team did not explain the mechanism whereby this cleaning would be achieved.

The landscape architect also defended his claims by comparing their design to what is done elsewhere in the world, stating: "*Engineered wetlands have succeeded in other locations. The Netherlands, for example, has been using them for years to help alleviate coastal flooding. There's no reason why [TOWN] should be different and* *should not be able to construct these wetlands."* The architect also emphasized the team's use of "storm surge models" that were used to demonstrate the effectiveness of the terraced wetland system at mitigating coastal flooding, stating: "*We've used hydrologic computer models to demonstrate that the wetlands will be as good at reducing the hazard of floods as the deployable sea wall*."

These claims regarding ES benefits and descriptions of the projects were vetted and member-checked using a follow-up, one-on-one interview with the team's project manager. The project manager agreed that the description of the context that I developed during observations at the public forum and document analysis, suitably captured the ecological dimensions of the problem and proposed solution.

The Researcher

For full disclosure, at the time of data collection, I was a resident of the town studied. I am an academic researcher specializing in ecology, environmental science, ecosystem services, and education. Prior to this study, I was not active in town politics and did not know any of the subject participants. Based upon my experiences in town, I did have my own perspectives on how to solve the city's flooding problems and shared in the community's desire for a solution. In the analysis that follows, I tried to hold at bay any potential biases and get a clear sense of the full scope of the problem and what was being proposed.

Theoretical Framework

Citizens engaging with science need to evaluate claims based upon their understandings of science and the types of information used to argue for a claim (Feinstein, 2014). These activities are guided by the epistemological beliefs that individuals hold about scientific knowledge, evidence, practices, and arguments, among others (Chinn, Buckland, & Samarapungavan, 2011; Chinn, Rinehart, & Buckland, 2014; Hoefer & Pintrich, 1997; Hogan & Maglienti, 2001; Kuhn & Weinstock, 2002). One commonly cited model of epistemological beliefs (Hoefer & Pintrich, 1997) includes four dimensions: (1) the certainty of knowledge, (2) the simplicity or complexity of knowledge, (3) the source of knowledge, and (4) the justification of knowledge. The Hoefer and Pintrich framework contributed greatly to the field's thinking about epistemic beliefs, however it does not fully capture cognition associated with evaluating the validity and accuracy of scientific claims.

In a theoretical piece, Clark, Rinehart, and Buckland (2014) refined the Hoefer and Pintrich (1997) framework in order to more fully capture *cognition* associated with evaluating the validity and accuracy of scientific claims. They argued that a holistic framework that contains not only dimensions of belief but also cognitive activities such as setting aims (e.g. explanation, understanding) and carrying out inquiring activities (e.g. Mohan, Chen, & Anderson, 2009; Chinn, et al., 2014) was needed. Adopting the umbrella *epistemic cognition*, which is used to describe a host of thinking processes and understandings related to acquiring knowledge and other epistemic products (e.g. models), the CRB (2014) framework contains three independent dimensions: (a) personal aims or targets of epistemic cognition, (b) ideals about the types of information that must be acquired in order to achieve an epistemic aim, and (c) processes that can be reliably used to achieve their epistemic aims (Chinn, Rinehart, & Buckland, 2014: hereinafter CRB). This model of epistemic cognition addresses components of cognition and beliefs that Feinstein (2014) suggested were reasons that some parents of children with Autism did not engage with (described in the introduction); therefore, I adopted this model of Epistemic Cognition to characterize engagement with science, and next explain each component in turn.

Aims

Aims are goals that drive cognition and action; these aims can be both epistemic and non-epistemic (CRB, 2014). *Epistemic Aims* are goals that drive epistemic practices such as evaluating the accuracy or truthfulness of a claim, as well as seeking more knowledge. For example, if a citizen with the epistemic aim of evaluating the accuracy of claims, encounters the claim “the wetland will clean the water in the river”, she might question the claim: “How will the wetland clean the water?”… “Is the wetland of sufficient size?”

Unlike epistemic aims, *Non-Epistemic Aims* are values that are not directly associated with epistemic practices. They include aims like the pursuit of pleasure or protecting one's image. In relation to the environment, a non-epistemic aim might include having a *desire for space to roam*.

Epistemic Ideals

Epistemic Ideals are the criteria or standards that people use to judge whether the epistemic products (e.g. science accounts, models, empirical evidence) they have accumulated as a result of engaging with science, are suitable and that their epistemic aims have been achieved (CRB, 2014). These criteria or standards include, but are not limited to, ideals about the sufficient complexity of an epistemic product or of the validity of different types of epistemic products. For example, an individual may view scientific models as needing to align with all available evidence.

Epistemic ideals are situated and specific to domains (CRB, 2014); what may count as good evidence in ecology, may be different in physics. Therefore, it is important to articulate the types of evidence that are suitable for supporting claims in a specific domain. There are three broad types of evidence used by scientists when supporting claims about ES: (a) case studies detailing conditions in a specific location, (b) data on changes in indicators of ES over time, and (c) outputs of socio-ecological models that can be used to predict ecosystem dynamics and changes in ES (Authors, 2015b). In this study, the project team that designed the wetland used two of these forms of evidence to support their claims about ES; they compared the town to a case study in the Netherlands, and provided citizens with evidence based upon the output of computer models.

Reliable processes for producing epistemic products

Processes are activities (e.g. developing explanations) that individuals use to acquire or produce epistemic products (e.g. science models) in route to achieving their epistemic aim, and some of these processes are more reliable than others (CRB, 2014). Reliable processes are those that consistently yield suitable epistemic products (CRB, 2014). For engagement with science, these reliable processes can include: (a) developing scientific accounts based upon ones prior understanding of a subject (a personally-generated epistemic product), or (b) carrying out a personal inquiry, during which one finds relevant epistemic products from scientists or those near the field (Authors, 2015b; Feinstein, 2014; Mohan, 2009). Like Epistemic Ideals, Reliable Processes also are situated and specific to domains; therefore, it is important to articulate types of science accounts that are important to informing aims associated with evaluating claims about ES. There are two types of scientific accounts associated with ES:

1) Accounts of features of the system that are necessary for ES to emerge.
2) Accounts of potential impacts to the system and its ES and their importance (Authors, 2015b).

Identifying those big science ideas that citizens use when constructing these accounts is important to answering the third research question: *What science ideas about ES do candidate competent outsiders use when evaluating authentic claims about ES from green infrastructure?* In prior research, I surveyed experts in ES to identify big science ideas that should be included in scientific accounts of ES (Authors, 2015a), but as I described in the introduction of this paper, it is important to further investigate the importance of these ideas using research on authentic engagement with science.

Epistemic Cognition Associated with Engagement with Science: a model for ES

I now return to the CRB (2014) framework for epistemic cognition to illustrate the connections between all three dimensions (Aims, Ideals, and Reliable Processes). Figure 2 contains a visual depiction of a hypothetical interaction between these three dimensions of epistemic cognition when applied to ES, which I describe as "goal-oriented activity." For the context of this study, and as I will describe in more detail in the methods section below, I guided participants to an epistemic aim, asking them to formulate an opinion about the accuracy of claims about ES that they were provided.

In order to achieve this epistemic aim, citizens might use reliable processes such as developing scientific accounts. Citizens might continue to carry out these reliable processes until the products of these processes meets their epistemic ideals, such as their accounts being sufficiently complex. In summary, how an individual engages with science can be described in terms of aims, ideals, and reliable processes that are invoked along with domain-knowledge (about ES and ecosystems in this case) to evaluate claims about ES. In this study, the aim is to use this framework to describe the authentic engagement with science and big science ideas that competent outsiders use during this engagement.

Methods

For this study, I interviewed actual stakeholders from the setting described above, asking them to evaluate the proposed wetland and five claims made by members of the wetland design team during the open public forum described in the Study Context section above. These claims are provided in Table 1. In the following sections, I describe the criteria used for identifying and selecting participants, the participants selected, the interview protocol, data reduction and analysis, as well as how I established reliability.

Criteria for Selecting Participants

As described in the introduction of this paper, *Competent Outsiders* are individuals with an ability to recognize moments when science is relevant to a decision at hand and have the wherewithal to find and interact with sources of scientific expertise to inform their decision-making (Feinstein, 2011). Feinstein argued that to judge competence, it is important to find citizens that are able to arrive at an outcome or epistemic product that fulfills their personal needs, but also that the researcher has to establish a position about whether the epistemic product is sophisticated enough (Noah Feinstein, personal communication, August 13, 2015). Because a goal of this research was to better characterize competent outsiders particularly with regards to how they engage with science when evaluating claims about ES, I did not establish a position on the required sophistication of an epistemic product *a priori*. In place of an *a priori* description of competence, I established a set of criteria for selecting citizens who are *candidate* competent outsiders based upon their prolonged and in-depth interactions with science as a result of an active public life. I chose the following criteria for identifying candidate competent outsiders and selecting participants for this study:

1. Competent outsiders have experience engaging with science when making decisions about coupled human-environment systems as a result of participation on local panels, committees, or task forces charged with solving environment-related issues.
2. Competent outsiders have a substantiated record of experience working on environment-related issues at the local level (preferably several years of such experience).

Fourteen citizens were selected as candidate competent outsiders for this study. The professions of these individuals varied widely and accordingly with their degree of "outsider-ness." Two of the participants were engineers from a local university, two were economists for the government, one a landscape architect (not the project architect), four were local elected officials, and the remaining five were leaders in local environmental activist groups. I recruited some of these participants at the public meeting when the wetland was first introduced. Others, I recruited by networking with policy makers and activists in town.

In order to capture a diverse set of perspectives, I asked participants to refer me to others that they do not necessarily always agree with. During all interviews, I first asked each participant to describe themselves and the role that they have played in town environmental policy. All participants met the selection criteria above for candidate competent outsiders.

Interview Protocol

Although, it is not possible to replicate all dimensions of an authentic context in interviews, it is important to design instruments in a way that they recreate some of the authentic circumstances that arise (Bredo, 1994; Brown, Collins, & Duguid, 1989; Hung and Chen, 2007). I used a two-part semi-structured clinical interview protocol (Ginsburg, 1997) to collect data for the main phase of this research that integrated authentic circumstances from the public meeting described in the context section earlier. In the first part of the interview, I provided participants with authentic images (from the project documents presented at the meeting) of both the terraced wetland design and an earlier design for the area that included a deployable floodwall and asked participants to describe benefits and limitations of both. For each claimed benefit, I asked participants to evaluate their own claims. This portion of the interview protocol was included to allow the participant to develop their own accounts of potential ecosystem services and disservices associated with the project design before being presented with some of the claims about ES that the project designers made during the public forum (Table 1).

In the second part of the interview, I provided participants with a series of five "claims" about ES, assembled during the first phase of this study (Table 1) and asked participants to evaluate each claim. I specifically asked: "How would you respond to the person making this claim?" The first three claims were selected because they articulated different types of ecosystem services (ES). The fourth and fifth claims were selected because they used supporting evidence to back the claim: (a) comparison to case study

(Claim 4) and (b) model output (Claim 5). I was particularly interested in the extent to which the evidence provided met participants' epistemic ideals.

Table 1 contains the claims provided to all participants during interviews. To the right of these claims, I provide a category for the type of ES in each claim. These categories of ES were articulated using a well-established framework developed as a result of the Millennium Ecosystem Assessment (MA, 2005), an international effort to assess the status of the world's ecosystems. During analysis, epistemic cognition associated with each category of ES was coded independently. This was done because I expected that the knowledge associated with different types of ES might be different.

During analysis, I also coded, into one of these categories, the ES that participants generated claims about in the first part of the interview. Therefore, analysis of ideas for different types of ES were based upon how citizens evaluated both personally-generated claims as well as those claims provided in Table 1. Table 2 contains some exemplary ES for these different categories to which the reader can refer for examples. All interviews were audio recorded and transcribed verbatim.

Data Reduction

In this study, I sought to characterize participant evaluation of claims about ecosystem services (ES) made either by themselves during the first part of the interview or during their evaluation of the claims made by the project team members (Table 1). I used a Grounded Theory approach to data reduction (Creswell, 2007), grounded in: (a) an epistemic dimensions of engagement with science including aims, (b) ideals about epistemic products (e.g. accounts, models and comparative evidence), and (c) conceptual science ideas used by participants in their scientific accounts. I used a propositional analysis (Frederiksen, 1975; Kintsch & van Dijk, 1978) to identify unique conceptual ideas in participant utterances. For example, for the following sentence, I identified four unique conceptual ideas about ES (unique propositions italicized):

> "So *how much water* is coming in and versus the *surface area of the wetland …how long it takes* for the drops of water to *make it through* the *whole system matter*."

These conceptual ideas are: (a) quantity of input, (b) size or area of wetland, (c) the time and rate of input in relation to size of wetland, and (d) movement of matter through a system.

For aims, I also used a propositional analysis, but this time in concert with a macro-level discourse analysis (Kintsch & van Dijk, 1978), which I explain next. I used a propositional analysis to identify unique non-epistemic aims from participant utterances. For example, in the following quotation, the participant expresses a non-epistemic aim that I characterized as a desire for recreational services: "*It has to be something that you know you still want people to feel like invited to the waterfront or like, the little people that they put in there, they're all happy*." For epistemic aims, I had to use a macro-level analysis in which I looked for characteristically different ways in which participants set the targets of their engagement. For example, I looked at how a participant questioned a claim, specifically looking at the source of a question (e.g. a science idea or a non-epistemic aim).

For epistemic ideals about the supporting evidence provided by the project team (model outputs and comparison to case study), I also used a propositional analysis of data. The propositional analysis was used to identify specific limitations of the supporting evidence provided or further parameters that would need to be included for the evidence to be persuasive. For example, a specific limitation might include geographic differences between a compared location and the site of interest. I also looked for key statements about the kinds of information they would like to see such as "proof" or "assumptions".

Reliability of coding

All interviews were coded by three individuals. I developed the coding scheme with the help of one of the other coders. This colleague and I then independently coded one half of the data set conferencing to resolve any differences. A third colleague then coded the other half of the data set, meeting with the principle researcher to resolve any differences. Finally, to ensure full reliability of results, the coders reviewed the codes for the half of the data set that had been completed by the other coder.

Results

I divide the results into two sections. In the first section, I provide a description of the epistemic aims, epistemic ideals, and conceptual science ideas about ES that emerged from data analysis, providing answers to the first three research questions of this study. In the second section, I provide two qualitatively different patterns of engagement with science to address the last research question of this study and show relationships between these patterns and the epistemic aims, ideals, and science ideas that emerged.

Research Question 1: Aims

The epistemic aim, "Evaluate the accuracy of a claim regarding the provision of a putative ES", was insinuated as a part of the interview prompt; however, citizens' personal aims were sometimes different than that provided in the prompt. Two personal aims emerged:

1. Evaluate the scientific merit of the claim that the wetland will provide a specific ES.
2. Evaluate whether the wetland design supports a preferred ES.

I discuss each epistemic aim in turn.

Evaluate the scientific merit of the claim that the wetland will provide a specific ES.

This aim was the more commonly used of the two, with 10 of the 14 participants using this aim to drive their epistemic cognition. These individuals focused primarily on whether the wetland was designed to fulfill the promised ES.

Evaluate whether the wetland design supports a preferred ES.

This aim was a mixture of non-epistemic and epistemic aims. For those individuals with this aim (4 of 14 participants), their non-epistemic preference for one ES drove their epistemic cognition. For example, two participants focused on recreation as the most important ES and went so far as to diminish the importance of the flood regulating ES if it meant sacrificing recreation in any way. Another participant focused on the biodiversity aspect expressing concern that using the wetland for sewage cleansing ES may decrease biodiversity. Those individuals with this aim all engaged in epistemic practices that forced deeper consideration of the design parameters associated with their preferred ES (e.g. recreation, biodiversity).

These epistemic aims had a substantial effect on the way that citizens approached their evaluation of claims about different ES. Those with the second aim had a vested interest in making sure that the ES would not only be possible, but that designing the wetland would be done in a way that didn't sacrifice their preferred ES. I discuss the outcomes of these two aims in more detail, and in relation to other dimensions of epistemic cognition (ideals and reliable processes), later in the Results.

Research Question 2: Epistemic Ideals about Epistemic Products

As described in the theoretical framework, when individuals engage with science, they use reliable processes and accumulate epistemic products (e.g. scientific accounts, supporting evidence) as a result of these processes. *Epistemic ideals* are the criteria or standards that people use to judge whether these epistemic products are informative (CRB, 2014). I focused on participant ideals in relation to two epistemic products that the wetland design team used as supporting evidence: (a) model outputs and (b) comparison to a case study. During analysis, I found two qualitatively different criteria for good epistemic products that affected how participants engaged with science:

1. Good epistemic products (i.e. models and comparative evidence) have clearly articulated limitations that constrain the inferences that can be drawn from these products.
2. Good epistemic products contain information that can provide proof-of-point or validation-of-point.

I discuss each ideal in turn.

Good epistemic products have clearly articulated limitations that constrain the inferences that can be drawn from these products.

This ideal aligns with scientific norms for thinking about scientific evidence; the inferences one can draw from these products are limited because evidence never addresses all dimensions of complex natural or social systems. Participants with this ideal clearly articulated specific structural criteria for a good model or comparison, indicating that some structures would be more informative than others for the situation at hand. For example, one participant stated that although the Netherlands comparison made by the wetland design team (Claim 4, Table 1) was useful, it was important to consider geographic differences between the Netherlands and her town. She specifically commented that the Netherlands has a larger area for water to spread than in her town and that she'd like to know more about how the project designers considered this fact in their design. About one half of the participants interviewed during this study identified limitations of epistemic products: seven for models, eight for comparisons (of 14).

Good epistemic products contain information that can provide proof-of-point or validation-of-point.

Some individuals expressed the idea that the best epistemic products involve or are proof that an ES will emerge or that a design will be successful. For example, one participant said: "*you do have to have proof that it's been done someplace else and that it's been successful.*" Others expressed models as fact: "*Models are fact…on a smaller scale you do something and if it works, then that's a fact.*" This ideal was seen in seven participant interviews for models and six for comparative evidence (of 14).

In summary, some of the participants in this study viewed good epistemic products as providing proof, where as others emphasized the importance of their limitations and the need to consider many parameters. I discuss the importance of these different epistemic ideals in relation to other dimensions of epistemic cognition later in the Results.

Research Question 3: Science Ideas about ES in Participants' Scientific Accounts

As described in the theoretical framework, reliable processes are those activities used to create epistemic products in order to achieve an epistemic aim. While citizens do not engage in creating science knowledge per se, they do engage in activities to gather epistemic products of scientists' work and create an account of these products. During analysis, I focused on one of these reliable processes, *generating personal science accounts*. Here, I provide an in-depth content analysis of two types of science accounts that participants generated while engaging with science to evaluate claims about ES that were associated with this wetland:

1) Accounts of features of the system that are necessary for ES to emerge.
2) Accounts of potential impacts to the system and its ES and their importance.

As described earlier, these accounts were identified as important to articulate when making decisions involving ES (Authors, 2015b). In the sections that follow, I describe those ideas that were more commonly and less commonly used, in participant science accounts.

Ideas associated with accounts describing features of the system that are necessary for ES to emerge

During analysis, I organized conceptual science ideas present in participant utterances into big idea categories, which emerged in relation to accounts describing features of an ecosystem that are necessary for ES to emerge: (a) matter and energy flow through ecosystems, (b) systems change but functioning ones are resilient, (c) structure-function relationships in ecosystems exist at different levels of organization, and (d) the scale or size of an ecosystem will affect the amount of ES. Here, I highlight components of each idea category that were commonly and less commonly used for each big idea category independently.

Matter and energy flow through ecosystems

Matter and energy flows are the foundation of what ecologists call ecosystem functioning and are considered as such because they are responsible for moving and transforming matter and energy so that it can be used by different organisms and reduce pooling of toxins (among other materials). The participants in this study more commonly used the idea that *matter and energy move through ecosystems* (code 1a in Table 5, 12 of 14 participants), but less commonly used the idea that there is a *rate of such movement* (code 1c, 6 of 14 participants) or the idea that *matter is transformed into different forms* (e.g. decomposing wastes, code 1d, 2 of 14 participants).

Flows through ecosystems and transformations of matter in ecosystems are a target understandings for science education (Carlsson, 2002; Gunkel, et al. 2012; Mohan, Chen, & Anderson, 2009). This concept is present in the NRC Framework in multiple locations, including the physical, life, and earth systems sciences (NRC, 2012). Interestingly, only about half of participants discussed flows and two discussed transformations, despite the relevance of these ideas in this context. It is not clear if these ideas were used with a lower frequency because participants did not view them as important or because they did not have a strong enough understanding of these concepts to evoke them when developing their accounts. The fact that some of the participants who did not use the concept of transformations of matter had an advanced education in a related scientific subject would suggest the first of these potential conclusions; however, I did not test participant's conceptual understandings directly.

Systems change but functioning ones are resilient

Environments are always in a state of flux, but functioning ecosystems are able to maintain their "resilience" over time (Holling, 1973; Hovardas & Korfiatis, 2010). Resilience is the capacity of a system to reorganize following a disturbance without affecting the fundamental nature of the system. Almost all participants in this study suggested that there will be changes in the environment surrounding the wetland (code 2a, 13 of 14 participants). When doing so, they discussed regular, recurring changes, such as cycles of salinity as a result of tides, as well as, long-term changes such as rises in sea level and major storm events. While participants brought changing circumstances to bear often, fewer specifically articulated the idea that for the wetland to be resilient, it would have to *reorganize in response to this change* (code 2c, 4 participants). The others suggested that the wetland would remain in its designed state in spite of changes around it. This finding is interesting because thinking about ecosystems as resilient is different from thinking about them as stable because ecosystems do need to change (Hovardas & Korfiatis, 2010). Resilience is also a part of the disciplinary core idea *Ecosystem Dynamics, Functioning, and Resilience* in the National Research Council's Framework on Science Education (NRC, 2012). Few participants used this sophisticated view of resilience in their science accounts in this context.

Structure-function relationships in ecosystems exist at different levels of biological organization

Ecosystem functioning is a term commonly used to describe the overall flows of matter and energy in an ecosystem. This functioning depends upon its structure, and ecosystem structure can be examined at different levels of biological organization.

Participants commonly examined ecosystem structure at the *ecosystem level* (14 of 14 participants) and *organism level* (12 of 14 participants). A common proposition about structure-function relationships at the organism level was that *plants block the flows of water*. At the ecosystem level of organization, a common structure-function relationship was that *having redundant or diverse components in an ecosystem is important because they can act to back up functioning* (code 4d in Table 4). Interestingly, when discussing diversity of components, only one participant also expressed this idea through a structure-function relationship at the level of *organisms*. The remaining participants spoke of redundancy of abiotic components such as having backup infrastructural components.

Another level of organization articulated as critical for thinking about ES is the *regional level* (Authors, 2015a; NRC, 2012). In the case of the wetland, a common proposition was that other wetlands would have to be constructed nearby to maintain functioning (8 of 14 participants). Participants expressed different reasons for this structure. Some said that the nearby wetlands could provide corridors of migration for aquatic organisms. Some others said that the nearby wetlands could provide plant seeds to replace damaged areas of the wetland.

Reasoning across levels of biological organization is considered an important target of environmental science education (Mohan, et al., 2009) and is also a concept in the disciplinary core idea *From Molecules to Organisms: Structures and Processes* of the NRC framework (NRC, 2012). For ecosystems, Mohan and colleagues (2009) emphasize the importance of molecular-level carbon-transforming processes in global carbon cycling. Interestingly, participants in this study did discuss structure at different levels of organization, but few discussed more sophisticated functional processes at multiple levels of biological organization instead focusing primarily at the level of the ecosystem. This was irrespective of ecological expertise; one participant majored in ecology in a top-tiered college and almost exclusively included more sophisticated structure-function ideas at the ecosystem level.

The scale or size of an ecosystem will affect the amount of ES

All participants included ideas about scale in their reasoning. They questioned the size of the wetland system and whether it would be large enough to provide the ES in the claim. They also expressed a general relationship between the scale of an ecosystem and ES: more nature or green infrastructure is better (code 6a, 12 of 14 participants).

Identifying potential impacts to ecosystem functioning and ES

Analysis of participant utterances yielded two big idea categories associated with identifying potential impacts to ecosystem functioning: (a) the type of and level of impacts matter because ecosystems have limited capacities to handle impacts, and (b) it is not possible to predict all possible impacts; therefore, there is an uncertain outcome. Following the structure of the previous section, I highlight components of each big idea category that participants evoked.

The type of and level of impacts matters because ecosystems have limited capacities to handle impacts.

Participants, on average, identified four different potential impacts to the wetland system. These included pollution, environmental forces (e.g. waves and currents), non-human organisms (e.g. invasive species), and direct human actions (e.g. trampling on the wetland). Recognizing that there are differences between different impacts has been highlighted as an important target of environmental education (Brody, 1991) and this requires evaluating the importance of different impacts. Evaluating the importance of different impacts involves, (a) identifying the overall amount of an impact, and (b) the rate at which this impact flows through a system (Authors, 2015b). Most participants used the idea that the *amount of an impact is important* (11 of 14 participants); however, fewer used the more sophisticated idea that it is important to consider the *flow rate of an impact in relation to the capacity of an ecosystem or organism to perform a function* (6 of 14 participants). Understanding flow rates and limited capacities is currently considered a target for an influential learning progression on water in environmental systems (Gunkel, et al., 2012), and though six participants used this sophisticated understanding when engaging with science in this situation, more than half did not. Again, it is not clear if these ideas were used with a lower frequency because participants did not view them as important or because they did not have a strong enough understanding of these concepts to evoke them when developing their accounts.

It is not possible to predict all possible impacts; therefore, there is an uncertain outcome.

Finally, nine of the fourteen participants in this study brought *uncertainty* to bear in some way when evaluating the importance of different risks. Uncertainty is important for recognizing that not all potential impacts can be enumerated and their importance is difficult to forecast. Most participants (9 of 14) used uncertainty to productively evaluate the merits of different claims about ES. Fewer, but almost half of participants, specifically noted the uncertainty associated with forecasting from scientific models (6 of 14). Interestingly, science insiders (from various fields including science education, natural sciences, history, sociology, and philosophy of science) expressed concern that citizens might use uncertainty in unproductive ways (Osborne, et al., 2003), nevertheless, many citizens appeared to use uncertainty productively in their engagement with science.

In summary, the scientific accounts that participants in this study developed were relatively sophisticated. Most participants used at least some components of each big science idea, big ideas that are all important components of the Framework for K-12 Science Education and NGSS. Interestingly, a number of the more sophisticated ideas, featured in the *framework* and NGSS, were used by less than half of participants and, in some cases, as little as two of 14. Researchers developing learning progression on similar topics (Gunkel, et al., 2012) have found that such understandings are hard to achieve, and it is unclear whether participants did not have this sophisticated understanding or that they did not view it as important to the context at hand.

Qualitatively Different forms of Science Engagement

The last research aim of this study was to characterize qualitatively, different ways in which participants engaged with science when evaluating claims about ES, and to also identify relationships between dimensions of epistemic cognition and these *patterns of engagement*. In this section, I describe two unique episodes that occurred during interviews with all participants that I will call: (1) the questioning cycle, and (2) the definitive justification (see Figure 3 for a graphical illustration comparing these moments). I call these different *episodes* because participants would switch between these patterns of engagement depending upon the ES (e.g. regulating versus ecosystem-supporting and enhancing) that was being discussed. In fact, *all participants*, at some point in their interviews engaged in a questioning cycle and at other times, a definitive justification. The following sections describe each moment of engagement and some of the components of epistemic cognition (aims, ideals, and reliable processes) associated with each.

The Questioning Cycle Pattern

A questioning cycle involves iteratively questioning a claim, not arriving at a definitive decision about the validity of a claim about ES. In many cases, a questioning cycle was driven by a specific big science idea that was not described well enough in the wetland design team's claims, such as how they planned to account for sea level rise. In these cases, participants' ideals about accounts and scientific resources were not yet met, leading them to more questions, not to a decision about the validity of a claim about ES. I provide an illustrative example of a questioning cycle engagement pattern in which Sam used big ideas (e.g. regional structure-function relationships) to guide questioning about the fist claim in the interview protocol:

> *Claim- You know we could think of the wetland as a way of improving our relationship with the [River]. Unlike the sea wall, the engineered wetlands along the…River will help enhance the…Estuary Ecosystem, particularly as more of these are built throughout the region. It does so by providing breeding ground for fish, processing natural wastes from the…River, providing a sanctuary for birds and other wildlife, etc.*

Sam is an economist by trade and has had experience working on infrastructure projects where ES had been prominent, similar to the wetland plan.

Sam began his response by focusing on environmental change and questioned whether the designers considered the effect this change might have on the organisms that could use the constructed wetlands and, therefore, “ecosystem enhancing and biodiversity services”:

> *So you know what kind of fish is it providing a breeding ground for and if the larger ecology of the … River is being disrupted by these larger processes like both Anthropogenic … like sea level rise to a certain degree. But you know I mean the larger ecology in which the site is situated is shifting and so on you know: a) what are the envisions for species or ecological benefits here? and b) how do those benefits change over time or those values change over time?*

In this instance, Sam also focuses on the big idea: structure-function, looking at the organism-level of biological organization. He specifically brings up that different fish will require different conditions, looking for more on what conditions will be present (code 4c, Table 4). He continues, in the same vein further questioning elements of the claim.

> *And you know for the natural wastes, where are they coming from? Like natural wastes from the city … or is it part of this green system that can be deployed throughout the River and kind of contribute to cleaning water as it filters its way down into the estuary?*

Sam’s iterative questioning was based upon his noticing a lack of specificity in the claims provided and that there are many ideas that should be considered before a decision about the validity of the claim can be made.

The Definitive Justification Pattern

Unlike the questioning cycle, when someone employs a definitive justification while engaging with science, his/her conclusion is not open-ended; that is, the individual uses the products of her reliable processes to arrive at a justified decision that a claim is accurate or inaccurate. For example, someone might make a definitive decision that a claim about biodiversity and ecosystem enhancing ES is a good claim and justify that claim with the idea there will be more space available for fish. Why they end their questioning is an important question for research on scientific literacy because the longer one remains in a questioning cycle, the longer they engage with science and the more their decision-making is informed by science.

The sections that follow provide qualitative findings focusing on the role that *non-epistemic aims* and *epistemic ideals* play in switching from a questioning cycle to a definitive justification. I then provide a quantitative description of the association between the overall number of science ideas brought to bear and the different types of engagement with science (i.e. questioning cycle and definitive justification).

Aims and the definitive justification pattern

While ten (of 14) participants maintained an epistemic aim associated with evaluating the scientific merit of a claim about ES in a relatively unbiased way, four evoked the second epistemic aim, which is intertwined with non-epistemic aims: *Evaluate whether the wetland design supports a preferred ES.* When individuals evoked this second epistemic aim, their engagement with science often followed the definitive justification pattern. These individuals sought to either *justify* a claim associated with their preferred ES (a non-epistemic aim), or justify why a claim about another, non-favored ES, was invalid. Here, I provide a description of one participant, Bill, whose epistemic aim was to defend recreational ES and make sure that no actions would be taken that would reduce them. Bill is an activist in town, focused on making cities more livable. In the quotation below, Bill was responding to the same claim as Sam, an argument about biodiversity and ecosystem-enhancing services (Claim 1, Table 2).

> *I'll just stop at this…we don't see birds sitting there…I don't see this argument…I think what's also going to be better is being that we're in an urban environment, this is just hopefully going to be a mixed-use, outdoor activity space for residents, which I think outweighs the scenario of a wetland for the River*.

Throughout his interview, Bill expressed a clear belief that public spaces should be for the use and enjoyment by citizens. In this example, Bill cites a personal observation that there are currently no birds present at the location to justify his disbelief of the biodiversity claim and turn attention back to recreation. Contrary to Bill's use of this observation, the fact that birds are not there now could be used by others as a reason to support building the wetland: provide a habitat for the birds.

To get a clearer picture of Bill's reasoning, I shared an idea with him: that the project designers could add boardwalks going out into the wetland as a compromise. To this, Bill instantly responded.

> *Oh yeah! That would be kind of interesting. Yeah actually, exactly, there's more public space usage out of it, which would be nice considering we're so land locked around here.*

While Bill clearly was more amenable to a public-space, boardwalk design, he still concluded with, *"Otherwise, there's no purpose to it"*. Bill was using a definitive justification pattern of engagement and would find any way to draw attention away from claims about non-recreational ES. An important point to communicate before drawing implications from this description is that, Bill is a stakeholder for recreational space in town. His epistemic evaluation of ES on the basis of their potential to interfere with recreational services is an important component of planning because often there is a tradeoff between different ES (MA, 2005). That being said, when he discussed other ES, his tone was belittling and abrupt, which made it difficult to find common ground with him and engage him with more sophisticated questions.

Epistemic ideals and the definitive justification

Earlier in the Results, I described two epistemic ideals associated with epistemic products (Table 3). The second of these ideals was regularly associated with a switch to a definitive justification pattern: *Good epistemic products contain information that can provide proof-of-point or validation.* As with the previous section, I provide an interview excerpt exemplifying the association between epistemic ideals and the definitive justification pattern. This excerpt is taken from an interview with Christine. Christine is a policy-maker in the community who is serving a representative role in town government. She has been active in town policy for approximately 17 years and engages with science as a part of her role, but has no academic background in science. When shown the first claim (the same claim used for the previous two examples on biodiversity and ecosystem enhancing ES), Christine responded with immediate support:

> *The wetland is probably just beneficial in general for keeping the river clean. I mean…It sounds like it would be to me…That it would be beneficial to keep the river clean so if it's something that would benefit that, it would probably be worth it.*

I asked her how she knew this, to which she used a source of scientific knowledge: a personal observation that a plant can ‘clean water’ to argue why this ES “makes sense” and would “be worth it”:

> *I have a beta fish and they told me to put a plant in the water when I got it to help keep the water clean and it does… You know, it makes sense that a plant would keep something clean…What’s good about this to me is … It’s giving it another purpose outside of storm surge, which to me makes me happy.*

In this example, Christine has clearly made a decision that the wetland will clean the water and uses scientific accounts and resources from her personal experiences to *validate* this decision. As a whole, epistemic ideals associated with proof-of-point, prompted a quick transition to a definitive justification either for or against a claim.

Science knowledge and the definitive justification

Thus far, I have discussed specific associations between epistemic aims, ideals and a definitive justification. There is also an apparent role for prior knowledge in maintaining a questioning cycle; in instances when participants engaged with science using a questioning cycle, they evoked statistically more unique science ideas and developed more sophisticated science accounts (Table 5). On average, instances with a questioning cycle had three more ideas than instances with the definitive justification pattern. The reason for this relationship was not just because some types of ES had fewer relevant ideas; in fact, at least one participant used a wide range of ideas for each type of ES. Similarly, as mentioned before, all participants at some instances engaged in a definitive justification pattern and in other instances a questioning cycle, and these instances were based upon the type of ES that they were evaluating. It is, therefore, clear that prior conceptual knowledge can play a role in the pattern of engagement that citizens use, in concert with the other dimensions of epistemic cognition.

Discussion

Questioning is one of eight key scientific practices in the NGSS and the questioning cycle embodies a mode of scientific reasoning that more closely reflects authentic science and progressive engagement with science, a constant pursuit of knowledge (Bransford, Brown, & Cocking, 1999; CRB, 2014; Duschl, 2008; Feinstein, 2014; NRC, 2012;). The findings of this paper indicate that despite their years of experience engaging with science in the public domain, participants did not use questioning-cycle for all types of ES. The was the case for all participants, even academic scientists, who at some point during their engagement with science, stopped questioning and used a definitive justification pattern depending upon the ES that they were considering. These results illustrated a role of epistemic ideals, epistemic aims, and prior knowledge in determining the pattern of engagement used for a specific type of ES and here I discuss these findings in relation to knowledge, important to scientific literacy and what it means to be a competent outsider.

The questioning cycle was clearly linked to the science ideas that participants brought to bear. Most of the participants in this study used big science ideas about ES (e.g. change in systems, structure function) in education literature, national policy documents, and standards (Authors, 2015a; NRC, 2012). The Framework includes most of the ideas as crosscutting concepts (NRC, 2012), which is a testament about their necessity for scientific literacy. These findings, however, show less consistency in the use of some of the DCIs and their components; some of the more sophisticated component ideas were less common (e.g. *Rates of flows, transformations, resilience, organism needs, scale of context, impacts across levels of organization, and non-linear change*). While interesting, again, it is unclear whether the lower use of these more sophisticated ideas was representative of limited knowledge of participants or their view that the idea was not important to the situation at hand. It is clear, however, that citizens should be able to apply the NRC Crosscutting Concepts to situations involving ES.

I also found a clear relationship between using a definitive justification pattern of engagement, and the use of epistemic aims and epistemic ideals, that are incongruous with that of science (e.g. using non-epistemic aims to guide judgment and viewing good epistemic products as providing proof-of-point). In this way, we can answer the question: *What does one need to know in order to be scientifically literate about ES?* It is important to have a deep understanding: (a) of the NRC Crosscutting Concepts, (b) that epistemic aims and non-epistemic aims need to be articulated and separated, and (c) that epistemic products are limited and do not provide proof-of-point.

In light of these findings, I propose building on Feinstein's definition of a Competent Outsider (Feinstein, 2011). Here, I provide a revised definition of Competent Outsiders with revisions in *italics*:

> Competent outsiders are people who have learned to, *(a)* recognize the moments when science has some bearing on their needs and interests, *(b) articulate ideas related to Crosscutting Science Concepts, (c) recognize their non-epistemic aims and place them aside in the interest of reducing their biases when engaging with science, (d) look at sources of scientific expertise as limited not proof of a point,*

and (e) to interact with *such* sources of scientific expertise in ways that help them achieve their own goals.

The findings of this study indicate that those who fit this definition of a Competent Outsider will be better positioned to engage in questioning cycles when they have the appropriate context and situation-specific knowledge.

Implications and Limitations

Although this study identified a number of science ideas that are used widely in evaluating the specific claims about ES in the context explored in this study, the results described herein are reflective of this singular context and an account of a small group of citizens with experiences engaging with science. The results of this study nonetheless indicated that, even within this single situation, the ways in which individuals engaged with science varied depending upon the dimension under consideration. This result points toward a need for an extensive research agenda that studies engagement with science by competent outsiders, in a wide array of situations and specifically identifies those science ideas that come up again and again, situation after situation. Research is also needed on later stages of community decision-making, as individuals use other reliable processes such as finding and interacting with sources of scientific expertise. The patterns of engagement identified here suggest aspects of learning and engagement that require support in the classroom. Teachers will need to, (a) bring students' attention to the multiple aims that people will have when engaging with science, to evaluate ES, as well as their potential impact of scientific engagement, (b) help learners focus on an epistemic aim that limits biases associated with non-epistemic aims, (c) help students incorporate limitations of scientific resources into their reasoning about a claim, and (d) provide learners with help developing personal scientific accounts, that include at least some of the science ideas that we found as most commonly brought to bear (Table 5).

References

Anderson, C.W. (2010). Learning progressions for environmental science literacy. Paper presented to the NRC National Standards Framework Committee, March, 2010.

Anderson, C.W. & Doherty, J.H. (2014). Ecosystems: Interactions, Energy, and Dynamics. Unpublished manuscript under review for publication.

[Authors, 2015a] Dissertation Chapter 2

[Authors, 2015b] Dissertation Chapter 3

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

Bredo, E. (1994). Reconstructing educational psychology: Situated cognition and Deweyan pragmatism. Educational Psychologist, 29(1), 23–35.

Brody, M.J. (1991). Understanding of pollution among 4th, 8th, and 11th grade students. Journal of Environmental Education, 22, 24-33

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32–42.

Carlsson, B. (2002). Ecological Understanding 2: transformation – a key to ecological understanding. International Journal of Science Education, 24, 701-715.

Chinn, C.A., Buckland, L.A., Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. Educational Psychologist, 46(3), 141-167.

Chinn, C.A., Rinehart, R.W., Buckland, L.A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D. Rapp and J. Braasch (Eds.), Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences (pp. 425-453). Cambridge, MA: MIT Press.

Covitt, BA., Tan, E.,Tsurusaki B.K., & Anderson, C.W. (2009). Students' use of scientific knowledge when making decisions in citizens' roles. Paper presented at the Annual Conference of the National Association for Research in Science Teaching, Garden Grove, April 7-21.

Creswell, J.W. (2007). Qualitative Inquiry and Research Design: Choosing Among the Five Approaches. Los Angeles, CA: Sage Publications, Inc.

Duschl, R.A. (2008). Quality argumentation and epistemic criteria. In S. Eduran & M.P. Jimenez-Aleixandre (Eds.), Argumentation in Science Education (159-178). Netherlands: Springer

Feinstein, N. (2010). Salvaging scientific literacy. Science Education, 95(1), 168-185.

Feinstein, N. (2014). Making sense of autism: progressive engagement with science among parents of young, recently diagnosed autistic children. Public Understanding of Science, 23, 592-609.

Frederiksen, C. H. (1975). Representing logical and semantic structure of knowledge acquired from discourse. Cognitive Psychology, 7, 371-458.

Ginsburg, H. (1997). Entering the child's mind: the clinical interview in psychological research and practice. New York, Cambridge University Press.

Gunkel, K.L, Covitt, B.A., Salinas, I. & Anderson, C.W. (2012). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching, 49, 843-868.

Hoefer, B.K., & Pintrich, P.R. (2002). Personal epistemology: the psychology of beliefs about knowledge and knowing, Mahwah, NJ: Lawrence Erlbaum Associates.

Hogan, K. & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. Journal of Research in Science Teaching, 38, 6, 663-687.

Holling, C.S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4, 1–23.

Hovardas, T. & Korfiatis, K. (2010). Towards a critical re-appraisal of ecology education: scheduling an educational intervention to revisit the 'balance of nature' metaphor. Science and Education, Online First™, 30 November 2010.

Hung, D., Chen, D-T. V. (2007). Context-process authenticity in learning: implications for identifying enculturation and boundary crossing. Education Technology Research and Development, 55(2), 147-167.

Hurd, P. D. (1958). Science literacy: it's meaning for American schools. Educational Leadership, 16(13–16), 52.

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. Psychological Review, 85(5), 363-394.

Krasny, M.E., Russ, A., Tidball, K.G., Elmqvist, T. (2014). Civic ecology practices: Participatory approaches to generating and measuring ecosystem services in cities. Ecosystem Services, 7, 177-186.

Kuhn, D & Weinstock, M., (2002). What is epistemological thinking and why does it matter? In B.K. Hoffer & P.R. Pintrich (Eds.), Personal epistemology: the psychology of beliefs about knowledge and knowing (pp. 121-144). Mahwah, NJ: Lawrence Erlbaum Associates.

Layton, D., Jenkins, E., Macgill, S., & Davey, A. (1993). Inarticulate science? Perspectives on the public understanding of science and some implications for science education. Leeds, England: University of Leeds.

Lewenstein, B.V. (2015). Identifying what matters: science education, science communication, and democracy. Journal of Research in Science Education, 52(2), 253-262.

[MA] Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis, Washington, DC: Island Press.

McCallie, E., Bell., L., Lohwater, T., Falk, J.H., Lehr, J.L., Lewenstein, B.V., Needham, C., Wiehe, B. (2009). Many experts, many audiences: public engagement with science and informal science education. A CAISE Inquiry Group Report. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE). http://caise.insci.org/uploads/docs/public_engagement_with_science.pdf

Mohan, L., Chen, J., & Anderson, C.W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46, 675-698.

[NRC] National Research Council (2011). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea. Washington, DC: National Academies Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. Journal of Research in Science Teaching, 40, 692-720.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M. (2004). Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. Landscape and Urban Planning, 69, 369-384.

Rodriguez, A.J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the Next Generation Science Standards. Journal of Research in Science Teaching, 52(4), 448-460.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research in science education (pp. 729–779). Mahwah, NJ: Erlbaum.

Roth, W-M. & Lee, S. (2002). Scientific literacy as collective praxis. Public Engagement with Science, 11, 33-56.

Stigloe, J., Lock, S.J., & Wilsdon, J. (2014). Why should we promote public engagement with science? Public Engagement with Science, 23(1), 4-15.

Definition and Big Ideas about Ecosystem Services as articulated by Authors, 2015

Ecosystem Services (ES) are a vast array of direct and indirect, market and non-market, as well as perceived and intangible benefits that humans gain as a result of being connected to functioning ecosystems, native or modified. We can articulate some specific ES, but the total number of benefits gained from functioning ecosystems is beyond human comprehension; therefore, any accounting system developed to include ES will *not* include them all. Some ES result in resources that can be actively extracted as goods and traded, while others require no human effort to obtain and human activity alters the provisioning of these different ES by changing ecosystem structure. The ES that provision resources do so at a limited rate that changes depending upon the flow of matter and energy to that extractable resource, the rate of which is dynamic. Including ES in decision-making can provide incentives to conserve native ecosystems or restore functioning to ecosystems.

Big Idea 1*:* Humans are embedded within ecosystems and benefit from them in many, if not countless ways, directly and indirectly, actively and passively, and many of these benefits are not a part of traditional markets.

Big Idea 2: Ecosystems from which humans benefit have interactions at local, regional, and global scales that embed human populations in ecosystems close-by as well as far-away.

Big Idea 3: Ecosystems from which humans benefit can only process wastes and provision resources at limited rate. If humans extract resources or dump wastes at a rate that exceeds an ecosystem's capacity, that ecosystem will become over-exploited or polluted. This places constraint upon the human population.

Big Idea 4: Ecosystem functioning depends upon the flows of matter and energy through the system and this functioning is important for the provision of some Ecosystem Services, such as resource-provisioning and waste-processing services.

Figure 1: Definition and Big Ideas about Ecosystem Services as articulated by Authors, 2015

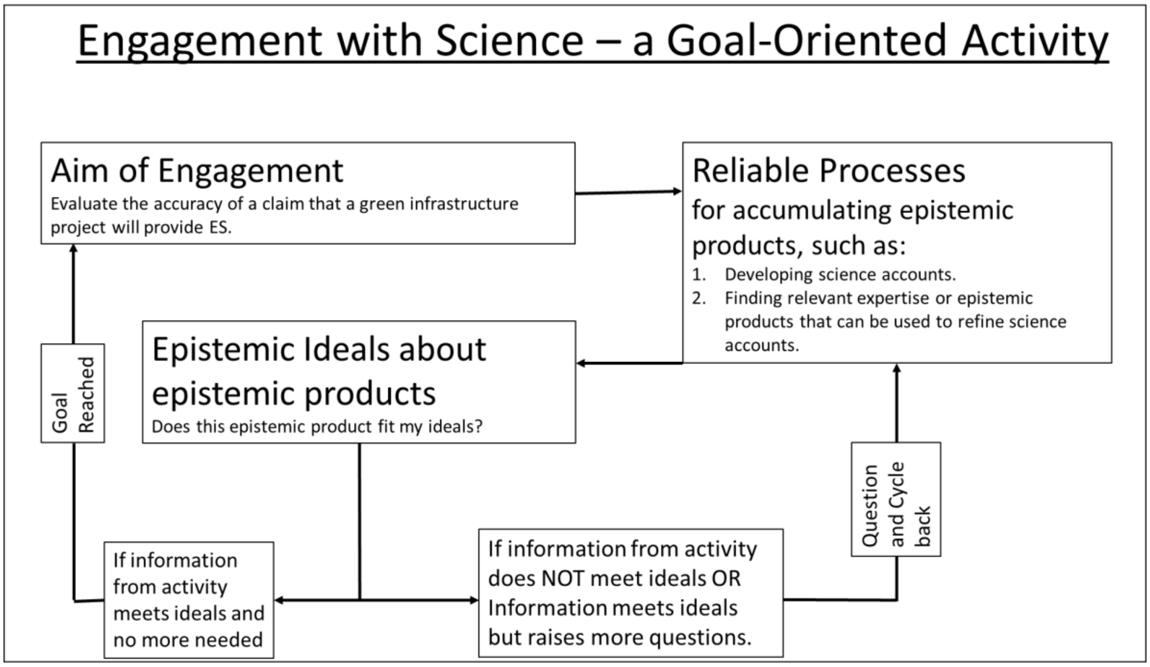

Figure 2: Engagement with Science

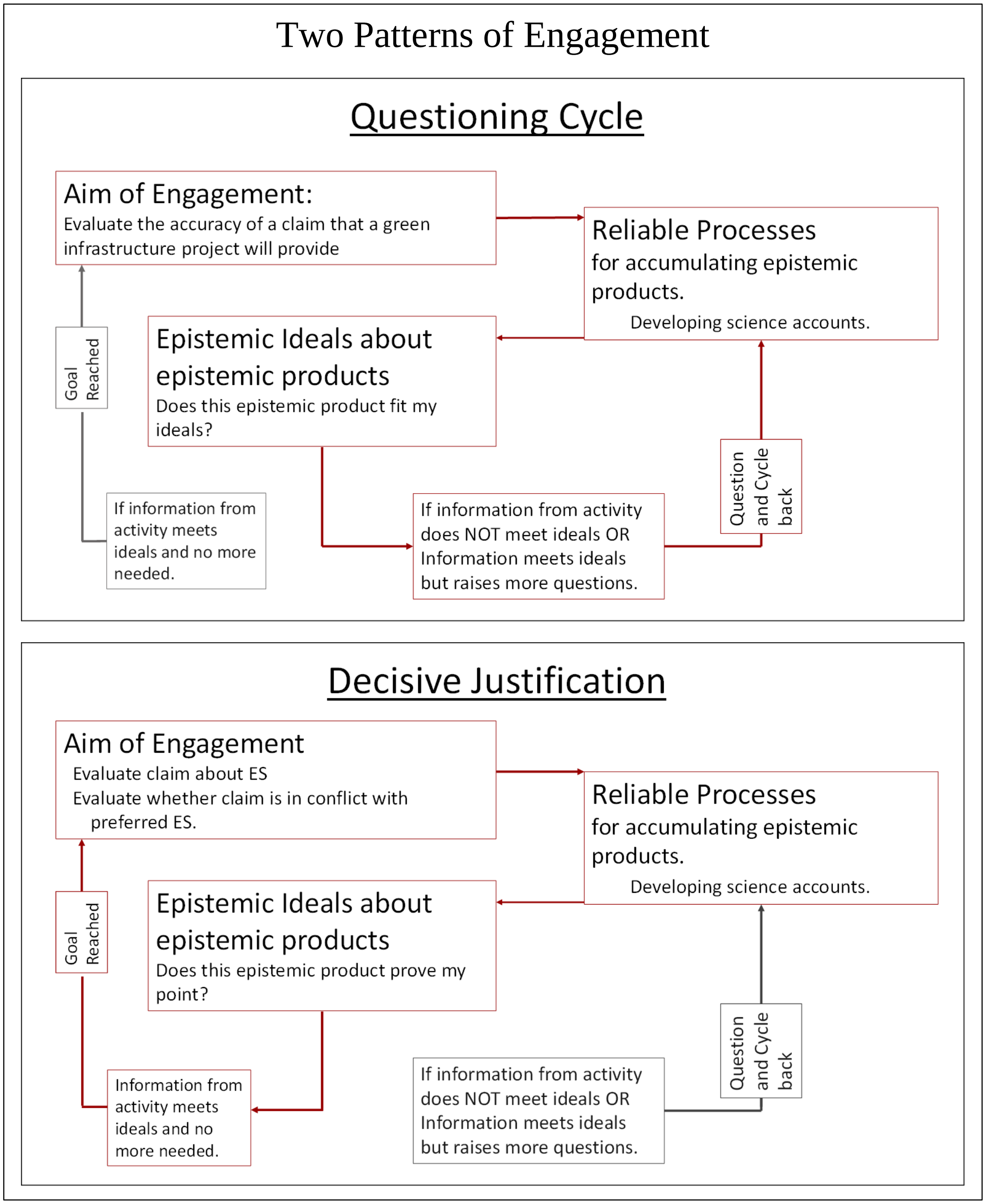

Figure 3: Patterns of Engagement

Table 1
Claims provided during interviews

Claim		Type of ES and supporting evidence used in claim
1	"You know, we could think of the wetland as a way of improving our relationship with the [River]. Unlike the sea wall, the engineered wetlands along the…River will help enhance the…Estuary Ecosystem, particularly as more of these are built throughout the region. It does so by providing breeding ground for fish, processing natural wastes from the…River, providing a sanctuary for birds and other wildlife, etc."	*ES: Ecosystem supporting and biodiversity enhancing services.*
2	"The constructed wetlands can provide benefits like flood control and shoreline stabilization as well. These can reduce risk and act as a sort of insurance policy to mitigate the effects of natural disturbances"	*ES: Regulating services*
3	"The wetlands can also help reduce direct costs associated with treatment of our waters. With new changes to Environmental Protection Agency (EPA) mandates, the…Sewer Authority will pay fines when their system is overwhelmed during heavy rain events forcing them to discharge untreated water into the river. In combination with an array of green design elements, the constructed wetlands can help clean water as a final polish during these events where some otherwise untreated water might end up in the [River]. Thus an added benefit of the wetland is not having to upgrade the treatment plant, avoiding costly expenses in this regard."	*ES: Provisioning services*
4	"It is important, to design the wetlands in a way that the components within them are resilient to the conditions of the city. They need to be designed to be functional beyond pretty. Engineered wetlands have succeeded in other locations. The Netherlands, for example, has been using them for years to help alleviate coastal flooding. There's no reason why [TOWN] should be different and should not be able to construct these wetlands."	*ES: Regulating Services Supporting evidence: Comparison to case study*
5	"We've used hydrologic computer models to demonstrate that the wetlands will be as good at reducing the hazard of floods as the deployable sea wall."	*ES: Regulating Services Supporting evidence: Model output*

Table 2
Types of Ecosystem Services

Category of ES	Examples
Cultural Services	Recreation, education, aesthetics, open space, improved human interactions, biodiversity *for human enjoyment*, etc.
Ecosystem Supporting and Biodiversity Enhancing Services	Biodiversity *for ecosystem functioning*, natural cleaning, improved watershed quality, etc.
Regulating Services	Flood regulation, shoreline stabilization
Disservices	Mosquitoes, sulfur smells during low tide
Provisioning Services	Storm water treatment, sewage treatment, provision of clean air for humans, etc.

Table 3
Frequency of Epistemic Aims and Ideals

			Number of Participants
Epistemic Aims	*Evaluate the scientific merit of the claim that the wetlands will provide specific ES.*		10
	Evaluate whether the wetland design supports a preferred ES.		4
		Epistemic Products	Number of Participants
Epistemic Ideals	*Good epistemic have clearly articulated limitations that constrain the inferences that can be drawn from these products*	Models	7
		Comparative Evidence	8
	Good epistemic products contain information that can provide proof-of-point or validation-of-point	Models	7
		Comparative Evidence	6

Table 4
Frequency of ES Content Ideas

Type of Account	ES Big Ideas	Associated Science Ideas with Increasing Level of Sophistication	Number out of 14
Identifying properties of ecosystems that contribute to ES	Matter and energy flow through ecosystems	1a. Matter & energy move through system or does NOT move through system.	12
		1b. Matter & energy pools or spreads (e.g. spreads to next lowest point).	10
		1c. Matter & energy, time to diffuse or move through system	6
		1d. Transforming matter to different form: mechanism of change articulated with inputs and outputs (Not just spreading or moving material or ES itself of 'cleaning').	2
	Systems change but functioning ones are resilient	2a. Systems change and deal with changing conditions, general	13
		2b. Environmental conditions change	5
		2c. Ecosystems need to adapt to environmental change and maintain themselves in spite of conditions	4
	Ecosystem-Level Structure - Functioning	3a. Ecosystem-wide structure related to functioning Can include "native-like" or "restored nature" as a descriptor	14
		3b. Having redundant or diverse components contributes to the adaptability and resilience of system.	12
	Organisms-Level Structure - Functioning	4a. Function (other than adaptability, e.g. ES) from component/organism scaled up to ecosystem	12
		4b. Specific resource or condition requirements of an organism (e.g. right amount of water, low salinity)	7
		4c. Diversity of organisms contributes to the adaptability and resilience of system.	1
	Regional-Level (context) Structure - Functioning	5a. Context: interactions between location at hand and surrounding region (e.g. migration, seed deposition)	8
	Scale, Proportion, and Quantity	6a. More nature/green infrastructure is better	12
		6b. Size/Measurement Scale: size, height, elevation of cartographic elements	14
Determining the importance of potential impacts to ES	Amount of impact and limits	9a. Limited amount of impact can be handled (includes frequency of impact. quantity, time not necessarily explicit)	11
		9b. Flow rate in relation to the capacity of an ecosystem or organism to perform function (amount/time)	6
	Uncertain Outcomes	10a. Outcomes not entirely predictable, not 100% guarantee	9
		10b. Uncertainty in future casting from scientific models	6
		10c. System may change uncontrollably/may do something unintended.	4

Table 5

Number of Science Ideas versus Type of Engagement

Engagement Type	Number of Instances	Mean Number of Science Ideas	Standard Deviation	*p*
Questioning Cycle	30	8.367	5.359	0.018
Definitive Justification	35	5.229	5.076	

Chapter 5: Concluding Discussion

This dissertation research has sought to improve understanding of scientific literacy associated with Ecosystem Services (ES), specifically adopting a perspective of scientific literacy for use in everyday life. A central aim of this research was to characterize what one needs to know, in order to be scientifically literate in this regard. I specifically was interested in characterizing: (a) *conceptual knowledge* about ES, (b) *epistemic knowledge* relevant to evaluating claims about ES, and (c) *strategic knowledge for engaging with science* when evaluating claims and making decisions about ES.

In this dissertation, I have used two different approaches to characterize important knowledge and arrive at a more comprehensive understanding of scientific literacy about ES: (a) develop a description of what is important, based upon the conceptual, epistemic, and strategic knowledge, experts agree is important in a domain (ES) and (b) develop a description of what is important, based upon what is used by citizens in everyday life. In Chapters 2 and 3, I used expert survey to characterize: (a) big conceptual science ideas about ES, and (b) strategies for questioning and finding relevant evidence about ES. In Chapter 4, I used the second approach, identifying conceptual, epistemic and strategic knowledge used by individuals when evaluating authentic claims about ES. In this concluding chapter, I provide a synopsis of the key findings that emerged regarding, (a) conceptual, (b) epistemic, and (c) strategic knowledge, important to scientific literacy about ES. I also look across the findings to offer recommendations for future research on scientific literacy and propose a model for classroom instruction on ES.

Conceptual Knowledge: Big Science Ideas about ES

This dissertation research identified important conceptual knowledge about ES based on both, (a) the big ideas of the academic domain and (b) the use of science ideas by candidate Competent Outsiders. In Chapter 2, I used a Delphi survey of academic experts in ES to identify big science ideas about ES that are important for citizens to know. Six big ideas assembled from a set of component concepts emerged as important (see Figure 1, Chapter 3). I noted that most of these big ideas and component ideas are present in the NRC Framework for K-12 Science Education (NRC, 2012), but dispersed among Disciplinary Core Ideas (DCIs) including, (a) Biodiversity and Humans, (b) Ecosystems: Interactions, Energy, and Dynamics, and (c) Earth and Human Activity. The presence of most of these ideas in the Framework is encouraging, and based upon the findings of this dissertation research, I argue that articulating ES in each of these DCIs is practical for two reasons: (a) most of the conceptual ideas are already present in these DCIs and provide an easy juncture for including ES at the ecosystem and earth-systems levels of organization, and (b) in Chapter 4, most participants discussed ecosystem services using structure-function relationships at the ecosystem level and biodiversity level, but used more sophisticated ideas at the ecosystem level of organization. As described in Chapter 4, reasoning across levels of biological organization is considered an important target of environmental science education (Mohan, et al., 2009). For example, Mohan and colleagues (2009) emphasize the importance of molecular-level carbon-transforming processes in global carbon cycling. This sophisticated way of thinking about ecological functioning and ES was uncommon among participants in Chapter 4, providing evidence that including ES at multiple levels of organization may be necessary to help learners develop a more comprehensive understanding of ES. Together, these findings strongly support linking ES to their component ideas in each of the DCIs in future iterations of the Framework. This argument is also echoed in emerging research on environmental science education (Anderson & Doherty, 2015).

Epistemic Knowledge for Engagement with Science

This dissertation used one data source to characterize important epistemic knowledge for engaging with ES: descriptions of authentic engagement with science by citizens. In Chapter 4, I analyzed the epistemic cognition of citizens as they engaged with science to evaluate authentic claims about ES from green infrastructure. From this research, I identified two important components of epistemic knowledge that can be used when evaluating claims about ES: (a) that citizens need to know their non-epistemic aims and the influence that these non-epistemic aims have on their reasoning and (b) that citizens need to know how to look for limitations of scientific evidence, not proof-of-point. These observations were drawn from the results in Chapter 4, showing a relationship between these qualities of epistemic knowledge and the pattern an individual used to engage with science while evaluating claims about ES. For example, I identified the first quality of epistemic knowledge (that citizens should learn to segregate epistemic and non-epistemic aims) based upon the findings that those with the epistemic aim, *Evaluate whether the wetland design aligns with a preferred ES over another ES (e.g. recreation over biodiversity)*, often cut their questioning cycles short and instead used a definitive justification pattern of engagement.

This finding that there is certain epistemic knowledge associated with epistemic aims is novel. The research in this dissertation is the first known empirical research using epistemic aims as an explicit component of epistemic cognition. CRB (2014) added epistemic aims as a dimension of epistemic cognition: a dimension of motivation that has historically been viewed as distinct from epistemic cognition. This distinction was a result of viewing motivation as a single unit rather than distinguishing it into epistemic and non-epistemic aims. This research has shown some of the ways in which epistemic aims can be molded by non-epistemic aims and that it is important to know how one's own epistemic aims are affected by their non-epistemic aims.

In addition to epistemic knowledge about aims, I also found that it is important to know that *epistemic products have limitations that are clearly articulated.* This is in contrast to products offering proof-of-point. I based this claim on both the fact that viewing epistemic products as *proof* is incongruous with scientific views, as well as the finding (presented in Chapter 4) that those participants who had this ideal, commonly used it to end their questioning cycle and transition to a definitive justification pattern of engagement. It is important to note that although knowing specific limitations of epistemic products in relation to different ES is likely dependent upon domain-specific and situation-specific knowledge, this knowledge may not be necessary to have epistemic ideals associated with having clearly articulated limitations. Some participants in Chapter 4 continued to demonstrate epistemic ideals associated with limitations even when they were less knowledgeable about a specific type of evidence or situation.

In summary, there are two components of epistemic knowledge that I found to be relevant to scientific literacy about ES: (a) knowing how to segregate epistemic and non-epistemic aims, and (b) knowing that all epistemic products have limitations to consider. From this discussion, it is clear that this research supports at growing consensus that epistemic cognition consists of independent dimensions of motivations and beliefs (Chinn Rinehart & Buckland, 2014; Hoefer & Pintrich, 1997). This type of epistemic knowledge is also considered important in literature on the Nature of Science (NOS) (Lederman, 2007; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003).

Strategic Knowledge: ES-Citizen-Inquiring Knowledge

When citizens engage with science, they ask questions and carry out reliable engaging processes to answer these questions and develop more informed decisions (CRB, 2014; Anderson, 2010; Mohan et al., 2009; Duschl, 2008). This engagement relies upon a set of domain-specific and citizen-specific strategic knowledge for engagement that I called *ES Citizen-Inquiring Knowledge* (ES-CIK). ES-CIK is strategic knowledge that citizens can use when engaging with science to evaluate claims and make decisions about ES. This ES-CIK includes knowing key inquiring-questions as well as practices that can be used to find relevant scientific expertise. In this dissertation research, I used two sources of data to characterize ES-CIK: (a) expert (in ES) consensus about academic questions and procedures that are useful for decisions involving ES, and (b) characterization of actual procedures used by citizens when engaging with science.

In Chapter 3, I used a Delphi Study to develop a description of ES-CIK, rooting this description in prior research on the kinds of questions citizens ask, when engaging with science in everyday life. This description of ES-CIK contained five core-inquiring questions and six inquiring practices for finding important scientific information related to these questions (see Table 4, Chapter 3). These inquiring questions and practices fit into two broad categories: (a) ecosystems and services identifying practices and (b) impact-identifying practices. In Chapter 4, I found that all participants asked questions and constructed science accounts related to both of these categories.

These inquiring questions and practices are important strategic knowledge that citizens can use to guide their engagement with science. Knowing good questions and practices for finding available scientific resources is a key component of engagement with science, that is "interacting with sources of scientific expertise" (Feinstein, 2011, p. 13) rather than pseudo-science (Feinstein, 2014).

Implications for Research on Science Education

In this section, I focus on three main implications that this dissertation work has for research in science education. I begin highlighting a major implication described in Chapter 2; a refined content model for future research on environmental science education. I then highlight implications for research using the concept of Competent Outsiders, refining this concept. I close highlighting the need to articulate domain-specific and citizen-specific practices that can more clearly connect science content to authentic problems and decisions that citizens' face in their everyday lives.

Refining upper anchor content understandings related to ES

In the prior section, I made the recommendation of including ES in three DCIs to better link the existing ideas in those DCIs to ES: *Biodiversity and Humans; Ecosystems: Interactions, Resilience, and Dynamics;* and *Earth and Human Activity*. Here, I specifically focus on the upper anchor for that knowledge.

The research in this dissertation provides recommendations for refining the upper anchor understanding of ES, a refinement that can guide future science education research in this domain. In Chapter 2, I provide a graphical representation of this refined upper anchor (Figure 3) that has six important refinements from the graphical model commonly used in science education research on coupled human-environment systems (Anderson, 2010; Covitt, Tan, Tsurusaki, & Anderson; Gunkel, Covitt, Salinas, & Anderson, 2013; Mohan, Chen, & Anderson, 2009): (a) humans systems are depicted as embedded within environmental systems at various scales, (b) there are multiple human populations embedded in this global and regional system, (c) between these local human systems, there is trading of resources, (d) there is a flow of ES from both local and regional/global environmental systems, (e) ES are vast including more than resources, and (f) there are human impacts to environmental systems that can affect the provision of ES to local, as well as other human populations. This refined model does not add a large array of new concepts, but a clearer visualization of most concepts already discussed in environmental science education literature. For example, the learning progressions developed for this domain commonly include *perception at various scales* such as local, regional and global scales (Gunkel, et al., 2012; Mohan, et al., 2009). Similarly, the research in this domain already articulates different types of ES, bringing to bear not only resource-provisioning ES (Gunkel, et al., 2012), but also those that contribute to human conditions (Wilson, et al., 2007).

The new framework articulated in this dissertation, therefore, adds only one truly novel idea: *there are multiple human populations, between which there is a trade of resources*. This new idea has ecological grounding (populations interact across landscapes in ecological systems), but primarily emerges from the social sciences side of ES research. The fact that humans trade resources and move them around the world plays a strong role in how we perceive the impacts of actions. For example, when citizens of the United States purchase products that have rare earth metals from a mine in Asia where environmental regulations are not as strict, they are unlikely to see or experience the environmental consequences of this action. The local populations in these distant locations are the ones who primarily feel these consequences. This example makes it clear that ES are at the intersection of the natural and social sciences, and a future task articulated in the NRC Framework is integrating social sciences into this framework (2012, pp. 13-14). The research in this dissertation provides information toward that aim.

Refining the definition of competent outsider

An important target for future science education research will be to use descriptions of how "Competent Outsiders" engage with science. In Chapter 4, I used interviews with citizens who fit a number of criteria for *candidate* competent outsiders, but also found that some of these participants had epistemic ideals about scientific evidence that were incongruous with scientific views. I also found that some of these participants had epistemic aims that were deeply embedded in their personal preferences and non-epistemic aims. Therefore, I developed a refined definition of Competent Outsiders that I recommend should serve as a criteria for selection of participants in future research of this nature:

> Competent outsiders are people who have learned to: *(a)* recognize the moments when science has some bearing on their needs and interests, *(b) articulate ideas related to Crosscutting Science Concepts, (c) recognize their non-epistemic aims and place them aside in the interest of reducing their biases when engaging with science, (d) look at sources of scientific expertise as limited not proof of a point,*

and (e) to interact with *such* sources of scientific expertise in ways that help them achieve their own goals.

Articulating domain-specific and citizen-specific practices

The ES-CIK presented in this dissertation adapts scientific practices described in the NRC Framework to citizenship-practices specific to the domain of ES. This domain-specific and citizen-specific adaptation is important in light of prevailing evidence that domain-specific knowledge plays an important role in scientific practices (McNeil & Krajcik, 2009; Muis, Bendixen, & Haerle, 2006; NRC, 2012; Penner & Khalr, 1996; Sandoval & Millwood, 2005). This adaptation is also important in light of evidence that citizens engage with science in different ways than experts (Layton, Jenkins, MacGill, & Davey, 1993; Feinstein, 2014). Future research on the "useful" dimension of scientific literacy should develop adaptations of practices for multiple domains and refine these practices over time as more becomes known about how citizens use these practices when engaging with science to solve meaningful problems and make informed decisions.

Implications for curriculum and instruction

This dissertation research when considered as a whole provides a vision for curriculum and instruction about ES. Learners should have an opportunity to engage in activities where they create and evaluate claims about ES in ways similar to those done by the participants in Chapter 4. These activities should be rooted in local everyday decisions for at least some of the decisions listed in Chapter 3. Because of the importance of learning about different epistemic and non-epistemic aims associated with ES, I recommend dividing a class into groups and assigning different group members different stakeholder roles. For this part of the activity, it will be important to scaffold learning of epistemic knowledge associated with aims, requiring learners to clearly describe the effect that their stakeholder role has on their epistemic aim.

In their roles as stakeholders, learners should also be given domain-specific and context-specific scaffolds (McNeil & Krajcik, 2009) to guide their engagement with science. The questions provided in Chapter 3 are adapted to specific decisions and can serve ES-specific scaffolds for inquiry. The inquiring practices in Chapter 3 can also serve as a guide to finding available scientific evidence; however, given the findings of Chapter 4, it will be important to provide more detailed domain-specific scaffolds to help learners identify important limitations of the evidence that they find.

As learners engage with science to develop their stakeholder opinions, they should develop scientific accounts of their findings. Again, in light of the findings in Chapter 4, learners will need domain-specific scaffolds to help them attend to important conceptual ideas. The important conceptual ideas identified in Chapter 2 can serve as a guide to developing these scaffolds. Throughout this activity, learners should regularly discuss their perspectives with others and identify important new questions to drive an iterative cycle of questioning that prompts deeper learning through progressive engagement with science.

Future Directions

This dissertation research was an attempt to more fully integrate ecosystem services (ES) into environmental science education research. I did so using a model for empirical research on scientific literacy developed by Feinstein (2011) that makes use of both expert knowledge and research on public engagement with science to more fully vet claims about knowledge important to scientific literacy. Based on expert opinion, I have articulated a contemporary definition of ES, a contemporary set of big ideas about ES, and important strategic knowledge for engaging with science that I call ES-CIK. Using a case study on public engagement with science, I then examined whether this knowledge purported as important (through expert survey) was indeed used by citizens in an authentic situation. The findings of this study supported some of those important ideas identified by experts, but also added depth to this description of what is important, specifically adding the importance of epistemic knowledge about personal aims and ideals about useful evidence.

This research has raised a number of questions. For example: What are specific limitations that citizens should look for in scientific resources (e.g. evidence, and near-science resources) about ES? Answering this question will be important to designing appropriate learning scaffolds for classroom activities. Going forward, research using the refined criteria for Competent Outsiders will be needed, to better characterize conceptual ideas used by those fitting this criteria. Similarly, this research should more deeply explore the interaction between conceptual knowledge and epistemic ideals. This research should explore multiple situations and different types of ES. Finally, it will be important to characterize the inquiring practices used by citizens as they engage with science over time. The research described in this dissertation provided a snapshot in time, and longer-term studies of engagement with science will be needed to develop a more holistic picture of what one needs to know, in order to be scientifically literate about ES.

References

Anderson, C.W. (2010). Learning progressions for environmental science literacy. Paper presented to the NRC National Standards Framework Committee, March, 2010.

Anderson, C.W. & Doherty, J.H. (2014). Ecosystems: Interactions, Energy, and Dynamics. Unpublished manuscript under review for publication.

Chinn, C.A., Rinehart, R.W., Buckland, L.A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D. Rapp and J. Braasch (Eds.), Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences (pp. 425-453). Cambridge, MA: MIT Press.

Covitt, BA., Tan, E.,Tsurusaki B.K., & Anderson, C.W. (2009). Students' use of scientific knowledge when making decisions in citizens' roles. Paper presented at the Annual Conference of the National Association for Research in Science Teaching, Garden Grove, April 7-21.

Duschl, R.A. (2008). Quality argumentation and epistemic criteria. In S. Eduran & M.P. Jimenez-Aleixandre (Eds.), Argumentation in Science Education (159-178). Netherlands: Springer

Feinstein, N. (2011). Salvaging scientific literacy. Science Education, 95, 168-185.

Feinstein, N. (2014). Making sense of autism: progressive engagement with science among parents of young, recently diagnosed autistic children. Public Understanding of Science, 23, 592-609.

Gunkel, K.L., Covitt, B.A., Salinas, I., Anderson, C.W. (2012). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching, 49(7), 843-868.

Hoefer, B.K., & Pintrich, P.R. (2002). Personal epistemology: the psychology of beliefs about knowledge and knowing, Mahwah, NJ: Lawrence Erlbaum Associates.

Layton D, Jenkins E, Macgill S and Davey A (1993) Inarticulate Science? Perspectives on the Public Understanding of Science and Some Implications for Science Education. Driffield: Studies in Education.

Lederman, N. G. (2007). Nature of science: Past, present and future. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research on science education (pp. 831–880). Mahwah, NJ: Erlbaum.

Mohan, L., Chen, J., & Anderson, C.W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46, 675-698.

McNeil, K.L., Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena. Journal of the Learning Sciences, 18, 416-460.

Muis, K.R., Bendixen, L.D., Haerle, F.C. (2006). Domain-generality and domain-specificity in personal epistemology research: philosophical and empirical reflections in the development of a theoretical framework. Educational Psychology Review, 18, 3-54.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschle, R. (2003). What "ideas-about-science" should be taught in school science? A delphi study of the expert community. Journal of Research in Science Teaching, 40, 692-720.

[NRC] National Research Council (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea. Washington, DC: National Academies Press.

Penner, D.E., Klahr, D. (1996). The interaction of domain-specific knowledge and domain-general discovery strategies: a study with sinking objects. Child Development, 67, 2709-2727.

Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations. Cognition and Instruction, 23, 23-55.

Wilson, C.D., Tsurusaki, B., Wilke, B., Zesaguli, J., & Anderson, C.W. (2007). The development of an environmental literacy learning progression: biological diversity and change over time in environmental systems. Paper presented at the Center for Curriculum Materials in Science Knowledge Sharing Institute.