A MODEL FOR SUSTAINABILITY SCIENCE IN HIGHER EDUCATION:

WATER RESEARCH, SCIENCE AND SUSTAINABILITY LITERACY,

AND COMMUNITY ADAPTIVE CAPACITY

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A MODEL FOR SUSTAINABILITY SCIENCE IN HIGHER EDUCATION: WATER RESEARCH, SCIENCE AND SUSTAINABILITY LITERACY, AND COMMUNITY ADAPTIVE CAPACITY

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Abstract

Climate change, population growth, land use changes, and a society more tightly connected at a global scale are impacting our freshwater resources and are forcing some communities to respond to their changing environment. Communities that want to plan for a more sustainable future require fundamental information about social-ecological systems, a scientifically and sustainability literate population who can use information for decision-making, and high levels of adaptive capacity (i.e., access to and ability to mobilize human, social, natural, and financial capital). Through their tripartite mission of research, education, and service, institutions of higher education can help ensure that these community needs are met. Many institutions are already answering this call by engaging in sustainability science. There is, however, a lack of insight from the field of education informing the field of sustainability science. One result of this is that conceptual and applied models for sustainability science are not fully developed. The goal of this work was to develop and test a model, based on literature and best practice, that institutions of higher education could use to inform their work in sustainability science. This work used a case study, action research approach to test the developed model to determine if the expected outcomes were achieved. Results show that the model was effective in generating knowledge about freshwater systems and in increasing student researchers' scientific and sustainability literacy. Results also show that the original model *slightly* increased community adaptive capacity and a refined model is

offered to improve outcomes in this area. One major contribution of this work is that it puts forth a new conceptual model suggesting that sustainability science is a field of research, learning, and community engagement. Another important contribution of this research is that offers a new applied model that demonstrates how society, through its institutions of higher education, can functionally and effectively integrate research, learning, and community to work in the field of sustainability science and foster sustainability in social-ecological systems. This study is potentially transformative in suggesting new ways that institutions of higher education can address the challenge of sustainability.

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CHAPTER 1:

Introduction

The Context and Needs

When this work began climate change, population growth, land use changes, and a society that was more vertically and horizontally connected at a global scale were contributing to an increased awareness of and focus on environmental change. Individuals and communities were considering how change might affect different components of a complex system and what *best practices* for local and regional planning, preparation, and mitigation might be. The need to respond to a changing environment had people around the globe thinking about sustainability in some new and innovative ways. This research is a contribution to the discourse on sustinability as it offers conceptual and applied models of how society, through its institutions of higher education, can functionally and effectively integrate research, learning, and community engagement to do sustainability science and foster sustainability in social-ecological systems.

Sustainability science.

By the first decade of the 21st century sustainability science had really gained momentum to the point where it was widely recognized in the academic literature and was being institutionalized in many of the more forward thinking institutions of higher learning (Clark & Dickson, 2003; Clark, 2007). This was the result of a growing body of individual work that began in the 1980s, a series of international events (see Figure 1.1), and the field of sustainability science unifying as a distinct field around the beginning of the new millennium (Bettencourt & Kaur, 2011). The growing interest in and importance of this body of work was evidenced by the number of peer-reviewed journals focusing on sustainability that were launched during these years (Calder & Dautremont-Smith, 2009) and by the fact that sustainability science was given its own section in the Proceedings of the National Academies of Science (PNAS) in 2006.

1972	UN Conference on the Human Environment
1987	Publication of Our Common Future (Brundtland, 1987)
1988	Formation of the Intergovernmental Panel on Climate Change (IPCC) by the World Meteorological Organization and the United Nations Environment Programme (UNEP) (IPCC, 2013)
1990	First IPCC report is released (IPCC, 2013)
1992	United Nations Conference on Environment and Development (a.k.a. "Rio Summit")
1992+	Agenda 21, a product of the Rio Summit, a plan to implement sustainable development goals
2002	World Summit on Sustainable Development
2005	Publication of the Millennium Ecosystem Assessment - assessed the consequences of ecosystem change for human well-being (Millennium Ecosystem Assessment [MEA], 2005)
2005-2014	United Nations (UN) launches the Decade of Education for Sustainable Development (2005-2014; United Nations Educational, Scientific, and Cultural Organization [UNESCO], 2013a).
2012	Rio +20 United Nations Conference on Sustainable Development (UN, 2011)

Figure 1.1. Timeline of events impacting sustainability thinking. This timeline depicts some of the major international events and publications that inform the concept of sustainability.

Sustainability science is currently described by the Proceedings of the National Academy of Sciences (PNAS, 2013) as:

> an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems. Research in this area focuses on both the fundamental character of interactions among humans, their technologies, and the environment, and on the use of such knowledge to advance sustainability goals relevant to water, food, energy, health, habitation, mobility, and ecosystem services.

How then is sustainability science research accomplished? Some current conceptual models show that sustainability science research is use-inspired reseach informed by stakeholder engagement (Lang et al., 2012; Sustainability Solutions Initiative [SSI], 2013). While these models allude to the export of knowledge they do not clearly articulate that learning is an essential element of sustainability science. Here, I offer a conceptual model that includes learning as a required component of sustainability science (Figure 1.2).

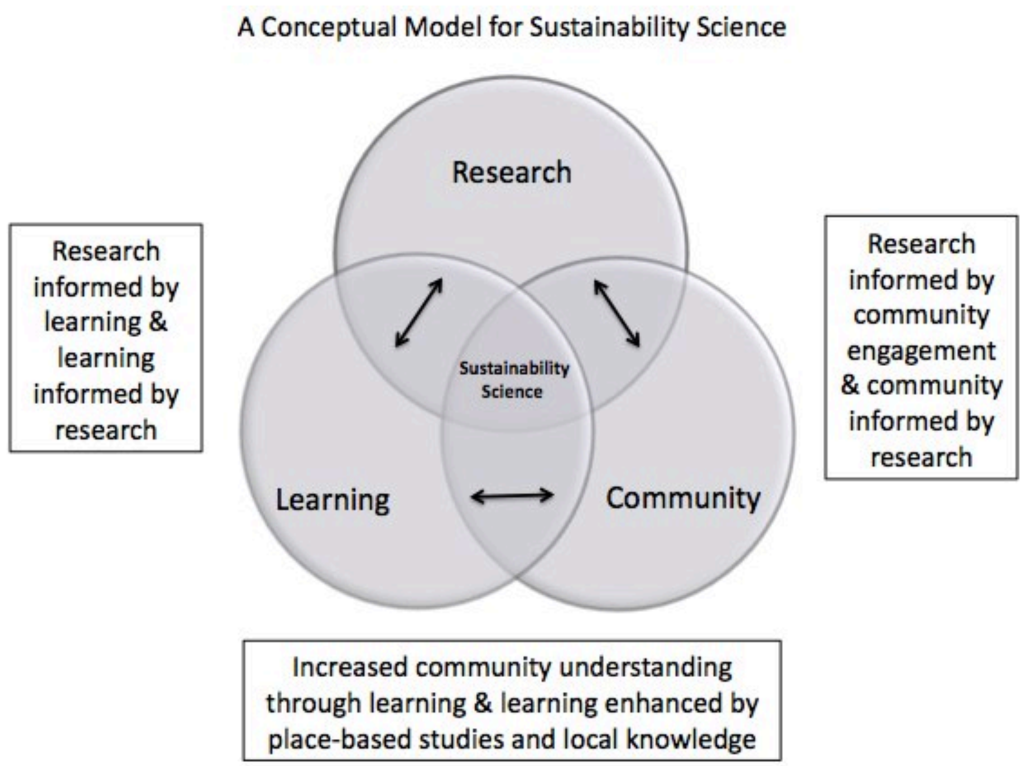

Figure 1.2. A conceptual model for sustainability science. This conceptual model illustrates that three essential components (i.e., research, learning, and community) inform one another to facilitate sustainability science.

It should be made clear that the domains of research, learning, and community shown in this conceptual model (see Figure 1.2) can take many forms but each is essential. *Research* is critical to sustainability science as it generates fundamental knowledge about social-ecological systems and the use of knowledge to achieve sustainability goals. *Learning* in sustainability science can be individual or social, formal or informal. It is vital to sustainability science because it is through learning that greater understanding is achieved. *Community* is an indispensible aspect of sustainability science because it is through an engaged community that relevant, place-based knowledge can be generated. The non-linear, iterative interactions among these components builds knowledge and understanding of social-ecological systsms and sustainability.

I used this conceptual model of sustainability science (see Figure 1.2) to develop an applied model showing how sustainability science can be done in the post-secondary setting. I then examined three aspects of sustainability science (i.e., research, learning, and community), as they were relevant in the applied model. The portion of the study that focused on the *research* aspect of sustainability science examined a process for generating knowledge about freshwater in social-ecological systems. The *learning* component of this work focused on the science and sustainability literacy of the student researchers. The section on *community* explored the idea of enhancing community adaptive capacity. These areas were chosen because there were distinct needs in each of these areas at the time this study began (see "Issues" in Figure 1.3). Furthermore, these were areas that higher education could address and bring together under a sustainability science framework (Figure 1.3).

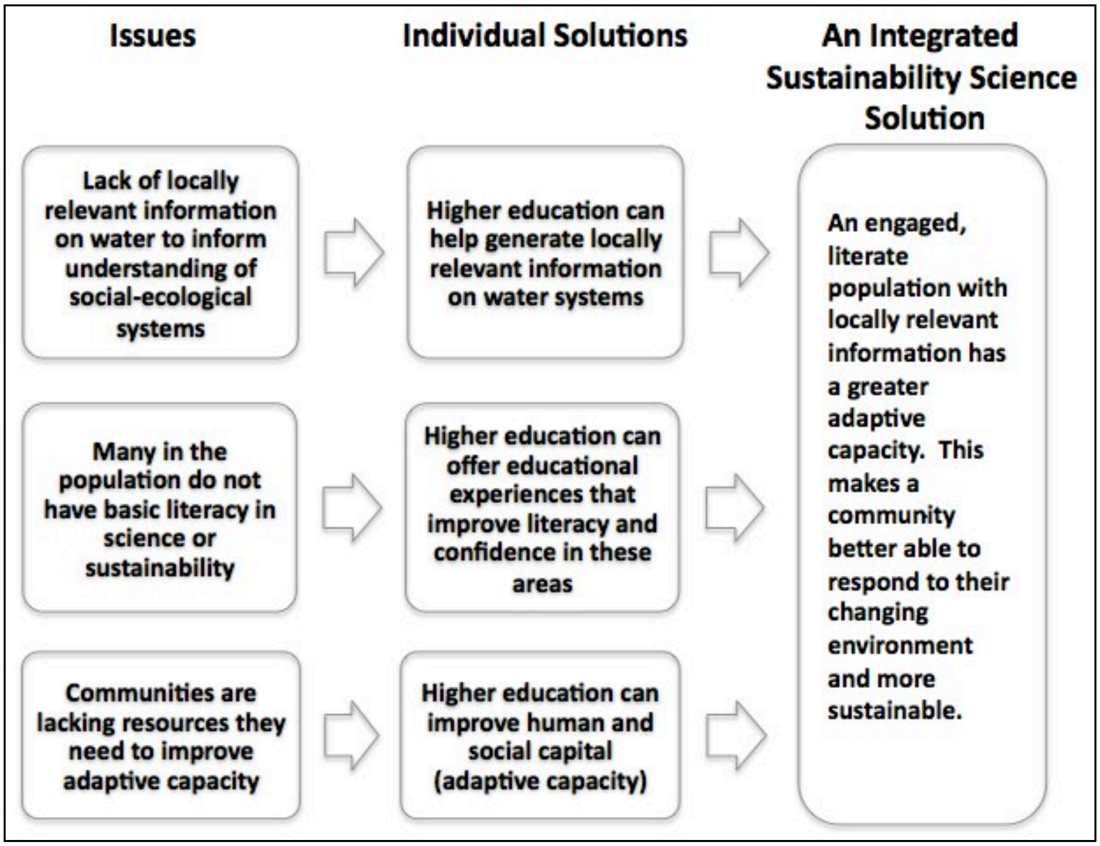

Figure 1.3. How sustainability science offers a holistic solution to a number of disparate issues. This map depicts some current issues in water research (top left), education (middle left), and community capacity (bottom left). It shows how higher education can address these issues (top, middle, and bottom center) and it illustrates how sustainability science can offer an all-encompassing solution (right).

Watershed science.

"Watershed science is the study of all of the natural processes and human activities that affect fresh water resources" (Colorado State University, n.d., p.1). Community health and sustainable ecosystems require healthy, productive water systems (MEA, 2005). It is for this reason that water is identified as one of the *critical sectors* for sustainability science research (American Association for the Advancement of Science [AAAS], 2009). When this work began there was a call to better understand freshwater systems.

The drivers of change mentioned previously (climate change, population growth, land use change, and a society more tightly integrated at a global scale) continue to affect our water resources and watersheds (Dozier, Braden, Hooper, Monsker, & Schnoor, 2009). The National Science Foundation (NSF) succinctly states the issue, "As a society, we have limited knowledge of how the unprecedented environmental changes now occurring will affect the water environment, or how we should re-orient our infrastructure and policies to accommodate these changes" (2008a, p. 1). With this challenge came growing recognition that more interdisciplinary work needed to be done with respect to sustainability and environmental change (NSF, 2008b; Dozier et al., 2009). These needs can be seen in the following Water and Environmental Research Systems (WATERS) Network research question (Schneider & Braden 2009, p. 3):

> How are climate change and human pressures affecting the water cycle over time, space, and scale, and what can be done technologically, institutionally, and behaviorally to protect water quality and ecosystems and to enhance

water security for future generations?

This study explores how institutions of higher education can do more to generate knowledge about water in local social-ecological systems to help answer these types of questions. This is the focus of Chapter 2. This chapter gives an overview of a model that universities can use to facilitate sustainability science research. Included here are three examples of integrated research and education projects to illustrate how this type of work provides new understandings of freshwater systems in Alaska.

Learning: Science and sustainability literacy.

Science literacy and sustainability literacy are generally defined as having the requisite knowledge, skills, and attitudes to understand important concepts of science or sustainability. Furthermore, literacy in these areas includes using and applying the knowledge and skills associated with these domains for personal and community well-being (AAAS, 1989, 2007; National Research Council [NRC], 1996; Rowe 2002; McKeown, Hopkins, Rizi, & Chrystalbridge, 2005; Stibbe, 2010; Achieve, Inc., 2013). When this work began there was a need to improve science and sustainability education.

In 2008, it was acknowledged that, "Americans may not know enough about science, technology, or mathematics to significantly contribute to, or fully benefit from, the knowledge-based society that is already taking shape around us" (National Academy of Sciences [NAS], National Academy of Engineering [NAE], Institute of Medicine [IoM], 2007, p. 94). A lack of proficiency and interest in science (NAS, NAE, and IoM, 2007; NSF, 2012; National Center for Educational Statistics [NCES], 2013; National Assessment Governing Board [NAGB], 2013) were but a few examples being cited to support this claim. A further disadvantage for U.S. students in today's society was the fact that they were receiving relatively little instruction about the concept and importance of sustainability at a time when the idea was becoming so prevalent.

Because science literacy and sustainability literacy are so crucial for individual and community well-being, it is essential that the field of education move toward more effective ways to facilitate learning in these areas. The need to improve scientific literacy and interest in science, can be seen in the NSF's Strategic Plan, 2006-2011, as they set a goal to, "Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens" (NSF, 2006, p. 5). To accomplish this goal the NSF's strategies for action include integrating research with education, leveraging collaborations, and engaging the public though informal education (NSF, 2006). The need to improve sustainability literacy, not only in the U.S. but around the globe, was evidenced by the call to mobilize education around sustainability through the United Nations Decade of Education for

Sustainable Development, 2005-2014 (UNESCO, 2013a). A few of the educational strategies identified as those needed to improve sustainability literacy include engaging learners on socially important issues, teaching from a systems perspective, and using participatory teaching and learning (UNESCO, 2013b).

This study explores how higher education can provide an educational experience that increases student researchers' science literacy and sustainability literacy. This is discussed in Chapter 3. This chapter provides background on the model used to facilitate science and sustainability learning and reports the gains students made.

Community engagement and adaptive capacity.

Adaptive capacity is the condition of having social and physical resources and the ability to mobilize these elements (Nelson, Adger, & Brown, 2007) to respond to a changing environment. Adaptive capacity is a precondition for adaptability, where "adaptability is the ability to perform in future conditions and meet future needs" (United Nations Development Programme [UNDP], 2010, p. 15). Communities that engage in a process of understanding their local social-ecological system enhance their adaptive capacity and are potentially better prepared to respond to change. The UNDP and other development organizations often work to enhance adaptive capacity as a mechanism to improve sustainability in a system.

Capacity development has been defined and studied but additional research on facilitating capacity development is still needed. There is literature that provides a number of strategies that are now recognized as positively influencing adaptive capacity (IPCC, 2001). Generally, establishing mechanisms to facilitate capacity development means finding ways for communities to acquire the requisite resources/capital (human, social, natural, and financial) that they need to facilitate effective responses to change (Brooks & Adger, 2004). Additional research is needed to identify effective strategies that communities and partner organizations can use to improve capital. Similarly, work that helps identify pathways that allow for *widespread* capacity development would be useful. Higher education is in a position to help with widespread capacity development, by helping build capital in their constituent communities, but these institutions need working models to help them achieve this goal.

This study looks at a process institutions of higher education can use to engage communities in research. It examines how that engagement affects the community's human and social capital and builds adaptive capacity. This is the focus of Chapter 4. This chapter explains the model used to engage communities in research. It then uses an adaptive capacity index to characterize how the adaptive capacity of communities changed as the result of university-based research projects. Three projects are shown as examples. Recommendations on how the model might be refined to further enhance community adaptive capacity are included.

An Overview of This Work

The overarching goal for this work was to develop a model for doing sustainability science in the post-secondary setting. I created a model that incorporated the three components I deemed to be critical elements of sustainability science (i.e., research, learning, and community). The resulting model (see Figure 1.4) is a useful heuristic for organizing thinking about sustainability science as a system of integrated components.

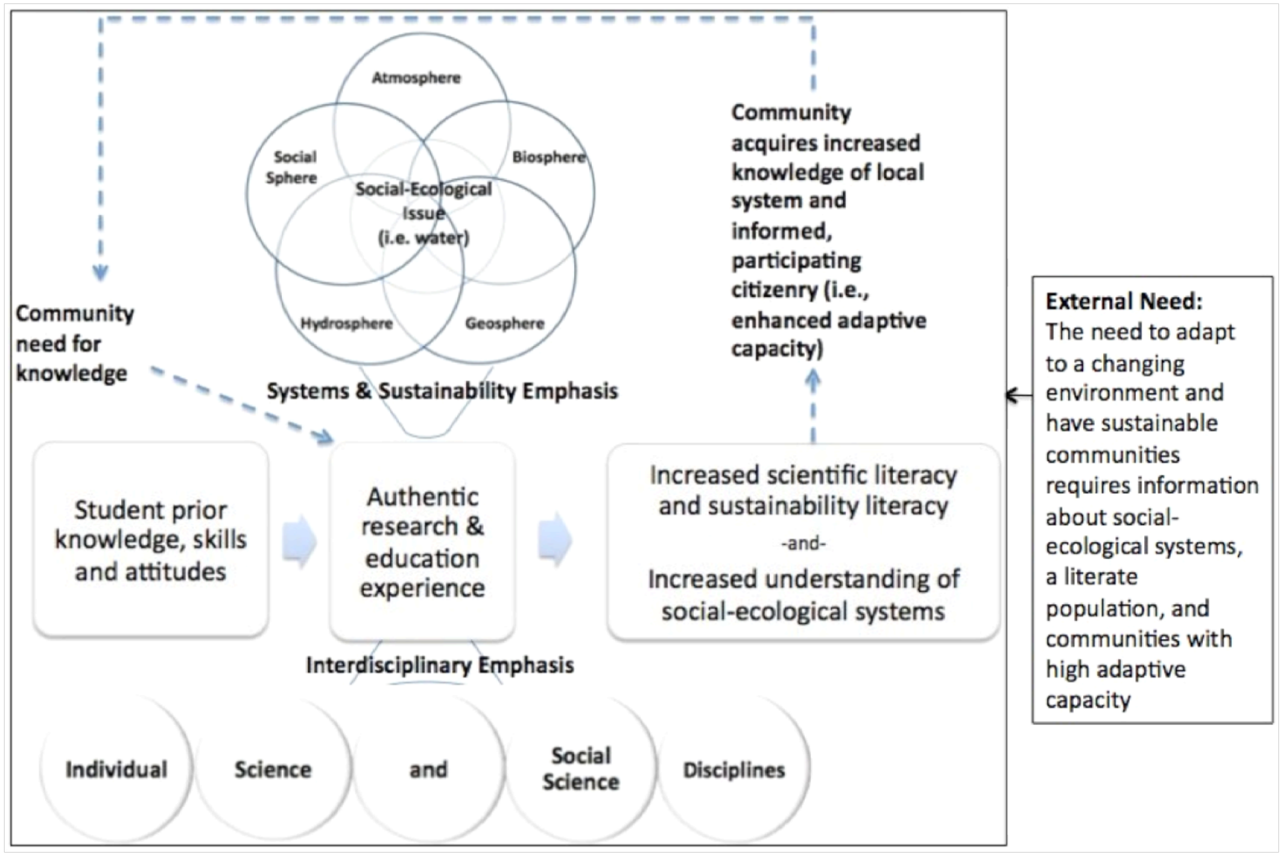

Figure 1.4 A model for sustainability science in higher education. This model provides a framework for developing a sustainability science experience that focuses on a social-ecological issue (e.g., water). It uses an integrated research and education experience to generate knowledge, increase science and sustainability literacy, and enhance community adaptive capacity.

The keystone of the model is an integrated research and education experience. Here, students conduct a real world research project as a part of a broader learning experience. Integrating research and education is one approach that the NSF identifies as essential for generating cutting-edge scientific information, developing scientific literacy, and providing insights on socially important issues (NSF, 2006, 2011).

The integrated research and education experience also provides opportunities for participatory and acquired learning (Sfard, 1998). Following Scott, Asoko, and Leach (2007), participatory experiences are grounded in the ideas of situated cognition and acquired experiences are rooted in constructivist thought. In the former, students learn from authentic activities (e.g., watershed analysis (Regional Interagency Executive Committee [RIEC], 1995; Chaves & Alipaz, 2007; Alessa et al., 2008)) associated with the domain being studied (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). The acquisition learning (i.e., lecture, readings, student presentations) builds on social constructivism where learning involves a passage from social and cultural contexts to individual understanding (Vygotsky, 1978). The integrated research and education experience can also be informed by constructivism as students connect their new ideas to prior interests and knowledge and assimilate new learning into their existing knowledge/cognitive structure

(Piaget, 1971; Ausubel, Novak, & Hanesian, 1978; National Research Council [NRC], 2000).

Other essential frameworks also inform this keystone experience. The research and education experience builds on the ideas of social-ecological systems (Chapin, Folke, & Kofinas, 2009; Earth System Science Education for the 21st Century [ESSE 21], 2010), sustainability (Brundtland, 1987), and education for sustainable development (UNESCO, 2013a; McKeown et al., 2005). (This is shown above the authentic research and education experience box in Figure 1.4) This approach makes in-depth study of an important social-ecological issue (e.g., water) possible. The central learning experience also captures the importance of providing disciplinary perspectives as well as an interdisciplinary perspective to teach essential content and skills (Blake, Sterling, & Kagawa, 2009; Association for Supervision and Curriculum Development [ASCD], 2010). (This is shown below the authentic research and education experience box in Figure 1.4) The research and education experience is informed by community input and this is an important aspect of model, as community input is a key element of *community engagement* (Carnegie Foundation, 2013). (This is shown as the dotted arrow coming into the authentic research and education experience box in Figure 1.4.) From an educational standpoint, community engagement is also an excellent way to facilitate place-based (Sobel, 2004) and culturally relevant science learning for the students (Stephens, 2003).

The expected outcomes of the research and learning experience are shown on the right side of the model (see Figure 1.4). Two of the three expected outcomes of the research and education experience are that 1) new knowledge about local social-ecological systems is generated and 2) science and sustainability literacy increases (AAAS, 1989, 1993; NRC, 1996; Rowe, 2002; McKeown et al., 2005; Stibbe, 2010). (This is shown in the box directly to the right of the authentic research and education experience in Figure 1.4). The third outcome of the research and education experience is that community adaptive capacity is improved through networking, participation, improved information, and learning (IPCC, 2001). (This is shown in the upper right corner of the model in Figure 1.4) This increased community adaptive capacity makes the community more sustainable as they are better able to respond to their changing environment. (It is assumed that, along the dotted line between acquiring information and determining community needs, a community uses their increased capacity to make their community more sustainable (e.g., through community-based management). This, however, is outside the scope of this study because it is beyond the ability of the university to control it.)

To test the model's effectiveness, I designed and taught a class based on the model and collected data to determine if the three expected outcomes occurred. As a faculty member at the University of Alaska Fairbanks (UAF), I developed a new, three-credit course *Liberal Arts and Science (LAS)/Natural Resource Management*

(NRM) 493 Water in the Environment and Society. The course learning goals (Figure 1.5), calendar, and major assignments (Table 1.1) follow.

1. Understand the basic structure of water, the concept of an Earth system framework, the role freshwater plays as an integrating resource in the social-ecological system, and how freshwater can be studied
2. Understand the concept of sustainability
3. Be able to use methods and skills of inquiry to conduct a real-world research/service project that contributes to our understanding of freshwater
4. Be able to communicate effectively, both orally and in writing, about freshwater issues
5. Be able to take responsibility for learning, have enhanced meta-cognitive skills, and be able to use an interdisciplinary perspective to study a topic
6. Have enhanced confidence in the ability to discuss, make decisions about, and participate in societal issues about freshwater

Figure 1.5. Course learning goals.This figure shows the learning goals for the course LAS/NRM 493 Water in the Environment and Society.

Table 1.1.

Course calendar and assignments. This table shows the major topics and schedule (left column) and assignments (right column) for the course LAS/NRM 493 Water in the Environment and Society.

Course Calendar	Assignments
Week 1: Course business **Weeks 2-6*:** Frameworks for the course (systems and sustainability); Water in the biophysical spheres, science disciplines **Weeks 7-12*:** Water in the social sphere, social science disciplines **Week 13*:** Water as an integrating resource (circumpolar and global perspectives) **Week 14*:** Water and change (climate change and land use change) **Week 15*:** Communicating about water (student presentations on their research) **Week 16*:** Final exam *Sustainability and systems were emphasized each week throughout the semester	• Class participation (read and contribute to discussions) • Read, present, and facilitate a discussion on relevant articles (student choice) • Conduct a research project (student choice) • Keep a research and learning notebook • Written presentation of research • Oral presentation of research • Final exam

The method used to test the model was a case study based on a framework of action research (Reason & Bradbury, 2008) and scholarship of teaching and learning (Huber & Hutchings, 2005). These concepts are defined in Figure 1.6. Data collection occurred in the context of my teaching assignment *LAS/NRM 493 Water in the Environment and Society*. The course was taught during Spring Semester 2011 and six people enrolled in the class (one student dropped the course because of a scheduling conflict).

"**Action research** is a participatory process concerned with developing practical knowledge in the pursuit of worthwhile human purposes. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities" (Reason & Bradbury, 2008, Page 4).

Boyer (1990) describes the **scholarship of teaching and learning** as giving teaching a place in a broader vision of scholarship that includes discovery through basic research and efforts to advance the integration and application of knowledge (as cited in Huber & Hutchings, 2005). Huber and Hutchings (2005) further describe the scholarship of teaching and learning as an inquiry and investigation that faculty undertake when they examine and document teaching and learning in their classrooms in order to improve their practice and make it available to peers. This work can include (at one end) studies with elaborate research designs and formal execution that go beyond a single classroom, program, or discipline, as well as (at the other end) quite modest efforts to document and reflect on one's teaching and share what one has learned.

Figure 1.6. Frameworks for this research. This figure gives definitions for action research and scholarship of teaching and learning.

During the class, I collected data to answer three research questions that align with the three expected outcomes of the model (Figure 1.7 and Table 1.2). After the course I analyzed the data to determine if the model produced the expected outcomes: 1) generation of new knowledge about local social-ecological systems, 2) an increase in science and sustainability literacy, and 3) enhancement of community adaptive capacity. This final step of analysis is based on the theory of analytic generalization, "in which a previously developed theory is used as template with which to compare the empirical results of the case study" (Yin, 1989, p. 38).

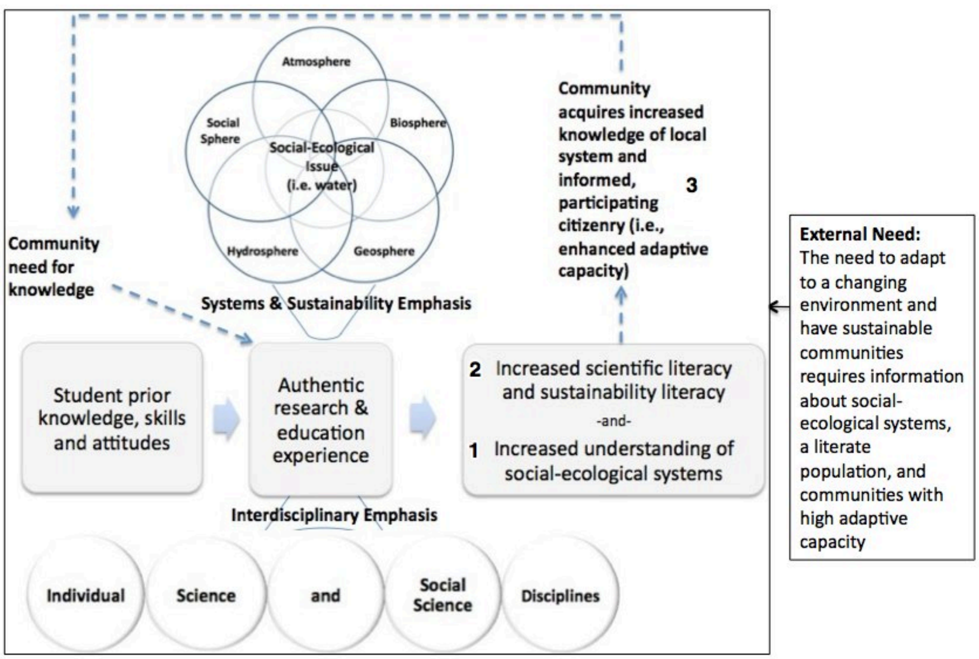

Figure 1.7. Expected outcomes of the research and education experience. This model shows the three expected outcomes of the sustainability science experience. These numbers correspond with the three research questions shown in Table 1.2.

Table 1.2.

Research questions, sources of data, and analysis methods. This table summarizes the research questions (left column), sources of data (center column), and data analysis methods (right column) used in this study.

Research Questions	Sources of Data	Data Analysis Methods
Overarching questions for the study: Is the model effective? Are the expected outcomes of the model achieved?		
Research Question for Expected Outcome 1: Is new information about local, freshwater systems generated through the integrated research and education experience? If so, what is learned?	• Student coursework • PI observations and notes	• Document analysis using emergent coding
Research Question for Expected Outcome 2: Are learning gains in areas associated with science and sustainability literacy seen as the result of the integrated research and education experience? If so, what gains are made and how?	• Pre-/Post-course Student Assessment of Learning Gains (SALG) survey (Seymour, Wiese, Hunter, & Daffinrud, 2000) • Pre-/Post-course short answer response and concept map (Novak & Cañas, 2008) • Student coursework • PI observations and notes	• Basic descriptive statistics • Document analysis using á priori and emergent coding
Research Question for Expected Outcome 3: Is community adaptive capacity enhanced as the result of the integrated research and education experience? If so, in what ways and to what extent?	• Student coursework • PI observations and notes • Email communications with students	• Document analysis using á priori coding • Adaptive capacity index

The background, methods, results and conclusions for research questions one, two, and three (Table 1.2) are described fully in chapters two, three, and four, respectively.

Findings

This dissertation emerged from a specific project to implement the model in the post-secondary setting. The results here are based on a single iteration of using the designed model in a course and the enrollment in the class was small. The small sample size did not allow for statistical analysis of findings. The research mainly used qualitative methods to see if the expected outcomes of the model were achieved. To make the study more robust additional iterations of the course would need to be conducted and evaluated and/or other analysis tools that allowed for comparative studies would be needed. This study was useful to pilot test the model, to identify areas where the model could be refined, and to lay the groundwork for future research.

The results suggest that the model was effective in achieving the expected outcomes in two of the three areas. The results show that the integrated research and education experience, as designed, was successful in generating new information about water in local social-ecological systems (Chapter 2). The results also show increases in students' scientific and sustainability literacy (Chapter 3).

The model was not entirely effective in the third research area. Results show that community adaptive capacity improved only *slightly* (based on community adaptive capacity index scale) as a result of the integrated research and education experience (Chapter 4). A revised model is suggested to address the identified shortcomings and improve the effectiveness of the original model.

Chapter 5 is a discussion of this study. It provides an overall summary of the work and shares the lessons that were learned as a result of the research. It also summarizes the significance of the work and provides suggestions for future research.

Significance of this Work

This work is significant because a diverse knowledge base was necessary to complete the research and the outcomes and new understandings produced by this work contribute back to those diverse fields.

Significance of the knowledge contributing to this work.

This single study brings together the three distinct fields of watershed science, education, and adaptive capacity under the broader field of sustainability science. It also brings sustainability science and educational science together to inform one another. The design for the model produced here is unique, as it builds on literature from these diverse fields of study.

Significance of the contributions resulting from this work.

Building conceptual and applied models in sustainability science has been limited by a gap in the knowledge base between educational science and sustainability science and this study helps fills this gap (Barth & Michelsen, 2013). This work offers conceptual and applied models, informed by the field of education, that contribute to a deeper understanding of sustainability science as a whole and demonstrates how it can be implemented in higher education.

This deeper understanding is important in light of the fact that sustainability science has emerged relatively recently and the field is still establishing itself. Some conceptual models exist that focus on sustainability science as a process of doing research with stakeholder engagement (Lang et al., 2012; SSI, 2013). This work builds on these models by articulating a conceptual model that depicts sustainability science as a research process that is informed by and informs learning and community (Figure 1.2).

Beyond conceptualizing what sustainability science is and how to do it, there is a need to apply theoretical concepts. Players in the field of sustainability science need proven, well-grounded models that build on the growing body of knowledge in sustainability science (Bettencourt & Kaur, 2011) to be able to implement conceptual ideas. This study is significant because it offers a specific model that demonstrates how individuals at institutions of higher education can *do* sustainability science (Figure 1.4). The model itself is significant because it is an example of how higher education can accomplish its tripartite mission of research, education, and service in a single process.

Together these models are important because they can be generalized for other purposes and contexts. The conceptual model can guide the work of others interested in sustainability science. The applied model demonstrates how to address water issues using a sustainability science approach but other critical sectors (e.g., energy, agriculture; AAAS, 2009) can easily be substituted for water in this model. Work in these key sectors is requisite for community planning and health and while this study shows a demonstration of concept in one area the model (i.e., water) it can actually be used a framwork to build a comprehensive program. An institution that uses this model to build a multi-faceted program that facilitates research and learning across sectors could potentially have a significant impact on the sustainability of their constituent communities.

Ultimately, this work offers a model of how society, through its institutions of higher education, can functionally and effectively integrate research, learning, and community engagement to foster sustainability in social-ecological systems. In doing so, this study provides an example that helps answer an important sustainability science question, "How can society most effectively guide or manage human environment systems toward a sustainability transition?" (Kates, 2011, p. 19450). This research is potentially transformative in that it offers higher education new insights that could inform how it does sustainability science.

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CHAPTER 2:

Freshwater Social-Ecological Systems and Sustainability in Alaska: Findings from Undergraduate Research Experiences [1]

Introduction

Many institutions of higher education include the goals of conducting research, instructing students, and serving communities in their mission statements. The National Science Foundation's (NSF) strategies for action further extend this idea by emphasizing the importance of integrating research with education and leveraging collaborations to provide insights on socially important issues (NSF, 2006). Furthermore, professionals and communities need research-based information for improved decision-making and to better adapt to a changing environment. Institutions of higher education have the opportunity to better meet these needs by finding ways to integrate research and learning in the classroom.

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[1] Fabbri, C.E. (2013). *Freshwater Social-Ecological systems and sustainability in Alaska: Findings from undergraduate research experiences*. (Prepared for Submission). *Agroborealis*, UAF School of Natural Resources and Agricultural Sciences: Fairbanks, Alaska.

When beginning this work, I wanted to find out if an integrated research and education experience, in the context of a university course, could facilitate the production of new knowledge about freshwater, social-ecological systems. Here, knowledge is purposefully defined in a broad sense to mean information generated by investigation. Methods for investigation can vary and knowledge can be culturally situated but in the end the investigator will have produced information and understanding. For my study, I assumed that knowledge gains would result and I intended to describe the nature of the knowledge produced. With this goal in mind, I developed a model for delivery (Figure 2.1) and designed a new course based on the model, *Water in the Environment and Society,* and set out to explore this idea.

I taught the 400-level, three-credit class during Spring Semester 2011 at the University of Alaska Fairbanks. I cross-listed the class as Liberal Arts and Science (LAS) and Natural Resource Management (NRM) in order to attract both social science and science students to the course. Five students took the course. Three students were social science majors, one student was a science major, and one was an engineering major. Over the course of the semester, the group studied freshwater using interdisciplinary, systems, and sustainability perspectives (Figure 2.1). To build an understanding of freshwater social-ecological systems and to increase scientific and sustainability literacies, students were required to complete independent research projects (reflected as "authentic research and education experience" in Figure 2.1).

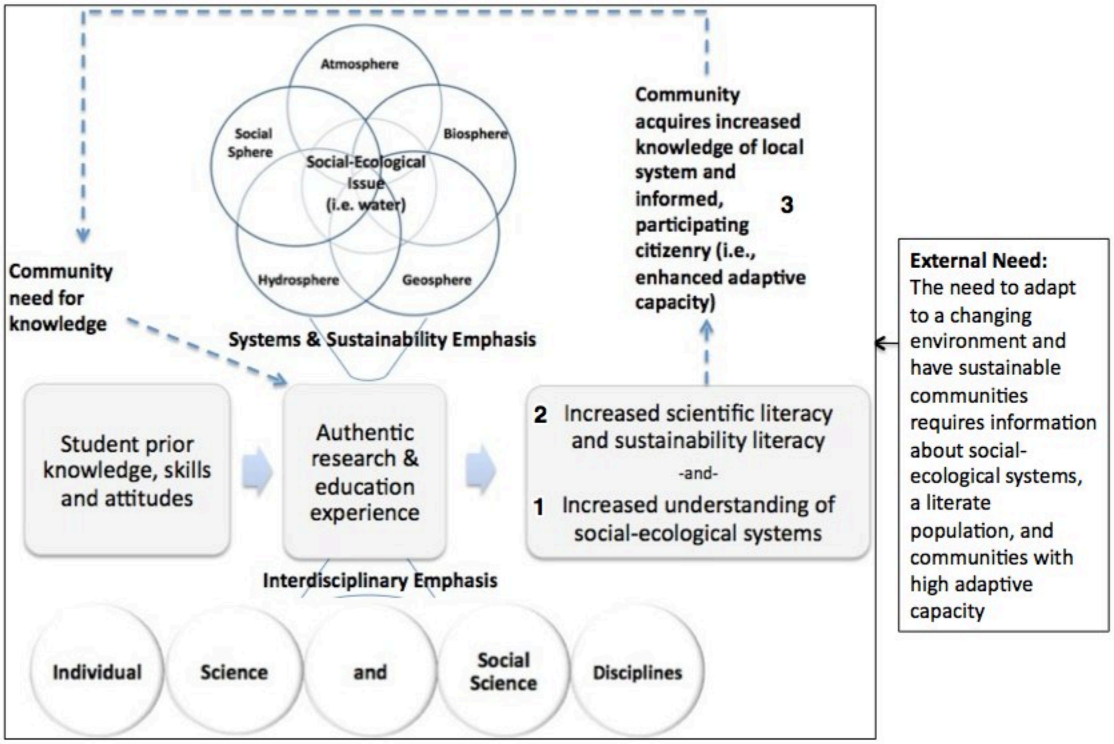

Figure 2.1. A model for sustainability science in higher education. This model shows how an integrated research and education experience in the post-secondary classroom can lead to an increased understanding of freshwater social-ecological systems (see number 1).

Here I use the student projects to show that new knowledge about freshwater, social-ecological systems can effectively be produced in the context of a university course. I describe the findings and generalize about the types of knowledge gains that were made. Three projects are discussed in the results section of this paper, and findings about what can be learned from these cases conclude the paper.

Methods

One aspect of this work focuses on evaluating an á priori model/theory (Figure 2.1) and is exploratory in nature. The work is based on a framework of scholarship of teaching and learning and action research (Huber & Hutchings, 2005; Reason & Bradbury, 2008). This study used a multiple case, holistic design method (Yin, 1989), and I used a qualitative methods approach for data collection and analysis. Data were generated from course instructor observations and notes as well as from document analysis of student work. The data analysis, to generalize from case study to theory, was based on the process of analytical generalization (Yin, 1989). I also used these methods to generalize about the nature of the knowledge produced in the case studies/student projects.

The aspect of the study focused on reporting the new knowledge was descriptive in nature (Lauer, 2006). The students used various quantitative and qualitative methods to produce the knowledge and in some cases I did additional data analysis. The specific methods are detailed in the following accounts.

The following cases are a distillation of the most important aspects of the research conducted by the students. Large pieces of these summaries are taken directly from student's final papers. Student names have been deleted to provide anonymity, as students signed informed consent agreements that included a stipulation that confidentiality would be maintained. Any significant changes made to the student's work for this publication are noted in the individual cases.

Results

Case 1: The Arctic Water Resources Vulnerability Index (AWRVI) for Minto, Alaska.

Introduction.

Environmental change, from both climate and human pressure (population growth, land use/cover), affects water, the water cycle, and related earth systems over time, space and scale (Dozier et al., 2009). Increased understanding of freshwater systems and their responses to change improve the ability to manage resources for sustainability. The Arctic Water Resource Vulnerability Index (AWRVI) can be used to assess relative vulnerability or resilience to factors influencing freshwater resources at the watershed scale (Alessa et al., 2008). It does so by methodically evaluating individual physical and social components of a community's interaction with their water resources. AWRVI helps identify aspects that contribute to overall water vulnerability and resilience and can provide information that is useful in helping determine how a community might want to adapt or adjust their water-related resources.

Two students collaborated and completed the AWRVI for the community of Minto, Alaska. They chose Minto for its relative proximity to Fairbanks, Alaska, for which more data are available. Also, Fairbanks is in interior Alaska, allowing the students to compare the results for an interior community with those found for western and south central communities previously studied by Alessa et al. (2008).

Methods.

These two students collaborated to complete the AWRVI as described in Alessa et al. (2008) and is shown in Figure 2.2. Student one focused on the physical sub-index and student two completed the social sub-index. The students accessed existing data sets and public documents to collect data. They also conducted informal interviews with key informants, including UAF faculty, a Minto community member, and a public official with the Tanana Chiefs Conference. Methods for individual sub-indices (physical and social) are described in Alessa et al. (2008) and the students followed those recommendations. In general, data were collected for various indicators to measure the degree of vulnerability or resilience on a standardized rating scale (see Figure 2.2). The ratings for these indicators combine to give scores for constituent sub-indices. These constituent sub-indices then combine to give scores for physical and social sub-indices and, finally, these scores are used to calculate an overall vulnerability-resilience score for the community. I corrected one calculation error made when finding a total score for the physical sub-index but the summary is otherwise as produced by the student researchers.

Arctic Water Resource Vulnerability Index:	Rating	Vulnerability-resilience
	0	Highly vulnerable
	0.25	Moderately vulnerable
	0.50	Threshold
AWRVI = [AWRVI $_{physical}$ + AWRVI $_{social}$]/2	0.75	Moderately resilience
	1.00	Highly resilient

Physical sub-index:

AWRVI $_{physical}$ = [AWRVI $_{natural\ supply}$ + AWRVI $_{municipal\ supply}$ +AWRVI $_{water\ quality}$ + AWRVI $_{permafrost}$ + AWRVI $_{subsistence\ habitat}$] / 5

Constituent sub-indices:

AWRVI $_{natural\ supply}$	= *f* (precipitation, surface water, river runoff)
AWRVI $_{municipal\ supply}$	= *f* (yield, source diversity, treatment technology, hydraulic gradient, permafrost risk)
AWRVI $_{water\ quality}$	= *f* (upstream modification, water quality testing)
AWRVI $_{permafrost}$	= *f* (permafrost distribution)
AWRVI $_{subsistence\ habitat}$	= *f* (aquatic habitat, terrestrial habitat)

Social sub-index:

AWRVI $_{social}$ = [AWRVI $_{knowledge}$ + AWRVI $_{economic}$ + AWRVI $_{information\ capacity}$ + AWRVI $_{sensitivity}$] / 4

Constituent sub-indices:

AWRVI $_{knowledge}$	= *f* (traditional knowledge, Western knowledge, residency time)
AWRVI $_{economic}$	= *f* (community wealth)
AWRVI $_{information\ capacity}$	= *f* (protected area status)
AWRVI $_{sensitivity}$	= *f* (subsistence values, social network diversity, perception of change)

Figure 2.2. Arctic Water Resource Vulnerability Index (AWRVI). This figure shows the AWRVI sub-indices and the rating scale for indicators (Alessa et al., 2008).

Results.

The physical sub-index score was 0.48 (see Table 2.1), the social sub-index score was 0.48 (see Table 2.2), and the resulting overall AWRVI score for Minto was a rating of 0.48. This score indicates the community is nearly at a threshold rating (0.5), falling just slightly on the vulnerability side of the vulnerability-resilience scale (Figure 2.3).

Table 2.1.

Arctic Water Resource Vulnerability Index (AWRVI) physical sub-index for Minto, Alaska. This table shows the results for AWRVI physical sub-index for Minto, Alaska.

Sub-index	Constituent Sub-indices	Parameter/Indicator	Value for Minto	Resilience / Vulnerability Rating for Minto	Subtotal and Total
Physical Sub-index	Natural supply	Av. ann. precip. (mm/yr)	272.5	0.5	0.6
		Variance in av. ann. precip.	0.04	1.0	
		Surface water storage (%)	7.9	0.5	
		Change in surface water over recent 30 year period (%)	-1.8	0.25	
		Av. ann. river runoff (cumecs/km^2)	No data	-	
		Variance in ann. river runoff	No data	-	
		Seasonal variation in discharge	1.71	0.75	
	Municipal supply	Reservoir and well yield per capita per day (liters)	2,128	1.0	0.4
		Water-source diversity	2 ground wells	0.25	
		Treatment technology	Chlorine	0.25	
		Hydraulic gradient of water supply (m/m)	0.002	0.5	
		Infrastructure on permafrost (%)	70%	0.0	
	Quality	Upstream development sites (#)	2 mining	0.5	0.375
		Streams with water quality data (%)	16.7	0.25	
	Permafrost	Permafrost Distribution (%)	70	0.0	0.0
	Subsistence Habitat	Aquatic habitat – fish recruiting streams (#/km)	0.57	1.0	1.0
		Terrestrial habitat –tundra and boreal forest cover (%)	100	1.0	
				Total Rating Physical Sub-index =	0.48

Table 2.2.

Arctic Water Resource Vulnerability Index (AWRVI) social sub-index for Minto, Alaska. This table shows the results for AWRVI social sub-index for Minto, Alaska.

Sub-index	Constituent Sub-indices	Parameter/Indicator	Value for Minto	Resilience / Vulnerability Rating for Minto	Subtotal and Total
Social Sub-index	Knowledge	Traditional (% of population)	27	1.0	0.67
		Western (% of population)	4.7	0.25	
		Residency (% of population)	27	0.75	
	Economic	Per capita income ($)	9,742	0.25	0.25
	Information Capacity	Area in protected status (%)	25	0.5	0.5
	Sensitivity	Subsistence harvest (kg)	66.09	0.5	0.5
		Network diversity	No data	-	
		Perception (existence of water action plan)	YRITWC draft plan	0.5	
	Total Rating Social Sub-index =				0.48

AWRVI for Minto = [AWRVI $_{physical}$ + AWRVI $_{social}$]/2

= [0.48 + 0.48]/2

= 0.48

Rating	Vulnerability-resilience
0	Highly vulnerable
0.25	Moderately vulnerable
0.50	Threshold
0.75	Moderately resilience
1.00	Highly resilient

Figure 2.3. Overall Arctic Water Resource Vulnerability Index (AWRVI) score for Minto, Alaska. This figure shows the vulnerability-resilience rating system and the final AWRVI rating for Minto, Alaska.

Discussion.

The physical sub-index score for Minto was higher than those found for other small, rural communities (White Mountain had a score of 0.33; Wales, 0.27) but lower than the larger, road-accessible town of Eagle River which had a score of 0.72 (Alessa et al., 2008). The indicators of least resilience for Minto which are possible to improve are the following: source water diversity, treatment technology, placement of water infrastructure regarding permafrost, the number of upstream development sites, and measurement of water quality. Community and government agencies may want to consider these topics when dealing with water issues in Minto.

The social sub-index score for Minto was lower than those found for White Mountain, Wales, and Eagle River, with respective values of 0.63, 0.54, and 0.77 (Alessa et al., 2008). This may be due to the fact that no data were available for the "network diversity" indicator so it was eliminated in the index computation. In general, Minto's knowledge capacity is its strength, and its economic capacity is its area of vulnerability. Minto's information and sensitivity sub-indices fall at threshold levels (0.50) and along with economic capacity, these areas could be evaluated to see if improvements could be made to make Minto a more resilient community. The student working on the social sub-index noted that it would have been very useful to have a partner from the village to collaborate with and verify the values in this report. She attempted to find a resident of Minto to work with but was unable to do so.

As a whole the AWRVI rating of 0.48 for Minto indicates that they are only slightly below the threshold between vulnerability and resilience. This result indicates that Minto has areas it could work on to improve its resiliency but is not in an altogether vulnerable position. Like any community, Minto has both assets and challenges it can consider as it deals with change and thinks about sustainability of its freshwater system.

Case 2: The prevalence of non-precipitation watering techniques among Alaskan commercial growers, farmers and ranchers.

Introduction.

Approximately 70% of the world's freshwater consumption is devoted to agriculture (Black & King, 2009), but it is widely recognized that many agricultural watering systems do not use water efficiently. To find ways to help producers improve their systems and use water more efficiently it is important to understand the prevalence and extent of non-precipitation watering techniques (NPWT). NPWT include any use of water that does not come directly from the sky (Figure 2.4). The goals of this student project were to quantify the prevalence of NPWT used in commercial growing, farming, and ranching operations (Figure 2.4) in Alaska, to gauge future use, and to evaluate the importance of increasing NPWT efficiencies in Alaska. For the purposes of this study, the state was divided into six regions: North Slope, Bering Strait, Interior, Bristol Bay and Aleutian Chain, Southcentral, and Southeast.

Non-precipitation watering techniques (NPWT) include any use of water that does not come directly from the sky; this definition does not include contained rain catchment systems, but does include any system that draws water from ground or surface water sources, such as irrigating or filling stock tanks from wells or rivers.

Growers are those who grow or produce plant products that are sold without the intent of their being consumed by animals or humans; this includes the growing of flowers, starter plants (even if the starter plants are vegetable or fruit starters, since the plant itself hasn't usually produced the edible portion at the time of sale), etc.

Farmers are those who grow or produce agricultural plant products for animal and/or human consumption; this includes those who produce edible goods from purely natural resources, such as the gathering of wild mushrooms or berries, or the production of syrups from natural forests.

Ranchers are those who keep animals and use the animal or animal products to make merchandise, such as meat, eggs, milk, live young, or materials from animal fibers.

Figure 2.4. Agricultural definitions relevant to the study. This figure shows important definitions for this study as established by the student researcher.

Methods.

To acquire information about commercial operations across the state, the student used two methods to disseminate a survey. She acquired email addresses from the State Division of Agriculture and from the Cooperative Extension Online Directory of Farmers and Ranchers. The sample group of 182 received an email request to participate in the online survey. She also disseminated paper copies of the survey, at the Seventh Annual Sustainable Agriculture Conference, in Fairbanks, Alaska, to a group of 15 individuals, who had been pre-screened and were identified as recognized commercial operators.

The survey contained three sections. The first section of the survey recorded demographic information. The second section gathered data from individuals who had never used NPWT to gauge if they would like to use it, and if so, what would make the transition to NPWT feasible. The final section collected information from individuals who have used NPWT, currently or in the past, to determine how much water was used and how motivated they were to improve the system. The student performed basic descriptive statistical analysis of the data. I performed further analysis of the student-collected data to provide additional insights about agriculture and water use in Alaska and these data are included here.

Results.

Sixty-one individuals responded to the survey (30 from Southcentral, 26 from Interior, 3 from Bristol Bay/Aleutian Chain, 2 from Southeast, 0 from North Slope, 0 from Bering Strait, and 1 from an unspecified location). The respondents represented a diverse set of operations including hay, dairy, vegetable, fruit and perennial operations; a greenhouse producing rose seedlings; a group based out of a natural forest that produced syrups; and an aquafarm producing geoduck clams.

A large percentage (86.9%) of the respondents indicated they used NPWT. Data for NPWT users are presented in the middle column of Table 2.3. This group included representatives from all four regions of the state for which responses were collected. Among the operations, 81.1% were crop-based and 19.9% were livestock-based. Of these respondents, 40.4% indicated that the operation was their main source of income. These operations varied in size from less than an acre to 1700 acres. Operators who knew their annual water usage indicated that they use from 300-1,500,000 gallons of water per year.

Only 13.1% of the operators said they have never used NPWT and they represented three out of four regions of the state for which responses were collected. Data for these respondents are presented in the right-hand column of Table 2.3. The majority (87.5%) of these operations were crop-based and 37.5% reported that the operation was their main source of income. The size of their operation ranged from less than an acre to 500 acres. Of these respondents, 50% indicated that they would like to use NPWT.

Table 2.3.

Survey results for Non-precipitation Watering Technique (NPWT) users and non-users. This table shows the survey results for NPWT users (middle column) and non-users (right column).

Question	Responses for NPWT Users	Responses for NPWT Non-users
Do you use NPWT?	86.9% (53/61)	13.1% (8/61)
	These 53 respondents report…	These 8 respondents report…
Their operation is located in:		
• Bristol Bay/Aleutian Chain	5.7% (3/53)	0% (0/8)
• Interior	43.4% (23/53)	37.5% (3/8)
• Southcentral	49.1% (26/53)	50% (4/8)
• Southeast	1.9 % (1/53)	12.5% (1/8)
They run a crop (farmer & grower) operation	81.1% (43/53)	87.5% (7/8)
They run a livestock (rancher) operation	18.9% (10/53)	12.5% (1/8)
The operation is their main source of income	40.4% (21/52)	37.5% (3/8)
Acres of land in use		
• Range	<1-1700	<1-500
• Mean	120.7	155.9
• Median	5	70
• Mode	<1	500
# gallons of water used from NPWT (annually)		
• Skipped question (8/53 respondents)		NA
• Reported "no idea" (14/53 respondents)		
• Unusable data (7/53 respondents)		
• Usable data (24/53 respondents)		
○ Range	300-1,500,000 gal/yr	
○ Mean	89,883 gal/yr	
○ Median	11,850 gal/yr	
○ Mode	10,000 gal/yr	
Would you like to use NPWT	NA	50% (4/8)

Data depicting the type of operation (grower, farmer, or rancher) and the watering technique they use (NPWT user or non-user) are presented in Figure 2.5. This figure also shows watering technique (NPWT user or non-user) for operations growing only hay versus operations growing hay and some other product.

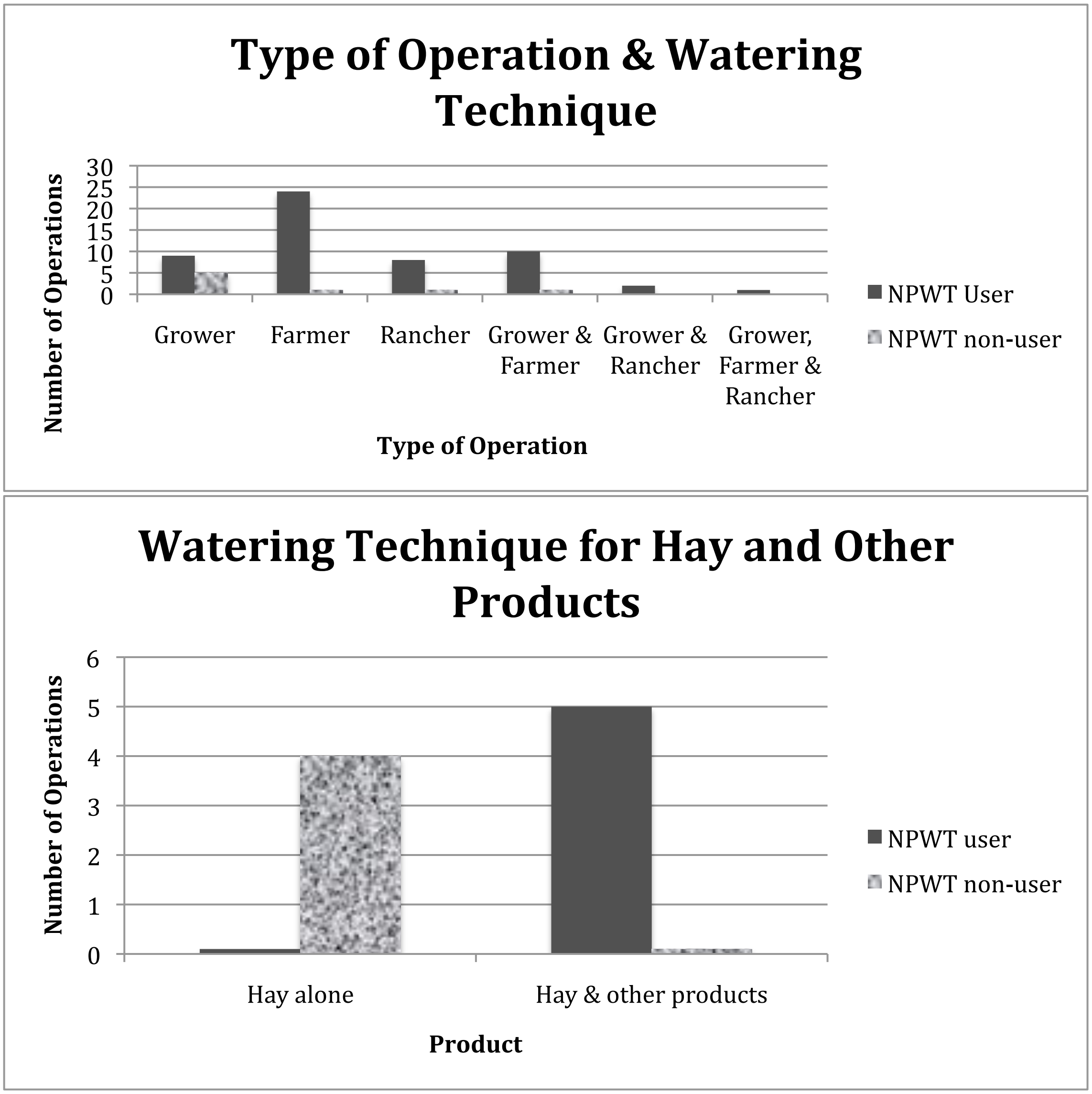

Figure 2.5. Type of operation and watering technique. These graphs show the relationship between the type of the agricultural operation and the type of watering technique used.

Additional findings for respondents who do not use NPWT follow. When asked why they do not use NPWT, respondents stated a variety of reasons, the most common being cost (Figure 2.6). The respondents who do not use NPWT but would like to state that lower costs would make it more feasible for them to do so. There was also an indication that making practical information readily available would be helpful.

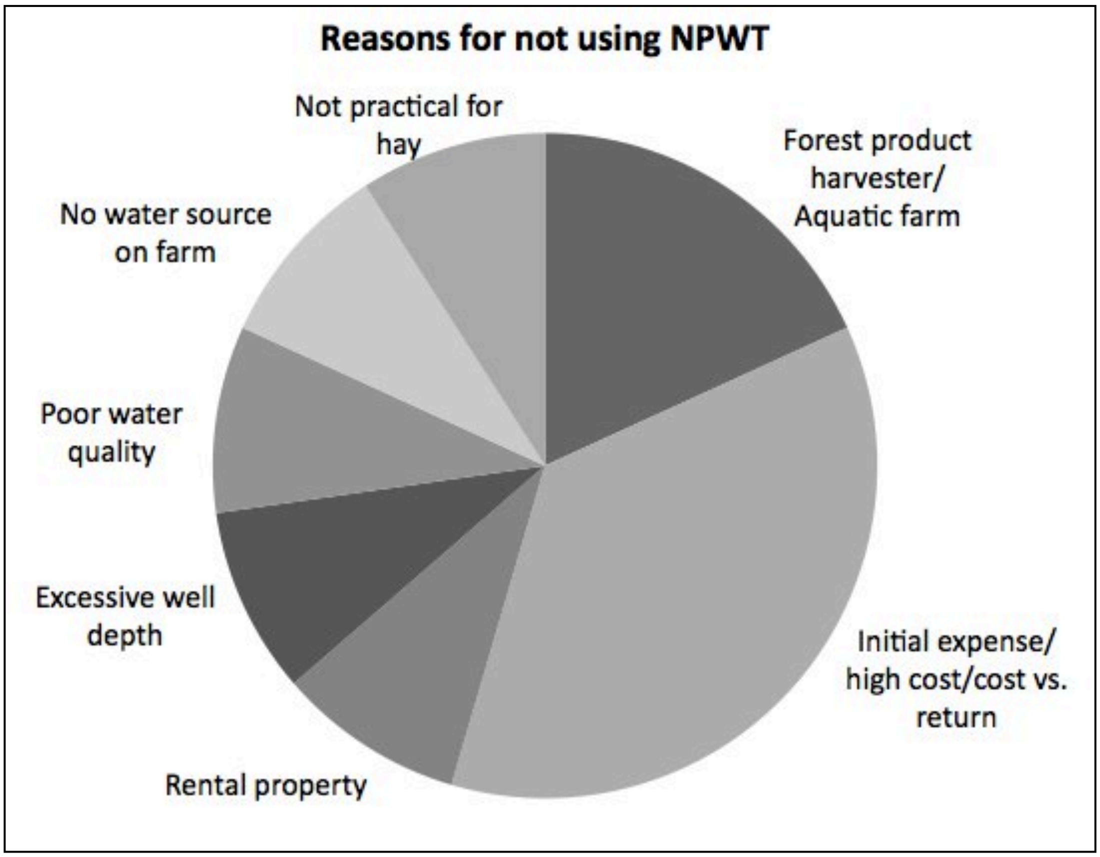

Figure 2.6. Reasons operators do not use non-precipitation watering techniques (NPWT). This pie chart shows reasons operators gave for not using NPWT.

Respondents who currently use NPWT report varying levels of motivation to improve the efficiency of their watering systems (Figure 2.7).

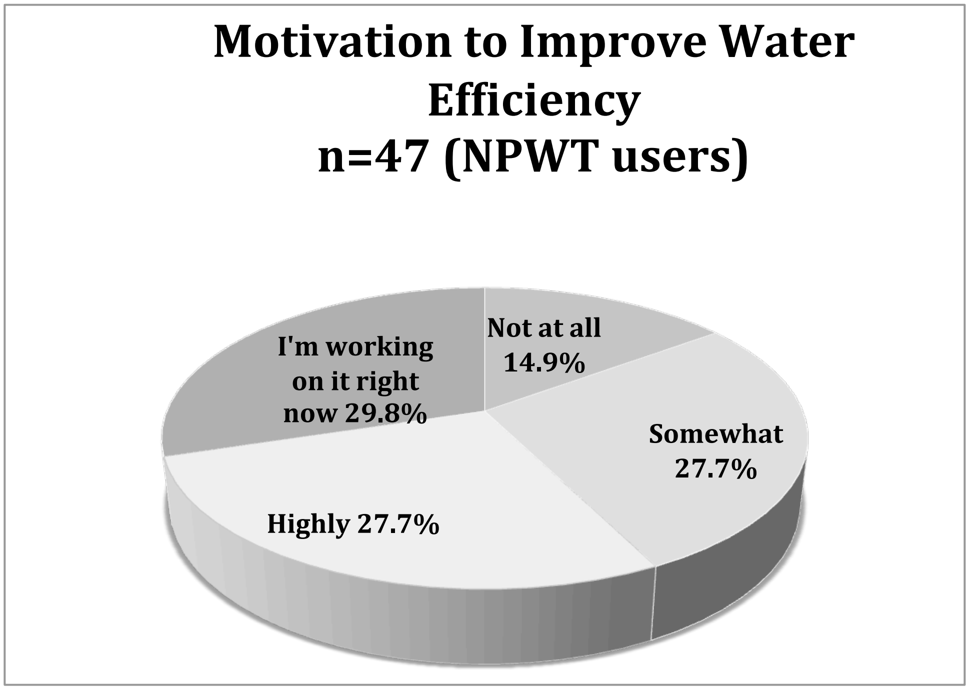

Figure 2.7. Motivation to improve water systems. This graph shows the level of motivation to improve water systems among NPWT users.

Discussion.

There are a variety of noteworthy results from this study. Cost is a key factor in people's decision to not use NPWT. Lowering costs through subsidies is a key area where government agencies can assist operators. Furthermore, making additional information available will help people set up NPWT systems and this is an area where universities, non-governmental organizations, and agencies may be able to provide assistance to operators.

The vast majority of respondents are using NPWT across all four regions for which data were obtained. Of the eleven respondents running livestock operations, ten of them use NPWT (one non-user was the geoduck clam operation). Also of note is that those operators growing hay alone do not use NPWT, and those growing hay along with another product do use NPWT (see Figure 2.5). Over a quarter (26.4%) of NPWT users who responded did not have any idea how much water they were using. Another 28.3% skipped the question or did not report usable data (e.g., gal/day without total number of days). This means those with no idea how much water they are using could potentially be more than half of all the NPWT users. Of the 47 NPWT users who responded to the question, 85.1% wanted to improve the efficiency of their water system. These results indicate that there is interest in running more sustainable agricultural systems in Alaska, but one significant challenge to this is operators knowing how much water they are using and how often. This lack of knowledge about water use and interest in improved efficiency are areas where more work could be done in the future.

Case 3: Drinking water and sanitation in rural Alaska villages.

Introduction.

Approximately 75% (Griffith, 2011) of the 280 rural villages (Magee, 2011) in Alaska have indoor plumbing; however, in 73 villages, one fourth of the homes do not have piped water and sewer. There are other villages that have systems needing to be repaired but they lack necessary resources and skilled technicians. Across the state, the cost to repair old systems and put in new ones could cost over $7 million (Griffith, 2012). As such, it is necessary to find emerging, innovative technologies that will lower cost and maintenance, and be sustainable and adaptable to climate change (B. Griffith & C. Rosa, personal communication, March 22, 2011). Connecting these homes to water systems is essential to help prevent illnesses caused by a lack of running water (Hennessy, 2011; Ritter, 2012).

Methods.

Improved in-home running water and sanitation services in Rural Alaska are priority goals for the U.S. Arctic Research Commission (USARC) and Centers for Disease Control and Prevention. The student working on this project assessed various emerging technologies that might be useful in achieving this goal (USARC, 2012). The aim of this student project was not to generate new primary knowledge but to add value to existing information by evaluating, summarizing, collating, and communicating it in a useful form (Millennium Ecosystem Assessment [MEA], 2005). This synthesis represents new (secondary) knowledge in so far as it used investigation and an evaluation system to bring information together in a new form.

The student researched a variety of water treatment systems and compiled a review of promising technologies that met the following criteria:

- an emerging technology from a research institution, an innovative idea from anywhere in the world, or an improvement on an old technology;
- a decentralized, in-home system;
- sustainable;
- adaptable to climate change; and
- appropriate for a regional climate in Alaska.

Results.

Five types of water systems (drinking water, wastewater, water saving, greywater, and rainwater) may offer solutions to improving in-home running water and sanitation services in Rural Alaska (Table 2.4).

Table 2.4.

Water treatment systems and their uses. This table identifies water treatment systems that may be useful for Rural Alaska.

Purpose	Name	Main Technology Used
Drinking Water Systems	Kanchan Arsenic Filter (KAF) Gem505	slow sand filter that can be modified to include a basin with rusty iron nails to remove arsenic
	Trekker by Noah Water	uses a sediment filter, carbon block filter and Ultraviolet (UV) light to purify the water
	Piranha by Act2 Technologies	the system digests sludge and is designed for water re-use and "zero discharge"
	AQUACHLOR30 by Bakhir & Zadorozhny	uses an electrochemically activated oxidants mixture, produced from sodium chloride, for purification
Wastewater Systems	Imhoff septic tank	uses a sedimentation tank to separate solids for decomposition and subsequently creates an effluent that is suitable for easier treatment
	Infiltration System septic tank	lightweight plastic tank and leachfield system
	Constructed wetland	constructed with an impermeable liner, a layer of gravel/stone, and planted with native emergent wetland species
Water Saving Systems	Water saver toilet	Has an option to use a reduced amount of water per flush
	Sink on the back of the toilet tank	greywater from hand washing goes directly into the bowl to be used during the next flush
	AQUS Toilet System	water from the bathroom sink goes into a storage/filter tank under the sink for disinfection and is then plumbed to the toilet tank
Greywater systems	5-step activated sludge greywater system	water is diverted from the greywater sources in the house to run through 5 barrels for filtration and then the water is piped to a holding tank
	Constructed marsh for greywater filtration	Uses gravel and native plants to filter greywater
Rainwater systems	Catchment and Cistern systems	uses pipe and barrel system to catch and store water

Discussion.

There are a wide variety of innovative technologies that may be suitable for rural Alaskan villages. With the proper research, collaboration between stakeholders, and a willingness to explore new options, all homes in rural Alaska could have indoor running water and sanitation systems. No one system is the perfect for a specific climactic region; furthermore, the potential for change in the region should be a considered before installing any system.

Discussion and Conclusion

These three cases support the theory put forth (Figure 2.1) that an integrated research and education experience, in the context of a university course, can facilitate the production of new knowledge about freshwater, social-ecological systems. Students asked unique questions of interest to them, developed and implemented a research plan, and communicated their findings. In each case, students produced new information that added to the knowledge base about freshwater systems.

By evaluating these cases, some common characteristics emerge about the nature of the new knowledge. Through this research and learning experience students did the following:

- *created new knowledge* about freshwater systems and contributed it to the broader knowledge base;
- put forth knowledge that included *insights about both social and ecological* aspects of the area they studied;
- produced knowledge that was *place-based*, as all studies addressed local (Alaska) systems;
- conducted *applied research* studies, in so far as their work could be used to address practical issues or improve the human condition; and
- created knowledge that related to or *informed sustainability* of freshwater systems (Figure 2.8).

"It [the research project] definitely increased my knowledge on sustainable drinking water treatment and sanitation systems. It allowed me to interact with professionals who are working on sustainability issues and to take part in a small way."

"…Building the AWRVI, in my mind, was the ultimate sustainability task to do because this index and the use of it enhances abilities to apply/improve the sustainability of a community."

Figure 2.8. Student quotes about their research and sustainabilty. This figure uses student quotes to show the connection between their research project and sustainability.

While the model proved successful in producing new knowledge about freshwater systems, it is important to articulate the challenges and areas that deserve further consideration. In particular, some students in the LAS/NRM class had problems choosing a topic. Some students also struggled with different facets of the research itself which impacted the quality of their final product. More generally, the extent of the research was limited by time (one semester) and students working individually had to focus on smaller projects. The path of the research could potentially be limited by the professor's expertise, as they might guide students in one direction over another. The quality of the projects could potentially be hindered by a lack of time for the professor to advise, supervise, and give feedback on the research at regular intervals and this could be especially problematic in a class with a large enrollment. Finally, projects could be affected by a student's ability to make contact with experts or community members or the willingness of these people to work with the student.

There are some possible solutions and areas for future work that could help address some of the issues described above. A course spread out over a longer time frame (two semesters) might allow for more in-depth projects. The possibility of co-instructing the class could solve issues of professor time and expertise. Expanding the project-bank and contact list, prior to formal course delivery, could help facilitate high quality projects. It would be useful to continue this line of research, collect more data and evaluate the additional cases to determine if they too support the findings put forth here.

Using the proposed model (Figure 2.1) proved useful in generating new knowledge about freshwater social-ecological systems. In one case (i.e., the study of NPWT), the student generated entirely new primary knowledge. In another case (i.e., water and sanitation study), the student produced new knowledge based on a synthesis of existing ideas. Finally, in the third case (i.e., AWRVI), the students used a combination of existing data sets and new research to generate new knowledge. In all cases, new knowledge was produced in so far as the students generated information based on investigation.

This knowledge is useful, not only for the student as a learning experience, but may be valuable for professionals and communities interested in freshwater systems. Knowledge generated through these integrated research and learning experiences may provide fresh insights from students not entrenched or encumbered with certain ways of doing things. Knowledge generated could also be especially relevant in addressing a current need or could be important to a specific community. This knowledge also provides an excellent springboard for further studies. All knowledge is potentially useful as communities and professionals look for ways to make freshwater systems more adaptable in changing environments and this work adds to that knowledge base.

Acknowledgements

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CHAPTER 3:

Enhancing Scientific and Sustainability Literacy: A Model using an Integrated Research and Learning Experience with a Focus on Social-Ecological Systems [2]

Abstract

Environmental change and growing human pressure in an interconnected global landscape require new approaches to develop more sustainable communities. One necessary component is a scientifically literate citizenry informed by sustainability thinking. This work develops and tests a model for course design that aims to enhance students' science and sustainability literacy. This case study reports the findings from the design and delivery of a 400-level course, *Water in the Environment and Society*, based on the model. Sources of data in the study are a pre-/post- Student Assessment of Learning Gains (SALG) Likert-scale survey, a pre-/post- short answer survey, and student coursework. While this is a pilot study, the data suggest that the model is effective. The course developed with this model shows learning gains in areas associated with scientific and sustainability literacy.

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[2] Fabbri, C. E. (2013). Enhancing scientific and sustainability literacy: A model using an integrated research and learning experience with a focus on social-ecological systems. (Prepared for Submission). *Journal of College Science Teaching*. Arlington, VA: National Science Teacher Association.

This work is important as it brings together sustainability science and science education, provides a concrete model for course development, increases scientific and sustainability literacy of students, and has the possibility of informing higher education and benefiting communities.

Introduction

Environmental change and growing human pressure in an interconnected global landscape require new approaches to develop more sustainable communities (Millennium Ecosystem Assessment [MEA], 2005; National Science Foundation [NSF], 2008). One necessary component is a scientifically literate citizenry, informed by sustainability thinking, who can use reliable, timely information for decision making. Higher education is in a position to respond to this need by generating information through research and promoting science and sustainability literacy through education. This work developed and tested an instructional delivery model that higher education can use to achieve these goals.

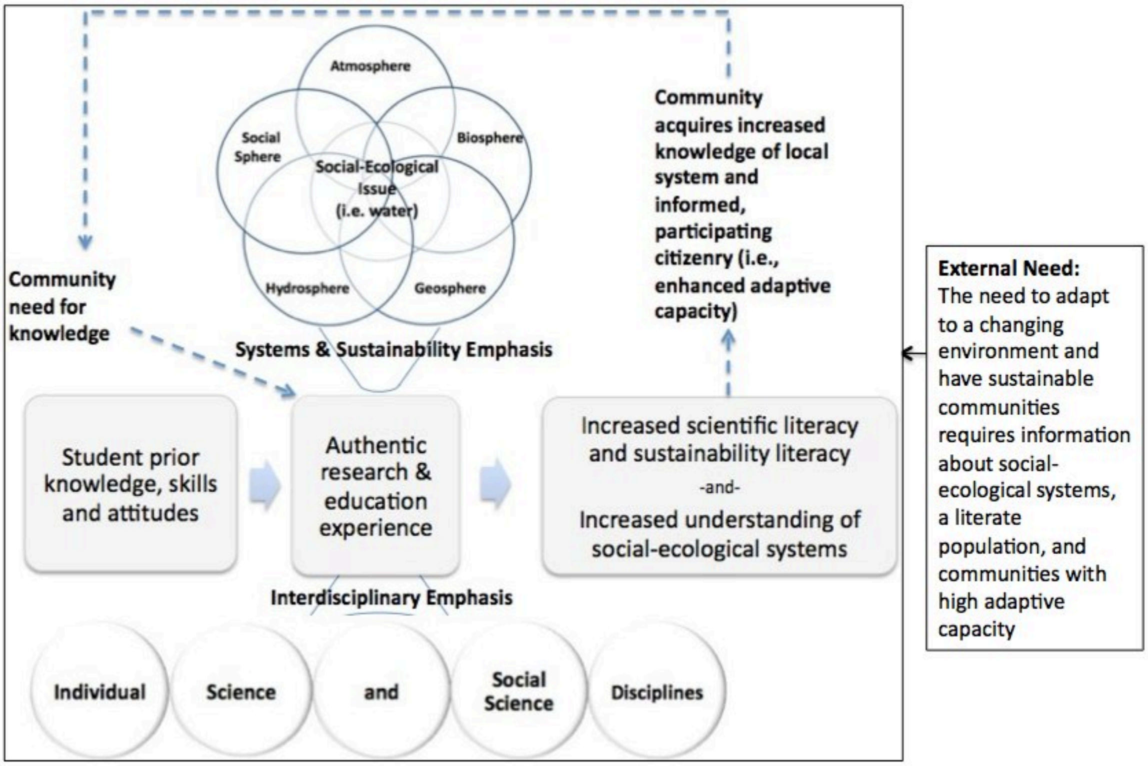

Figure 3.1. A model for sustainability science in higher education. This model shows how increased science literacy and sustainability literacy are achieved through a research and education experience with systems, sustainability, and interdisciplinary emphases.

The model incorporates recommendations from a number of sources. The keystone in the model is a classroom-based integrated research and education experience (Figure 3.1). Integrating research and education is one approach that the National Science Foundation (NSF) identifies as essential for generating information at the frontiers of science, developing scientific literacy, and providing insights on socially important issues (NSF, 2006; NSF, 2011).

Literature from the field of education also informs this model. By integrating research and education, this model provides opportunities for students to have both participatory and acquisition type learning experiences (Sfard, 1998). Following Scott, Askoko & Leach (2007), participatory experiences are grounded in the ideas of situated cognition and acquired experiences are rooted in constructivist thought. In the former, students do authentic activities associated with the domain or subject being studied (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Here, those experiences are the students' real world research projects. The acquisition learning (i.e., lecture, readings, student presentations) builds on social constructivism where learning involves a passage from social and cultural contexts to individual understanding (Vygotsky, 1978). The research and education experience can also be informed by constructivism as students connect their new ideas to prior interests and knowledge and assimilate this learning into their existing cognitive structure (Piaget, 1971; Ausubel, Novak, & Hanesian, 1978; National Research Council [NRC], 2000).

Disciplinarity, interdisciplinarity, systems, and sustainability emphases feed into the central strand of the model (Figure 3.1) and make an in-depth study of an important social-ecological issue (e.g., water) possible. The systems perspective in this model builds on the concept of social-ecological systems (Chapin, Folke, & Kofinas, 2009) and earth system science (Earth System Science Education for the 21st Century

[ESSE 21], 2010). It draws from the understanding that sustainability occurs when well-being in social, environmental, and economic systems is achieved (United Nations Environment Programme [UNEP], 1972) and defines sustainability as meeting the needs of today without compromising the ability of future generations to meet their own needs (Brundtland, 1987). Disciplinary and interdisciplinary perspectives have been incorporated to teach important conceptual ideas as well as to support understanding of systems (Blake, Sterling, & Kagawa, 2009). The final element of the model is that the community informs and is informed by the student's learning experience via *community engagement* (Carnegie Foundation, 2012). From an educational standpoint, community engagement is also an excellent way to facilitate place-based (Sobel, 2004) and culturally relevant science learning for students (Stephens, 2003).

I used this model to create the course, *Water in the Environment and Society*, a 400-level, three-credit course cross-listed between Liberal Arts and Science (LAS) and Natural Resource Management (NRM). The course also met oral and writing intensive requirements at the university. The course calendar and assignments are shown in Table 3.1. Overarching frameworks for the class were systems and sustainability and each week the class discussed how they were relevant to the current topic.

Table 3.1.

Course calendar and assignments. The left column of this table shows the major course topics and schedule for the semester. The right column lists the major assignments for the class.

Course Calendar	**Assignments**
Week 1: Course business **Weeks 2-6*:** Frameworks for the course (systems and sustainability); Water in the biophysical spheres, science disciplines **Weeks 7-12*:** Water in the social sphere, social science disciplines **Week 13*:** Water as an integrating resource (circumpolar and global perspectives) **Week 14*:** Water and change (climate change and land use change) **Week 15*:** Communicating about water (student presentations on their research) **Week 16*:** Final exam * Sustainability and systems were emphasized each week as relevant to the topic at hand	• Class participation (read and contribute to discussions) • Read, present, and facilitate a discussion on relevant articles (student choice) • Conduct a research project (student choice) • Keep a research and learning notebook • Written presentation of research • Oral presentation of research • Final exam

As a result of the instructional delivery methods brought together in this course, there was an expectation that students' scientific and sustainability literacy would improve. Students would learn content and practice process skills associated with science literacy (American Association for the Advancement of Science [AAAS], 1989, 2007; NRC 1996) and sustainability literacy (Rowe, 2002; McKeown, Hopkins, Rizzi, & Chrystalbridge, 2005; Stibbe, 2010). In addition, students' attitudes (e.g., enhanced confidence and interest) would be affected by the instructional delivery methods. Impacts on students' interest in civic engagement was of particular interest as definitions of scientific literacy and sustainability literacy discuss the importance of using personal knowledge and skills to contribute to societal issues. These three areas (content, process skills, and attitudes) are indicators of literacy and as such are reflected in the course learning goals (Figure 3.2). They are also the focal points for data collection and analysis.

1. Understand the basic structure of water, the concept of an Earth system framework, the role freshwater plays as an integrating resource in the social-ecological system, and how freshwater can be studied
2. Understand the concept of sustainability
3. Be able to use methods and skills of inquiry to conduct a real-world research/service project that contributes to our understanding of freshwater
4. Be able to communicate effectively, both orally and in writing, about freshwater issues
5. Be able to take responsibility for learning, have enhanced meta-cognitive skills, and be able to use an interdisciplinary perspective to study a topic
6. Have enhanced confidence in the ability to discuss, make decisions about and participate in societal issues about freshwater

Figure 3.2. Course learning goals. This figure shows the six learning goals for the course.

I taught *LAS/NRM 493 Water in the Environment and Society* at the University of Alaska Fairbanks during Spring Semester 2011. Six students (five women and one man) enrolled in the class and one student dropped because of a scheduling conflict. The research conducted in conjunction with this course is the basis for the case study described here.

Methods

This work is a case study based on a framework of action research (Reason & Bradbury, 2008) and scholarship of teaching and learning (Huber & Hutchings, 2005). I collected data from students in my course *LAS/NRM 493 Water in the Environment and Society*. I used a mixed methods approach for data collection and analysis (Creswell, 1994). Sources of data included two pre-/post-course surveys and student coursework (see Table 3.2).

One survey was the Student Assessment of Learning Gains (SALG), an online course evaluation tool (http://www.salgsite.org/) developed by Elaine Seymour through her work as an evaluator of the NSF-funded Chemistry Consortium (Seymour, Weise, Hunter, & Daffinrud, 2000). Using a Likert scale (1=NA; 2=Not at all; 3=Just a little; 4=Somewhat; 5=A lot; 6=A great deal), the survey asks students to rate their understanding and confidence relating to content knowledge, skills, and attitudes. Due to a lack of access to computers in class, I printed, distributed, and collected the pre- and post-SALG surveys during the first and last classes.

Other sources of data were a second survey and student journal entries. The second pre-/post-course survey consisted of open-ended short answer response questions, including one asking students to draw a concept map of their current understanding of freshwater (Novak & Cañas, 2008). The students' weekly journal entries were the other source of data. In these journals, students kept a record of all work completed on their research projects, wrote about what they were learning, and discussed how they were learning.

Table 3.2.

Data and analysis methods. The left column shows the sources of data used in this research and the right column shows the corresponding data analysis methods.

Sources of Data	**Analysis Methods**
• Pre/Post-course Student Assessment of Learning Gains (SALG) survey (Seymour et al., 2000)	• Basic descriptive statistical analysis
• Pre-/Post-course assessment of content knowledge consisting of short-answer response questions and a concept map (Novak & Cañas, 2008)	• Document analysis using á priori coding
• Student journals (weekly entries)	• Document analysis using á priori and emergent coding in Atlas TI

I collected data on students' perceived and demonstrated learning gains to ascertain if students made gains in areas associated with scientific and sustainability literacy: content knowledge, process skills, and attitude (i.e., interest and confidence in civic engagement). I used the data as evidence that the expected outcome of the model, an increased literacy in science and sustainability, was achieved. This approach to data analysis was based on the theory of analytic generalization, "in which a previously developed theory is used as template with which to compare the empirical results of the case study" (Yin, 1989, p. 38).

Specific analysis methods are shown in Table 3.2. I evaluated the pre-/post-SALG survey data using basic descriptive statistics to identify learning gains and losses. I used nine á priori codes with the pre-/post-course short-answer survey to determine the extent of students' understanding (limited, partial, in-depth) of science, sustainability, and systems. I evaluated the students' weekly journal entries using a different set of á priori codes to designate if students made content gains in science, sustainability, or systems and to identify if the gains were a result of acquired or participatory learning experiences. I also used an emergent coding system to evaluate students' journal entries. The emergent coding indicated if an attitude or skill gain was made, what that gain was, and if the gain came from an acquired or participatory learning experience. I used Atlas TI software to code the students' notebooks.

Results

The data indicate that students made learning gains in the areas of content knowledge and process skills. The information gleaned about changes in attitude, particularly their confidence in civic engagement, is less conclusive. Following are the results by area: content knowledge, skills, and attitude.

Content.

Results of the pre-/post-course SALG indicate that students perceived themselves as making content knowledge learning gains as a result of the course. While the sample size was too small to statistically test significance, the SALG showed gains (increased mean) in the seven science content questions and in the two sustainability questions on the survey (Table 3.3).

Table 3.3.

SALG survey data for content knowledge. This table shows the results (mean and standard deviation) for the pre- and post-course SALG survey questions that focus on students' content knowledge (n=5).

Question	Pre-test		Post-test	
Presently I understand…	Mean	Std Dev	Mean	Std Dev
1.1 the structure of water, the implications the structure has for its behavior and the role energy has in transforming its state	3.2	1.92	4.6	0.89
1.2 how the Earth is a complex system of interacting components - anthrosphere, atmosphere, biosphere, geosphere and hydrosphere	4.6	0.89	5.8	0.45
1.3 the roles/processes that freshwater plays in individual components of the Earth's system	4.4	1.14	5.4	0.55
1.4 the role freshwater plays in biophysical parts of the system	4.0	1.22	5.4	0.55
1.5 how social conditions impact water and how water impacts social conditions	4.4	0.89	5.8	0.45
1.6 how freshwater connects components of Earth's system at various scales	3.2	0.84	5.4	0.55
1.7 the various tools available to study freshwater	3.0	1.22	4.8	1.10
1.8 the concept of sustainability	4.6	1.14	5.6	0.55
1.9 ways that use, management, and change (human and environmental) may impact sustainability of freshwater resources	3.8	0.84	5.6	0.55

This finding of perceived content knowledge gains shown in the SALG is supported by data garnered from the students' weekly journal entries and from the pre-/post-course short answer survey. Coding the students' weekly journal entries provided evidence of them making content knowledge learning gains in science, sustainability, and systems through both acquired and participatory learning experiences (Figure 3.3). The pre-/post-course short answer survey also shows that content knowledge gains were made in the areas of science, sustainability, and systems, as students generally moved towards a greater understanding (on a continuum of limited, partial, or in-depth) on the post-test (Figure 3.4).

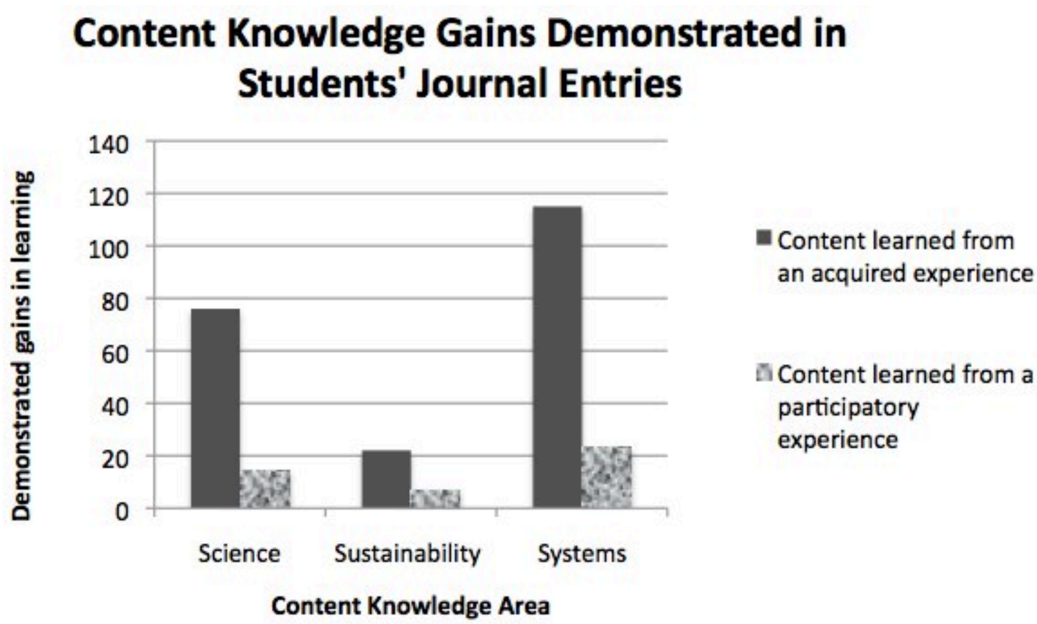

Figure 3.3. Students' demonstrated content knowledge gains. This graph shows students' demonstrated content knowledge gains as found through á priori coding of their weekly journal entries. Acquired learning experiences were things like lectures, readings, videos, etc. and participatory learning experiences were tasks related to the student's research project.

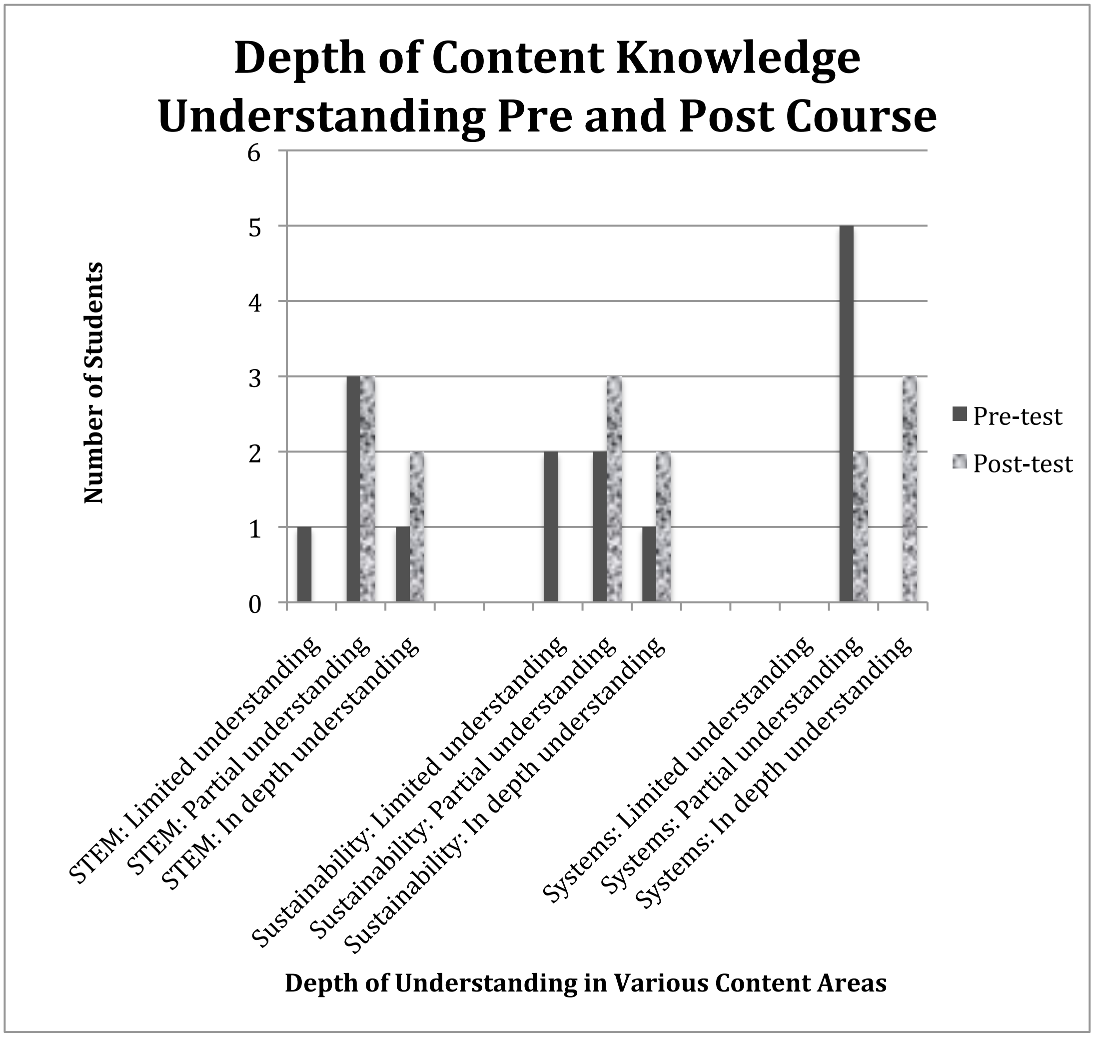

Figure 3.4. Students' level of content knowledge. This graph shows students' content knowledge gains from á priori coding of pre- and post-course short answer surveys.

Process skills.

Students reported making gains in process skills as evidenced in the SALG survey. The data show gains (increased mean) in all five areas surveyed on SALG (Table 3.5).

Table 3.4.

SALG survey data on skills. This table shows the results (mean and standard deviation) for the pre- and post-course SALG survey questions that focus on process skills (n=5).

Question	Pre-test		Post-test	
Presently I can…	Mean	Std Dev	Mean	Std Dev
2.1 work effectively with others in research or learning groups	5.2	0.45	5.4	0.55
2.2 utilize appropriate scientific and/or social scientific methods to implement a research or service project	5.0	0.71	5.2	0.45
2.3 evaluate findings and draw conclusions about research results	5.0	0.71	5.2	0.45
2.4 write documents that effectively communicate science information	4.6	1.14	5.2	0.45
2.5 prepare and give oral presentations	4.8	0.84	5.4	0.55

The coding from the students' science journals support the perceived gain in skills reported on the SALG. The journals provide evidence of the students using well over 50 different skills on more than 800 different occasions to complete work associated with their participatory and acquired assignments (Figure 3.5).

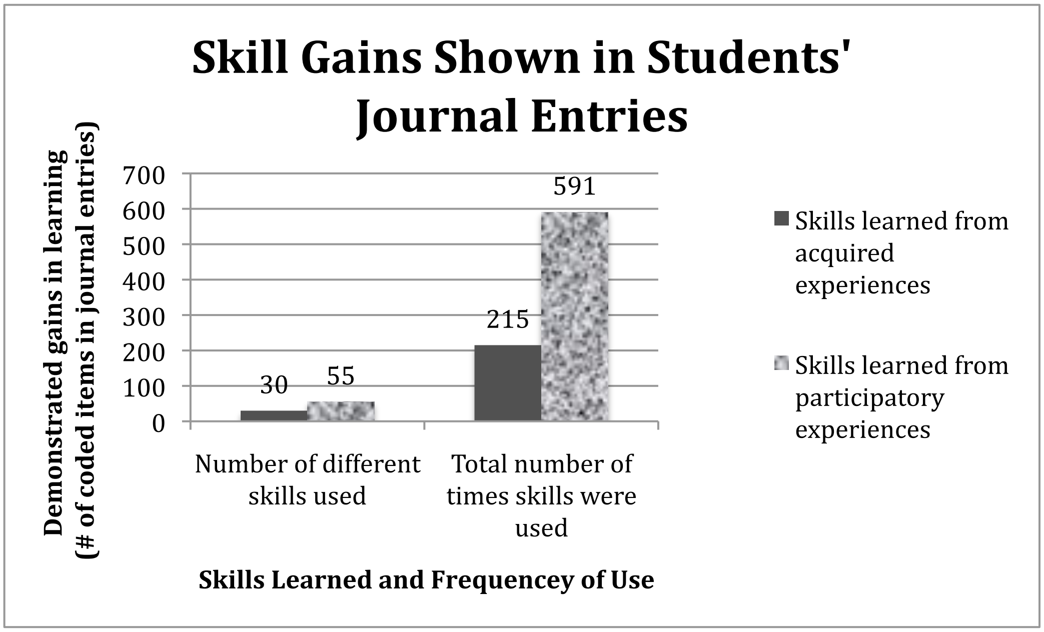

Figure 3.5. Students' demonstrated skill gains.This graph shows skill gains students made, as found through á priori and emergent coding of their weekly journal entries, for acquired and participatory learning experiences. Acquired learning experiences were things like lectures, readings, videos, etc. and participatory learning experiences were tasks related to the student's research project.

Attitudes.

While changes in attitude were of general interest in this study, students' interest and confidence in civic engagement were of particular interest because scientific and sustainability literacy cite the importance of individuals using personal understanding for social purposes. The results obtained on the SALG survey show a slight drop in confidence to participate in civic issues (Table 3.6, question 3.1). It is important to note that the larger standard deviation on the post-test results suggests that student sentiment on this point varied a good deal. Interestingly, students reported an increased confidence in analyzing social trade-offs and feeling prepared to make informed decisions (Table 3.6, question 3.2).

Table 3.5.

SALG survey data on attitudes. This table shows the results (mean and standard deviation) for the pre- and post-course SALG survey questions that focus on students' attitudes (n=5).

Question	Pre-test		Post-test	
Presently I am…	Mean	Std Dev	Mean	Std Dev
3.1 confident I can participate in civic issues related to freshwater	5.2	0.45	5.0	1.00
3.2 confident that I can analyze and discuss social trade-offs (benefits and costs of actions) impacting water resources and feel prepared to make informed decisions	4.6	0.89	5.2	0.84

The decrease in confidence related to civic engagement shown on the SALG are inconsistent with other sources of data. The weekly journal reflections show that students' attitudes were impacted as a result of learning experiences in the class (Figure 3.6). For instance, on seven separate occasions students described having an increased interest in current issues and civic engagement as a result of acquired learning experiences and at no time were there reports of students feeling less interested or confident. Furthermore, in responding to an open-ended prompt on the post-course short answer survey, four out of five students indicated an increased interest in civic engagement (the fifth student said she had always been interested).

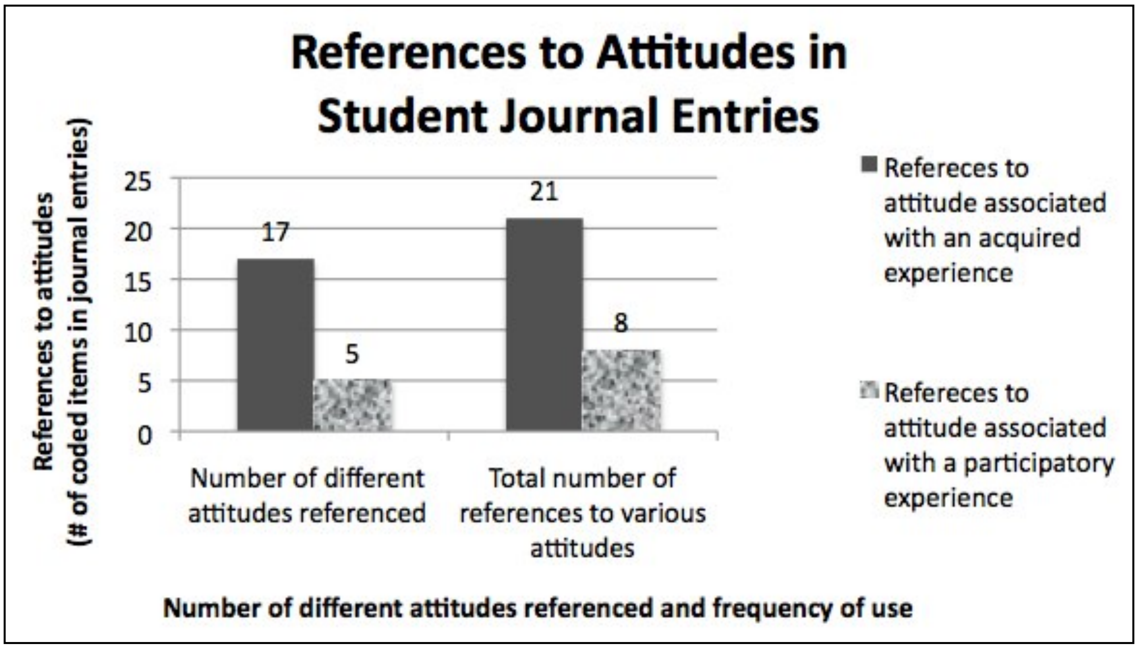

Figure 3.6. Impacts of learning experiences on students' attitudes.This graph shows the number of times students referenced different attitudes they were having as a result of their learning experiences. These results were obtained from á priori and emergent coding of students' weekly journal entries for both acquired and participatory learning experiences. Acquired learning experiences were things like lectures, readings, videos, etc. and participatory learning experiences were tasks related to the student's research project.

Discussion

This study is important for a number of reasons. This work created a unique course development model that was shown to have positive outcomes on student learning. Furthermore, this research informs the field of education, benefits society, responds to identified needs, can be generalized, and demonstrates how to do sustainability science in higher education.

One important aspect of the model is that it brings together a variety of different instructional delivery methods, based on educational theory, to facilitate a unique teaching and learning experience. Different types of courses already exist that incorporate the following types of learning: integrating research into the classroom (e.g., capstone classes), teaching about social-ecological issues, incorporating various disciplinary perspectives to build interdisciplinary understanding, using an Earth system framework, focusing on sustainability, building on students' interests or being student-driven, and integrating community or being place-based. What is unique about a course that is developed using the model proposed here is that it incorporates all of these features. A strength of this approach is that it includes the most important aspects of strong undergraduate learning experiences as identified by Project Kaleidoscope (PKAL) (PKAL, 1991; PKAL, 2006). (PKAL is a national alliance dedicated to identifying what works in undergraduate STEM education.)

The outcomes associated with this model are also important aspects of this work. The results produced in this case study suggest that the model is generally effective in facilitating learning gains in areas associated with scientific and sustainability literacy. The surveys and the students' journals show that the educational experience produced content knowledge gains in science, sustainability, and systems. The data also show that the learning experience provided an opportunity for students to learn and practice skills associated with science and sustainability literacy (e.g., ability to conduct research, ability to communicate effectively). In these ways and other ways (e.g., facilitating interdisciplinary thinking, building relevance and interest, and networking with professionals and contributing on societal issues; Figure 3.7) the course was successful and students met the first five course learning goals (Figure 3.2).

"This week I have thought about for the first time public policy and its impacts on water. I think doing this thinking is helping me connect two different aspects that I have never through of as related before."

"The research project made what I was learning in class relevant to a topic I was interested in…"

"It [the research project] definitely increased my knowledge of sustainable drinking water treatment and sanitation systems. It allowed me to interact with professionals who are working on sustainability issues and to take part in a small way."

Figure 3.7. Impacts of the course on student learning. These quotes illustrate how students felt about some of their experiences in the course and the impacts that these experiences had on their learning.

In looking at course learning goal number six in Figure 3.2, enhanced confidence related to civic engagement, it is not entirely clear why the post-SALG data is not consistent with the other sources of data on attitudes related to civic engagement. Perhaps, an increase in students' *interest* in civic engagement does not necessarily translate into an increase in *confidence* to act on it. Further investigation should be undertaken to explore how specific instructional methods influence changes in attitude (e.g., *interest* to act vs. *confidence* to act) and how the methods might be incorporated into either acquired or participatory learning experiences to make the model more effective.

Despite the inconclusive evidence on attitudes related to civic engagement, the fact that the students made content knowledge and process skill gains associated with science and sustainability is important. Increased scientific and sustainability literacy helps prepare these students for today's knowledge-based society that has a growing interest in sustainability. These literacy gains better prepare students to make informed decisions that can improve personal and community well-being.

This study also informs the field of education as it gives insights on how students learned (i.e., acquired and participatory learning). Based on evidence from coding the student journals, the following results appear: content gains were made primarily though acquired experiences (e.g., lecture, reading); skill gains were achieved through both acquired and participatory experiences (i.e., the student research project), but participatory learning provided an opportunity to learn more skills and to practice them more frequently; and attitude was impacted more often in acquired learning experiences.

The result that attitude was impacted more frequently through acquired experiences is especially interesting. The expectation was that the personal, participatory experiences would be a powerful way to impact students' attitudes, toward civic engagement for example. While the data confirm this expectation, they do not demonstrate that participatory experiences are the primary influence on students' attitudes. Perhaps powerful media tools (e.g., videos and readings) are just as likely or more likely to impact students' attitudes. Again, further study of what teaching techniques impact students' attitudes (i.e., confidence, interest) would be useful.

This study also informs the field of education as it provides some insights on how university courses with an emphasis in the sciences might engage non-traditional students, thereby having a broader impact. The results from this pilot study show that a course built with this model can create a diverse community of learners. Students enrolled in this course included an engineering major, a natural resources management major, and three liberal arts majors. Also of interest was that all the enrolled students were women (i.e., a group under-represented in the sciences). It would be useful, in future studies, to explore enrollment patterns for classes developed with this model to see if these types of classes can broaden the base of people participating in courses with an emphasis in the sciences.

Other *broader impacts* (NSF, 2013) achieved through this work included advancing discovery and engaging communities. The research portion of this course advances discovery and understanding as students produced new knowledge on social ecological systems (Figure 3.8; Fabbri, 2013a). It should be emphasized that this is especially relevant as the new knowledge is generated while promoting training and learning, a need identified by NSF (2006). The work also engaged communities (Carnegie Foundation, 2012). This engagement enhanced the networks available to conduct research and as a result increased community capacity (Fabbri, 2013b).

- Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine socio-economic vulnerability for Minto, Alaska
- Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine physical vulnerability for Minto, Alaska
- Study of the economic and social impacts of the sulfolane groundwater contamination in North Pole, Alaska
- Mechanisms for improving drinking water and sanitation in rural Alaska villages
- Prevalence of non-precipitation watering techniques among Alaskan commercial growers, farmers, and ranchers

Figure 3.8. Students' research projects.

This figure shows the titles of the students' research projects.

Ultimately, this work has the potential to benefit society because this model focuses university research and learning on important social-ecological issues. In the case shown here, the focus is on water but it could easily be adapted for other areas (e.g., WEHAB targets Water, Energy, Health, Agriculture, and Biodiversity) (United Nations [UN], 2002; AAAS, 2009). These type of sustainability science experiences have the possibility of helping communities respond to their changing environments.

NSF has articulated the need to integrate research and education; conduct transformative, interdisciplinary and systems-oriented research; expand the scientific literacy of all citizens; and leverage collaborations to provide insights on socially important issues, such as improving the ability to live sustainably on Earth (NSF, 2006; NSF, 2011). This work answers these calls and is potentially transformative as it provides a concrete model that can help higher education restructure their courses, research, and outreach to address sustainability (University Leaders for Sustainable Future, 2009). This model provides a clear framework for developing sustainability science experiences in higher education (Clark & Dickson, 2003).

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CHAPTER 4:

A Method for Building Community Adaptive Capacity: A Model For Sustainability Science In Higher Education [1]

Abstract

Climate change, population growth, land use changes, and a society more tightly connected at a global scale are forcing some communities to respond to a changing environment. This has people around the globe thinking about how to build sustainable communities. Institutions of higher education are uniquely positioned to work in the field of sustainability and in doing so they meet their tripartite mission of creating and disseminating knowledge and serving their constituent communities. The goal of this work was to propose and test a model that brought sustainability science into the post-secondary setting and enhanced community adaptive capacity. To accomplish this the model utilized a student-driven, integrated research and learning experience. The students' research projects were coded and analyzed using an adaptive capacity index to determine if they enhanced

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[1] Fabbri, C.E. (2013) A method for building community adaptive capacity: a model for sustainability science in higher education. (Prepared for Submission) *Sustainability Science.* Springer: Tokyo, Japan.

community adaptive capacity. Results indicate that the model facilitated projects that *slightly* increased community capacity. The model was refined and areas for additional research were identified. This work is important as it offers a concrete, research-based example of how higher education can engage students and communities in sustainability.

Introduction

Climate change, population growth, land use changes, and a society more tightly connected at a global scale are forcing some communities to respond to their changing environment. Other communities are contemplating changes that may affect them some time in the near future. This need to respond to a changing environment has people around the globe, including those in academia, thinking about sustainability.

Institutions of higher education are uniquely positioned to work in the field of sustainability as they have many of the resources required to work in this arena. They have access to diverse expertise (content knowledge and skill-sets) and the ability to bring that diverse knowledge base together to work on common goals. Post-secondary institutions also have an ever-changing population (i.e., faculty, staff, and students) and processes (i.e., classes, research grants) that constantly bring new combinations of people together. These assets provide opportunities for new perspectives, fresh ideas, and creative thinking thereby fostering innovation. The ability of higher education to work in this field coupled with their mission to create and disseminate knowledge and serve their constituent communities provides a strong incentive for them to engage in sustainability work.

Many institutions are answering this call and there are a growing number of programs now focusing their efforts on sustainability science. Clark and Dickson (2003) and Clark (2007) describe this relatively new area of sustainability science as a field defined by the problems it addresses and not by the disciplines it utilizes. It focuses on social-ecological systems and seeks to facilitate a transition toward sustainability by creating and applying knowledge in support of decision making for sustainable development. Interestingly, while there is a significant amount of interest in sustainability in higher education there is relatively little research from educational science contributing to the field of sustainability science to inform the effort (Barth & Michelsen, 2013). As a result, sustainability science is being implemented at post-secondary institutions with little knowledge, from an educational standpoint, of how to best bring it into this setting. This work addresses this gap by developing and testing an educational model with the potential to build more sustainable communities.

This work is rooted in sustainability literature. An underlying idea is that long-term community well-being depends on communities considering sustainability and ecosystem services in their decision-making (Millennium Ecosystem Assessment, 2005). Here I adopt the commonly cited definition for sustainability, development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). This study builds on the idea that enhancing adaptive capacity of individuals and communities is a way to move towards more sustainable futures (Chapin, Kofinas, & Folke, 2009).

Adaptive capacity is the condition of having social and physical resources and the ability to mobilize these elements (i.e., natural, economic, social, and human capital) (Brooks & Adger, 2004; Nelson, Adger, & Brown, 2007) to respond to a changing environment. Adaptive capacity is a precondition for adaptability, where "adaptability is the ability to perform in future conditions and meet future needs" (United Nations Development Programme [UNDP], 2010a, p. 15).

Given that adaptive capacity is a prerequisite for adaptability and because communities need to be able to respond to their changing environments, it is crucial to understand how to foster adaptive capacity. Enhancing capacity is about evaluating and improving aspects of natural, economic, social, and human capital in a social-ecological system. There is no universal list of adaptive capacity determinants or indicators. Capacity development is case specific. However, the authors of Chapter 18 of the *Climate Change 2001* report do summarize some key strategies for increasing adaptive capacity. The enhancement of adaptive capacity involves similar requirements as promotion of sustainable development, including the following (as cited by Intergovernmental Panel on Climate Change [IPCC], 2001):

- Improved access to resources (Ribot et al., 1996; Kelly & Adger, 1999; Kates, 2000)
- Reduction of poverty (Berke, 1995; Eele, 1996; Karim, 1996; Kates, 2000)
- Lowering of inequities in resources and wealth among groups (Berke, 1995; Torvanger, 1998)
- Improved education and information (Zhao, 1996)
- Improved infrastructure (Magalhães & Glantz, 1992; Ribot et al., 1996)
- Diminished intergenerational inequities (Berke, 1995; Munasinghe, 2000)
- Respect for accumulated local experience (Primo, 1996)
- Moderate long-standing structural inequities (Magadza, 2000)
- Assurance that responses are comprehensive and integrative, not just technical (Ribot et al., 1996; Cohen et al., 1998; Rayner & Malone, 1998; Munasinghe & Swart, 2000)
- Active participation by concerned parties, especially to ensure that actions match local needs and resources (Berke, 1995; Ribot et al., 1996; Rayner & Malone, 1998; Ramakrishnan, 1999)
- Improved institutional capacity and efficiency (Handmer et al., 1999; Magadza, 2000).

The goal of this work was to develop and test a model for use in the post-secondary setting that incorporates strategies for capacity building in order to bring sustainability science into the curriculum and improve community adaptive capacity. The proposed model is based on literature from the fields of sustainability science and educational science.

At the center of the model is an integrated research and education experience in which the students use acquired and participatory learning and conduct a real world research project as a part of a broad learning experience (Figure 4.1; Sfard, 1998; Lave & Wenger, 1991). This keystone experience is informed by students' prior knowledge and interests (National Research Council [NRC], 2000) and it builds on systems (Earth System Science Education for the 21st Century [ESSE 21], 2010), education for sustainable development (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2013), and interdisciplinary frameworks (Haynes, no date; Association for Supervision and Curriculum Development [ASCD], 2010) to teach essential content and skills. The outcome of the learning experience is that new knowledge about social-ecological systems is generated (Fabbri 2013a) and students become more literate in the areas of science and sustainability (American Association for the Advancement of Science [AAAS], 1989, 1993; NRC, 1996; Rowe, 2002, McKeown, Hopkins, Rizzi, & Chrystalbridge, 2005; Stibbe, 2010; Fabbri 2013b).

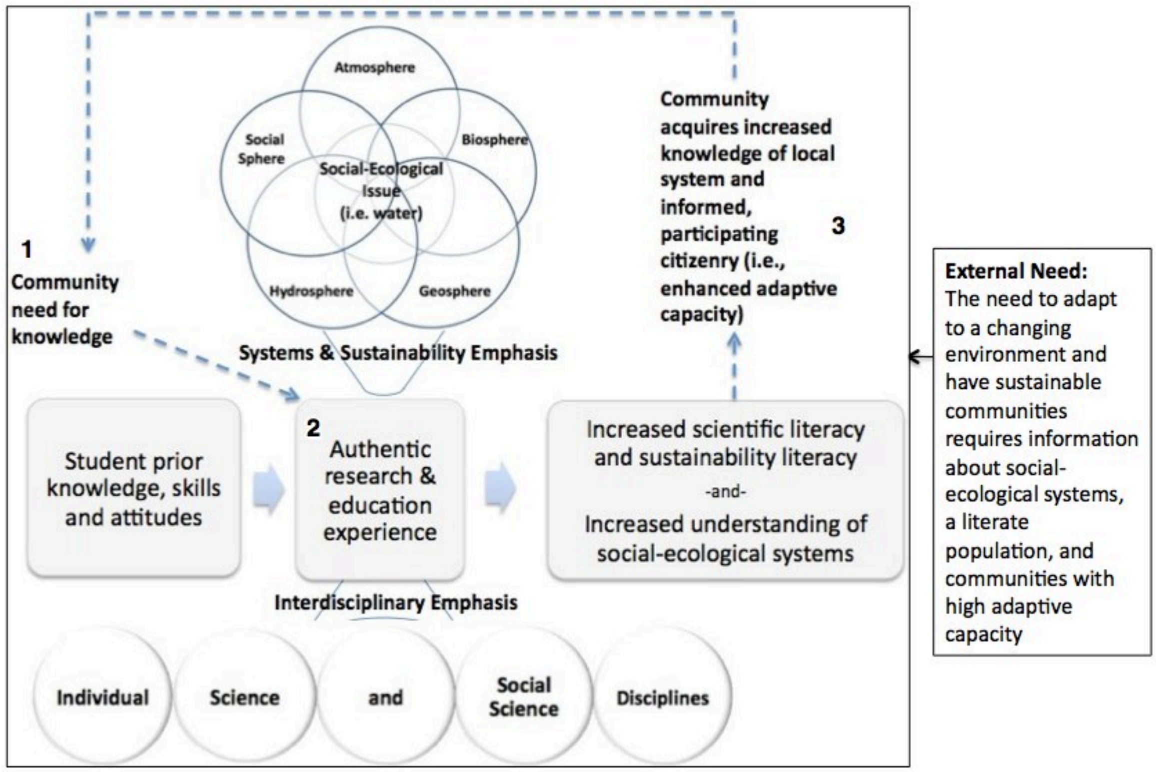

Figure 4.1. A model for sustainability science in higher education. This model shows how community capacity building occurs before, during, and after the central research experience, identified as 1, 2, and 3 respectively. It also shows that community adaptive capacity (number 3) improves as a result of the experience.

The aspects of the model that focus on community capacity building occur before, during, and after the central research experience and are identified as 1, 2, and 3, respectively, in the model (Figure 4.1). This approach of capacity building at multiple points is based on the idea of community engagement. "Community engagement describes the collaboration between institutions of higher education and their larger communities for the mutual beneficial exchange of knowledge and resources in a context of partnership and reciprocity" (Carnegie Foundation, 2013, Classification Definition section). Applying this concept in this context means acquiring input from the community before and during the research and disseminating the results of the study within the community when the research is complete. From an educational standpoint, community engagement is also an excellent way to facilitate place-based (Sobel, 2004) and culturally relevant learning for the students (Stephens, 2003).

The strategies that are incorporated into this model for building community adaptive capacity focus on improving areas of social and human capital. These specific forms of capital were chosen because they are the ones that an institution of higher education can directly influence from their position outside the community itself. The specific strategies for capacity building incorporated into this model are building networks, promoting active participation, having improved information, and educating (Figure 4.2). In the model, the strategies of networking and active participation occur before, during, and after the research experience. The strategy of having improved information mainly occurs after the research is complete (Figure 4.3). It is assumed that educating occurs throughout this process as a result of the networking, participating, and generating and acquiring information.

Social capital is improved by

- *Building a network* (engage) that respects local needs/experience and *promotes active participation* by concerned parties (IPCC, 2001; Brooks & Adger, 2004; UNDP, 2010b)

Human capital is improved by

- *Generating/Having information* about social-ecological systems (IPCC, 2001; UNDP, 2010b)
- *Educating* - knowledge, issues, skills, perspectives, values, interests, behaviors and preparation are changed as a result of experience (IPCC, 2001; UNESCO, 2006; Diduck, 2010; UNDP, 2010b)

Figure 4.2. Strategies for improving social and human capital. This figure shows the stratgies for improving human and social capital that are incoporated in the model.

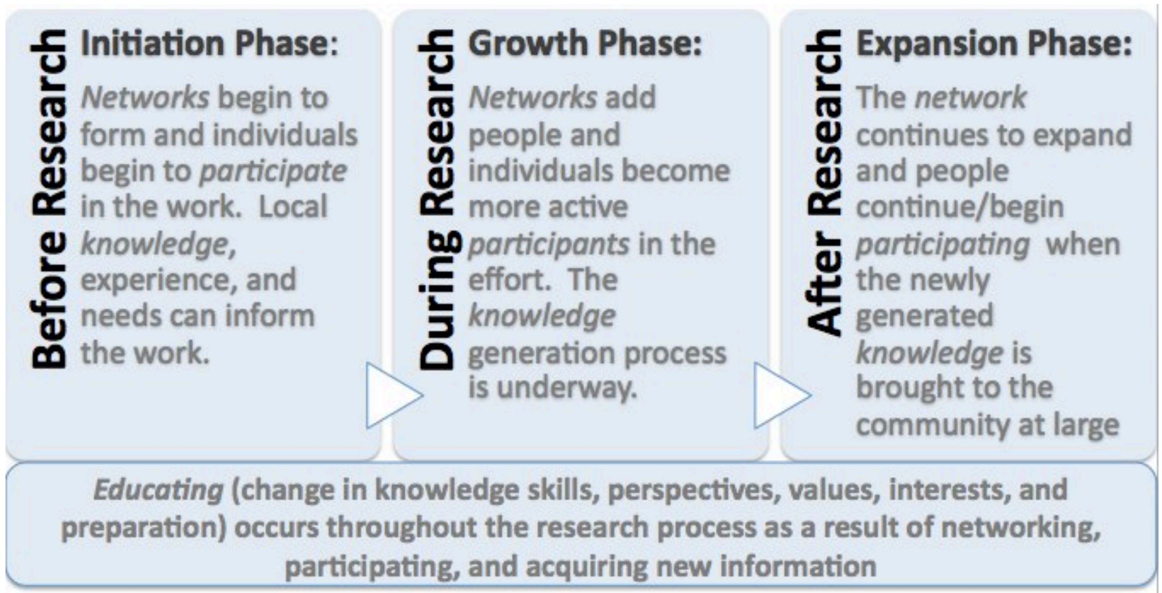

Figure 4.3. How human and social capital can increase through a research a process.This figure shows how social and human capital (i.e., networking, participation, knowledge generation, and education) are present and evolve during the research process.

The expectation that learning and educating are happening throughout the research process and by multiple means is important for a couple of reasons. This multi-faceted learning strategy provides opportunities for both individual and collective learning to occur. This sets the stage for learning to happen though social learning contexts (social constructivism; Vygotsky, 1978; Bandura, 1977), in real-world communities of practice (situated cognition; Lave & Wenger, 1991), and through more individual modes (constructivism; Piaget, 1971; Ausubel, Novak, & Hanesian, 1978). These varied approaches increase the likelihood that more people will be brought into the learning circle as their individual needs are met.

Building a broad network in which participants can learn through formal and informal, individual and collective experiences is important for the following reasons:

- Learning can produce changes in the behavior of individuals and that in turn can result in changes in the larger community (Fazey et al., 2007).
- Education and training of scholars can improve capacity (International Council for Science [ICSU], 2002) as can informal education and training of community members.
- Social learning can develop capacity to deal with differences in perspective, to solve conflicts, to make and implement collective decisions, and to learn from experience (Pahl-Wostl, 2007).

Together these educational experiences build overall capacity. Armitage (2005), Folke et al., (2003), and Walker et al., (2002) discuss how entities (communities) that are adaptive reflect learning at individual and collective levels (as cited in Diduck, 2010).

Methods

This work is a case study based on a framework of action research (Reason & Bradbury, 2008) and scholarship of teaching and learning (Huber & Hutchings, 2005). I collected data from students in enrolled in *LAS/NRM 493 Water in the Environment and Society*. I taught this three-credit course during Spring Semester 2011 at the University of Alaska Fairbanks.

During the course, students kept research and learning journals and these weekly entries were the primary source of data for this study. Other sources of data were investigator observations and notes and email communications with the students. I coded these documents using an á priori coding system. The documents were coded relative to previously developed scoring criteria (Table 4.1) put together as an adaptive capacity index.

Table 4.1.

An index to characterize change in community adaptive capacity.

This index characterizes change in community adaptive capacity that may occur as the result of an external research project (i.e., student research project).

Capital	Indicator	Scoring Criteria*	Score
Social	NETWORKING: The extent of student-community engagement (how many people) before, during, and after the research	Before research:	
		• Student engaged 0.26% or more of the total community population (In cases where this percentage is less than one, at least one person should be engaged in the work and the 0.01%-0.25% scoring option below is not used.)	2
		• Student engaged 0.01%-0.25% of the total community population.	1
		• Student engaged no community members	0
		During research:	
		• Student engaged 1% or more of the total community population; or they worked with 0.50%-0.99% of the total community population but that network included community leaders (Elders, politicians, etc.)	3
		• Student engaged 0.50%-0.99% of the total community population; or they worked with 0.01%-0.49% of the total community population but that network included community leaders (Elders, politicians, etc.)	2
		• Student engaged 0.01%-0.49% of the total community population	1
		• Student engaged no community members	0
		After research:	
		• Student shared research with 50%-100% community members	3
		• Student shared findings with 25%-49% community members	2
		• Student shared findings with 1%-24% community members	1
		• Student did not share findings with community members	0

Table 4.1 continued

	NETWORKING: The extent of involvement from individuals outside the community (how many people)	During the process as a whole students worked with: • 10+ individuals from outside the community; or a lesser number of individuals but those with specific expertise with the community and its issues • 1-9 individuals from outside the community • 0 individuals from outside the community	2 1 0
Social	LEVEL OF PARTICIPATION: The depth of student-community member participation (active, partial, or limited level of participation)	Before research: • Student and community members worked together in a meaningful way to collaboratively plan the research • Community members gave the student some input and the student planned the research • There was no input from the community to plan the research	2 1 0
		During research: • Student and community members worked together to implement the research or community members actively and regularly contributed during the research process; or • Student implemented the research with some limited community guidance; or community members engaged with the research in a limited/cursory way (i.e. single interview) • Student implemented the research without community assistance	2 1 0
		After research: • Student and community members engaged with the research in a meaningful way (i.e. collaborative review/discussion of findings) • Student and community members engaged with the research in a cursory way (i.e. presentation) • Student transferred the results to the community (i.e. sent a report) • Student and community members did not follow-up on the research	3 2 1 0
Human	INFORMATION: Community access to the information produced by the project	As a result of the research, the community: • Acquired comprehensive, high quality information that met specific community needs • Acquired partial and/or mediocre information that met specific community needs • Acquired information that did not meet specific community needs • Did not acquire new information	3 2 1 0
		TOTAL POINTS POSSIBLE =	20

Note. These scoring criteria were established for use with small communities (population under 10,000 people).

The index of adaptive capacity used here was created to determine the impact a research project initiated outside the community had on the adaptive capacity of the community. Engle (2011, p. 653) describes characterizing adaptive capacity as "an attempt to assess adaptive capacity based on predetermined attributes, mechanisms, or indicators that are purported in the literature to increase adaptive capacity." The index here (Table 4.1) is modeled on similar work from the United Nations Development Programme (UNDP, 2010b) but incorporates indicators of capacity development identified by the IPCC (2001). It is not meant to rate overall capacity for a community but rather to rate the degree to which capacity increased as a result of research projects initiated outside the community.

The indicators of adaptive capacity used in this study are networking, participation, and information. (Each is defined in the indicator column of table 4.1.) I broke these three broad indicators down into eight areas that could be independently scored. I weighted some sub-sections with more points (i.e., 3 versus 2) being possible, reflecting the idea that some stages of the process have more potential to enhance adaptive capacity. I determined networking (i.e., the number of people involved in the work) for community members before, during, and after the research and for non-community members throughout the research process. Following UNESCO (2005) and UNICEF (2006), the networking criteria also account for the fact that some individuals (e.g., leaders, Elders) have a stronger influence over the behavior of others and over policy (as cited in Fazey et al., 2007) so bringing just a few of these people into the network can increase overall adaptive capacity: the scoring system reflects this. I rated the level of student-community member participation (i.e., active, partial, limited) for each step of the research process (i.e., before, during, and after) with more active involvement being indicative of greater community adaptive capacity. Finally, I evaluated the extent of community access to newly generated information. In all cases, higher scores indicate greater increases in community adaptive capacity being achieved.

Once all the data were coded, I evaluated each student's research project using the index. I then characterized each project's impact on community adaptive capacity using a range-based scoring system. The cut scores for the scoring system were arbitrarily chosen at intervals of 6-7 points (Table 4.2).

Table 4.2.

Scale to characterize change in community adaptive capacity. This table shows a ranking system that can be used with the adaptive capacity index (Table 4.1) to characterize the amount of change in community adaptive capacity.

	Characterization of Change in Community Adaptive Capacity			
Designation	***Significantly improved***	***Moderately improved***	***Slightly improved***	***No change***
Adaptive capacity index score	15-20 points	8-14 points	1-7 points	0
Designator descriptions	More substantial gains were made in developing human and social capital. A group of people has the capacity to help the community act on a social-ecological issue.	Modest gains were made in developing human and social capital. A group of people now has the capacity to help the community act on a social-ecological issue but they may need to extend their resource base to make action more feasible or effective.	An individual or small group of people gained knowledge and awareness of issues. They could arguably initiate more capacity development within the community.	No change in human or social capital is seen

The final step of the process was to evaluate the proposed model using the theory of analytic generalization, "in which a previously developed theory is used as template with which to compare the empirical results of the case study" (Yin 1989, p. 38). Here, the results of the analysis (overall rank and designation given to each project) were used to determine if the integrated research and learning experience led to significantly enhanced community adaptive capacity - evidence that the proposed model was effective.

Results

Five projects were completed during the class (Figure 4.4). Of the five projects, three were community-based, one was done in conjunction with an organization, and one was not associated with any specific community or organization. Here, “community-based” means that the project focused on one or more specific communities. The two projects that were not community-based focused on Alaska more broadly.

Community-based projects:

- √ Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine socio-economic vulnerability for Minto, Alaska
- Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine physical vulnerability for Minto, Alaska
- Study of the economic and social impacts of the sulfolane groundwater contamination in North Pole, Alaska

Project done in conjunction with an organization:

- Mechanisms for improving drinking water and sanitation in rural Alaska villages

Project not associated with any specific community or organization:

- Prevalence of non-precipitation watering techniques among Alaskan commercial growers, farmers, and ranchers

Figure 4.4. Students' research projects*.* This figure shows the titles of the research projects students completed as a requirement for the class LAS/NRM 493.

The results of the community-based projects show that they only *slightly* improved community adaptive capacity. The data supporting this claim are shown in Table 4.3 and are discussed, by indicator, in the subsequent paragraphs.

Table 4.3.

Adaptive capacity index results for three community-based projects. This table shows the amount of change to community adaptive capacity that occurred as a result of the integrated research and education experience (i.e., student research projects).

INDICATORS			PROJECTS & INDEX SCORES		
			Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine socio-economic vulnerability for Minto, Alaska	Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine physical vulnerability for Minto, Alaska	Study of the economic and social impacts of the sulfolane groundwater contamination in North Pole, Alaska
NETWORKING	With community members	Before research	0	0	0
		During research	3	0	1
		After research	0	0	0
	With others		2	1	1
LEVEL OF PARTICIPATION	Student-community member	Before research	0	0	0
		During research	1	0	1
		After research	0	0	0
INFORMATION	Community access to information		0	0	0
TOTAL SCORE =			6	1	3
Final designation of change the project had on community adaptive capacity (Based on scale shown in Table 4.2; Explanation of this designation is in the Discussion section.)			Slightly improved	Slightly improved	Slightly improved

The three community-based projects showed limited to no networking with community members and varying levels of networking with individuals from outside the communities. None of the three projects involved community members before or after the research. Two of the three projects worked with community members during the research phase of the project. One student met with a community Elder and attempted to contact three other community-members but her calls and emails were not returned. The other student worked with five community members during the research phase of her project. All three of the projects showed that students worked with individuals from outside the communities while conducting their work. The individuals from outside the communities had varying levels of knowledge about or experience with the communities themselves.

The level of student-community member participation with the project was tightly coupled with the networking results. Since no contacts were made prior to or after the research, there was no participation in these areas. The level of community participation during the research was limited. One student conducted individual interviews (without follow-ups) and the other student received limited input from a community member during her research.

The newly generated information produced by the projects did little to improve community adaptive capacity. Though the information from two of the three projects could be considered high quality and highly relevant the community did not acquire the project findings. The third project did not produce information that was especially useful or of high quality. Like the other two community-based projects, the community did not acquire the results of the project.

The other data of interest relate to the organization-based project. The student who completed the organization-based project networked with two individuals from the organization before, during, and after the project. She also worked with three individuals outside of the organization. The level of participation by the organization representatives varied during the research process. The group worked together actively prior to the research to plan the project. During the research the representatives of the organization gave the student some intermittent guidance. Afterward the student simply transferred a final report and database to the organization. In the end, the organization did receive information that was specific to their needs and was of high quality. The work was not a comprehensive piece on the subject at hand but was a relatively in-depth study.

Discussion

It is important to acknowledge that these results and conclusions reflect a very small sample size (three community-based projects and one organization-based project) and for this reason the work should be considered a pilot test. Analysis of these cases using the adaptive capacity index indicates that the proposed model is not entirely effective. The integrated research and learning experience, as depicted in the model, did not *significantly* enhance community adaptive capacity (rating from the community adaptive capacity scale [Table 4.2]).

From the data, it is clear that these projects did only a little to enhance community adaptive capacity. The projects facilitated very little networking or active participation from community members. Furthermore, the newly generated knowledge never reached the communities. Based on the index, each of these three projects scored as *slightly* (designation from the community adaptive capacity scale [Table 4.2]) improving adaptive capacity

Slightly improving adaptive capacity is a reasonable designation as the projects did facilitate some small gains that one could argue minimally increased community adaptive capacity. In two out of the three cases the community acquired at least some minimal gains in student-community member participation and the projects raised knowledge or awareness of the issue(s) for the students and the few people who were involved (Fabbri, 2013b). This increased awareness could result in future work that could continue to build capacity. The projects did generate new information on social-ecological systems and the communities could possibly acquire the information from the course instructor at a later date (Fabbri, 2013a).

These gains reflect ways that the model was successful in increasing adaptive capacity.

These results also offer an opportunity to ask where and why did parts of the model not work and what can be done to refine the model. Issues were identified before, during, and after the central "integrated research and education experience". The problems and corresponding refinements that could be made to address the issues are shown in the text boxes surrounding the model in Figure 4.5.

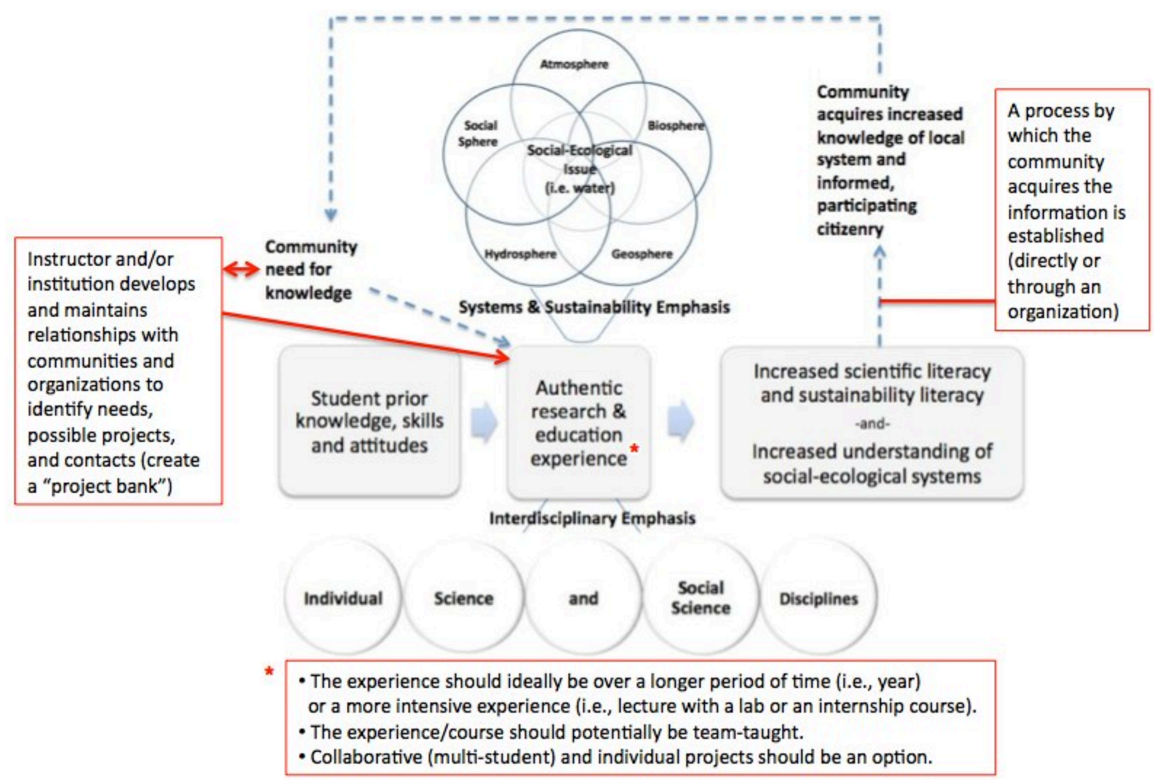

Figure 4.5. A revised model for sustainability science in higher education. This diagram shows how the original model might be revised (revisions in text boxes

surrounding the model) so that community adaptive capacity could be further enhanced. The suggested revisions are based on findings from the research.

The first issue is that students did not engage the communities before the project began. There was no networking with community members and as a result there was no participation by community members in self-identifying needs or giving input during the planning process. I believe there are two issues at work here. Students had neither the time nor the capacity to engage the communities before they began their projects. Students either did not have contacts in communities to work with or they had contacts but because they had only a semester to develop and implement the project they did not have sufficient time to engage community members in the planning process. One solution is to have the instructor or institution work with communities to pre-determine needs, possible projects, and contacts. Another solution is to provide opportunities for students to work on projects with organizations that are already immersed in communities so that students might plug into an existing structure where contacts and community input are already in place. A third solution is to provide a longer or more intense timeframe for the work (i.e., an academic year) so that students could pursue and develop the necessary contacts before the research began.

The second area where the model broke down was during the research phase. Again, time seemed to be a limiting factor so a longer timeline for implementing the research would be useful. For example, during a semester-long project students were so pressed for time to complete the research that they could only conduct single interviews with a limited number of community members or could only attempt a limited number of follow-up contacts when there was not response from a community member. A longer timeframe for research would make more interactions and potentially more meaningful interactions possible. This would provide more opportunities for student-community member networking and participation.

A third area where the model was ineffective was after the research was complete. Here the networking and participation broke down and the community did not acquire the newly generated information. When left to their own accord, the students did not (could not?) make their projects available to the communities. To resolve this issue some type of "facilitated platform", a process by which individual learning outcomes become part of a group learning experience through an informal, planned intervention to result in collective learning, needs to be put in place (Diduck, 2010). An additional recommendation is to post final projects to a website for communities to access.

The areas where the model was incomplete or insufficient provide opportunities for further research. Subsequent studies are needed to determine if refining key areas of the model (Figure 4.4) affects the outcome and can provide evidence that this type of integrated research and education experience in the higher education classroom can *significantly* enhance community adaptive capacity. One area where further research may be especially useful is on the use of organization-based projects in higher education and the resulting impacts on community adaptive capacity.

It is informative to reflect on and discuss the gains made by the organization-based project. (It is important to note that the organization-based project cannot be evaluated on the same index as the community-based projects because the scoring criteria for the two are different.) In general, this project demonstrated more networking and better participation in all stages of research than the community-based projects. A subjective analysis suggests that the organization-based project approach is potentially a very effective way for higher education to indirectly (i.e., through the organization) improve community capacity. Working with and through the organization, which is immersed in an important community issue, may provide a structured way for students to produce work that is relevant for the community. In fact, International Council for Science (2002) recommended the need for higher education to partner with other organizations on sustainable development efforts. The organization and the community could then use newly generated information to enhance capacity.

This study is important as it takes the theoretical concept of sustainability and applies it to develop a practical tool for implementing sustainability science in higher education and the broader community. This model provides a strategy for higher education to meet all three aspects of its tripartite mission, to conduct research, educate students, and serve communities, in a single experience. If these experiences are arranged around issues of sustainability then the process of learning and generating new knowledge is a formal learning experience for the student and the information, engagement, and participation (informal learning) that the community acquires builds their adaptive capacity. This model also demonstrates an approach higher education can use to make contributions in the field of sustainability, specifically in community development, by using the inherently positive framework of adaptive capacity.

This work provides two new tools that are useful for sustainability science and adaptive capacity research. This work describes the process of how social and human capital (i.e., adaptive capacity) in a community can increase as the result of an external research project (Figure 4.3). This study also provides a new adaptive capacity index to characterize how adaptive capacity changes as the result of a research project initiated outside the community (Table 4.1). These tools may be useful for others interested in capacity development work.

This model is also important as it can be a useful tool at multiple levels and in various ways. This model can be applied at course, programmatic, and institutional levels. Individual instructors can use this as a model to design their courses. For instance, this model is useful in thinking about how to bring social-ecological issues (i.e., WEHAB targets of Water, Energy, Health, Agriculture, and Biodiversity; UN, 2002; AAAS, 2009) into the curriculum in a formal way. Departments can use this model to think about the content and structure of the programs they offer (i.e., types of classes and their scheduling). For example, this model provides a framework that could be used to establish a comprehensive program for working on social-ecological issues. This model may be useful at the institutional level in thinking about course requirements for students (i.e., sustainability) and in determining appropriate criteria for those required courses. It might also inform institutional programming (i.e., the need for an office for community-based research and learning).

Currently, a growing number of institutions of higher education are mobilizing to address sustainability, but as the University Leaders for Sustainable Future (ULSF) remarks this is not an easy endeavor. The concept of sustainability offers a tremendous challenge for higher education. It requires educational institutions to rethink their missions and to restructure their courses, research priorities, community outreach, and campus operations (ULSF, 2009). Identifying proven models will be important if higher education wants to answer the call. This refined model could potentially be transformative in offering a concrete example of how higher education can engage students and communities in sustainability science. This model could precipitate *widespread* capacity development if it were adopted by a institutions with a sustainability science focus.

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CHAPTER 5:

Conclusion

Summary of the Work

I pursued this line of study because I was interested in examining how institutions of higher education *do* sustainability science. Commonly cited descriptions of sustainability science describe it as a field of research that focuses on social-ecological issues to inform a sustainability transition (Clark & Dickson, 2003; Clark, 2007; PNAS, 2013). Some existing conceptual models show that sustainability science is research informed by stakeholder engagement (Lang et al., 2012; SSI, 2013). These models suggest that knowledge is exported but do not portray learning as a key component of the process. Here, I offer a conceptual model that includes learning as a required element of sustainability science. This work suggests that sustainability science is a field of research, learning, and community (Figure 5.1). Sustainability science is a field of research that is informed by and informs learning (i.e., individual or social, formal or informal) and community in pursuit of a more sustainable future.

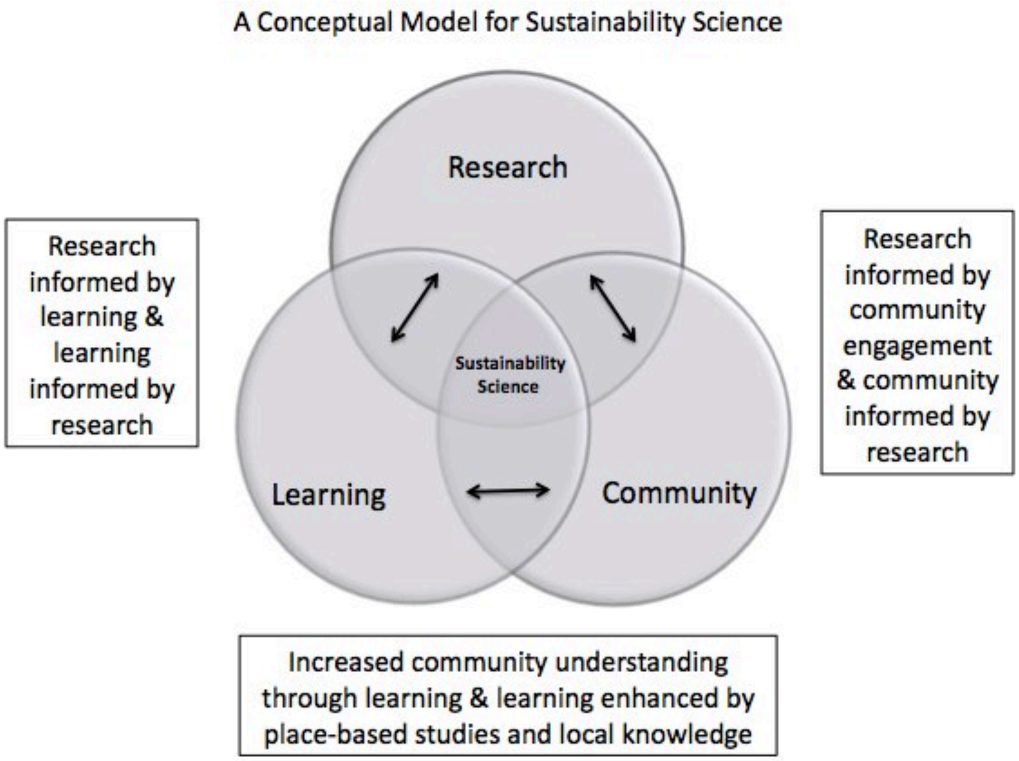

Figure 5.1. A conceptual model for sustainability science. This figure shows that sustainability science is a field of research, learning, and community/stakeholder engagement. Sustainability science is research that is informed by and informs learning (i.e., individual, social, formal, and informal) and community engagement in pursuit of a more sustainable future.

Based on this interpretation of what it means to do sustainability science, I developed and tested a model that institutions of higher education can use to do sustainability science. To be consistent with this conceptual idea of sustainability science, the model provided an opportunity to conduct research and generate knowledge about water in local social-ecological systems. The model also facilitated learning for student researchers and community members. Finally, the model coupled research and learning with community engagement to affect community adaptive capacity.

Developing and testing a model around these three areas of watershed science, learning, and adaptive capacity is important because these are all areas that institutions of higher education can and should be addressing but they need tested models on which they can rely to develop, plan, and implement their work. It was my hope that by developing and testing a model, I could provide a concrete example of how to effectively deliver sustainability science in the post-secondary setting.

To accomplish this goal, I developed a model (Figure 5.2) that had an integrated research and learning experience at its core. The expected outcomes (numbers 1, 2, and 3 in Figure 5.2) of this experience were the following: 1) generation of knowledge about local freshwater systems, 2) an increase in students' science and sustainability literacy, and 3) enhancement of adaptive capacity for the involved communities.

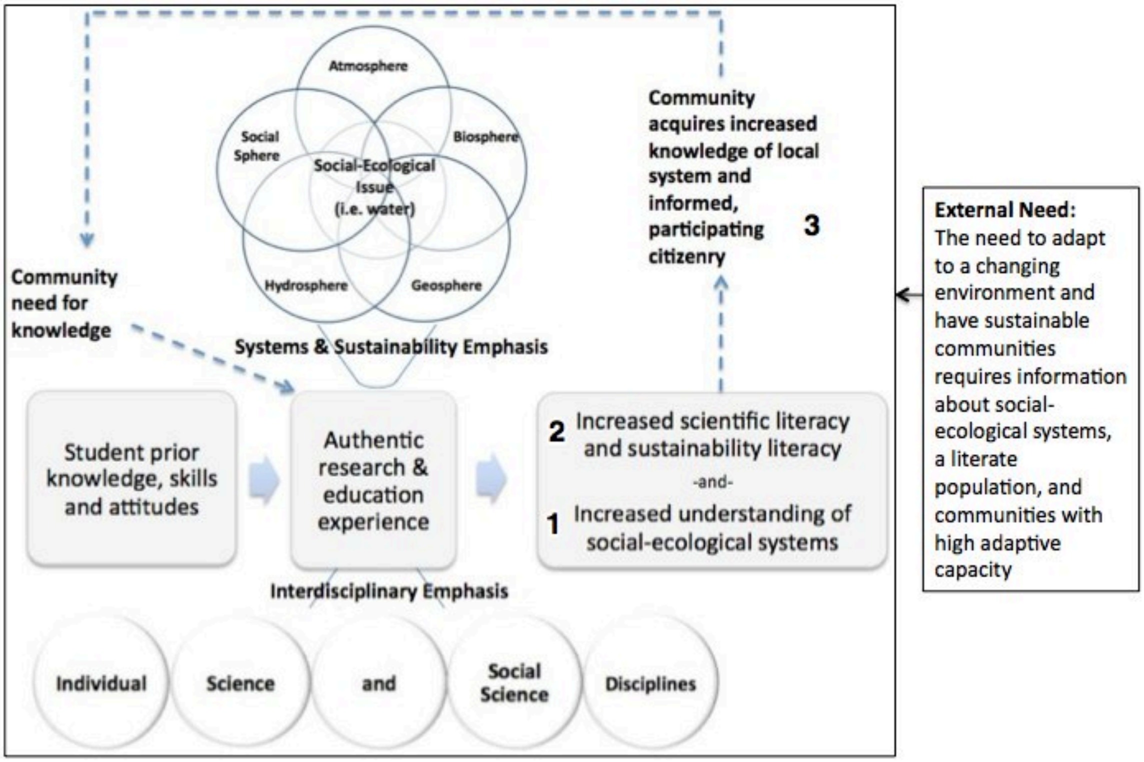

Figure 5.2. A model for sustainability science in higher education. This model shows how a sustainability science experience with a focus on a single social-ecological issue (i.e., water) can be developed. It also shows how an integrated research and education experience can 1) generate knowledge about social-ecological systems, 2) facilitate science and sustainability literacy, and 3) enhance community adaptive.

To study the effectiveness of the model, I developed three research questions. Each question focused on one of the expected outcomes of the model. I developed a course based on the model and used a framework of action research (Reason & Bradbury, 2008) and scholarship of teaching and learning (Huber & Hutchings, 2005) to collect data from students in my course, *LAS/NRM 493 Water in the*

Environment and Society. I taught this course during Spring Semester 2011 at the University of Alaska Fairbanks and then I analyzed the data to see if the expected outcomes of the model were achieved.

Lessons Learned

This test study of the model resulted in some compelling findings. First, the results show that the integrated research and education experience, as designed, was successful in generating new information about water in local social-ecological systems (Figure 5.3) as described in Chapter 2. Next, the results show that learning gains associated with science and sustainability literacy were made and how (i.e., acquired and participatory experiences) as described in Chapter 3. Finally, the integrated research and education experience also *slightly* enhanced community adaptive capacity as described in Chapter 4.

Community-based projects:

- Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine socio-economic vulnerability for Minto, Alaska
- Using the Arctic Water Resource Vulnerability Index (AWRVI) to determine physical vulnerability for Minto, Alaska
- Study of the economic and social impacts of the sulfolane groundwater contamination in North Pole, Alaska

Project done in conjunction with an organization:

- Mechanisms for improving drinking water and sanitation in rural Alaska villages

Project not associated with any specific community or organization:

- Prevalence of non-precipitation watering techniques among Alaskan commercial growers, farmers, and ranchers

Figure 5.3. Students' research projects. This figure shows the titles of the research projects students completed as a requirement for the class LAS/NRM 493 Water in the Environment and Society.

Along with these findings of what worked, this study also provides insights on how the model might be improved (Table 5.1 and Figure 5.4). One way the model could be refined is to remove barriers that impacted the students' research projects. While the majority of the students' projects were of high quality the projects were limited by the constraints of the class. For instance, the duration of the course limited the size and scope of the students' projects and a longer or more intense learning experience (i.e., lab or internship) could address this. This change would provide more opportunity to generate high quality information about social-ecological systems.

Another way the model could be refined is to strengthen the way it builds human and social capital and enhances community adaptive capacity. Finding mechanisms to increase community engagement before, during, and after the research and education experience would provide more opportunities to grow human and social capital. Things like increasing time for research and providing more structure to foster interactions with involved communities are ways the model might be refined to improve its effectiveness in building community capacity (Table 5.1 and Figure 5.4)

Table 5.1

Refining the proposed model. The left column shows where there are opportunities to improve the outcomes of the model and the right column shows the corresponding refinements that could be made to the model.

Opportunities to improve the outcomes of the model	Corresponding refinements that could be made to the model
Issues related to the students' research projects:	
• Research projects may be limited in size and scope by time, number of students working on the project, and instructor expertise	• increase the overall length of time of the course/experience (i.e. an academic year rather than a semester) or intensity of the course (i.e. require a lab with the lecture or conduct course as a fulltime internship); • consider the use of collaborative rather than individual student projects; • team teach the course so that instructor time, expertise, and ability is greater; and • identify contacts and pre-determined community needs to create a "bank of potential project areas" so that students would have a springboard to help initiate a study
• Quality of the research and final project may be influenced by the time and ability of the instructor to identify points in the research process where a student needs extra assistance and their ability to give that support	• team teach the course (or use a cadre of research mentors) so that instructor time, expertise, and ability is greater

Table 5.1 continued

Opportunities to improve the outcomes of the model	Corresponding refinements that could be made to the model
Issues related to community engagement:	
• Networking with and participation by community members could be improved throughout the research process	• The instructor/institution establishes a relationship with communities and or organizations immersed in community-based work to identify community needs, possible projects, and contacts (in essence building a "bank of potential project areas"). • The use of organization-based projects is considered so students can "plug in" to an existing structure. • Extend the length and/or intensity of the course to increase the amount of time available for student-community interaction.
• More could be done to ensure that the newly generated information is disseminated to and throughout the community	• Build a "facilitated platform" (Diduck, 2010) into the course structure to facilitate the delivery of the newly generated knowledge to and in the community.

Significance of the Work

This work is significant for the knowledge base that came together to make the work possible and for the outcomes and new understanding produced by the work that contribute back to the respective fields.

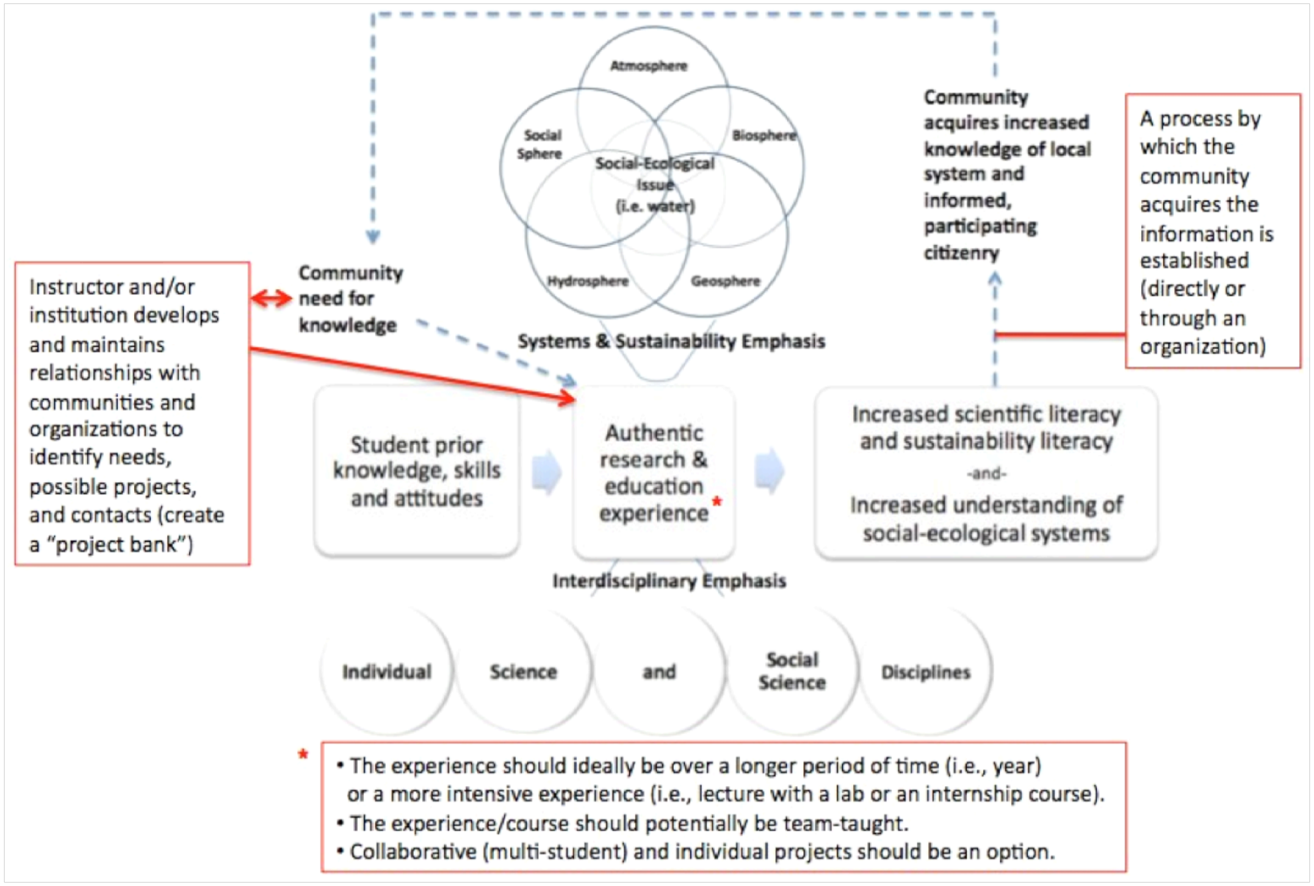

Figure 5.4. The revised model for sustainability science in higher education. This figure shows how the original model might be refined (see text boxes surrounding the model) to improve its effectiveness. The suggested revisions are based on findings from the research.

Significance of the knowledge contributing to this work.

This study is significant because it harnesses theory and practice from sustainability science, watershed science, educational science, and adaptive capacity research to build conceptual and applied models. It uses foundational concepts and *best practices* from these fields to deliver a high quality sustainability science experience in the post-secondary setting.

Significance of the contributions resulting from this work.

This work is significant for the outcomes produced by the model and because those outcomes meet identified needs.

Watershed science.

This model answers the call to generate knowledge that improves understanding of water in relation to systems, environmental change, and sustainability (NSF, 2008; Dozier et al., 2009; Schneider & Braden, 2009, p. 3). Facilitating student research is important because so much work is needed to understand water systems and students can help fill the gaps in the knowledge base through their research.

Knowledge produced by students might be especially useful for the following reasons:

- Students bring potential for fresh ideas as they are not encumbered by routine or fixed perspectives.
- Their projects can lay the groundwork for future studies.
- They may have personal insights or connections to a community making research there possible that might not be accomplished otherwise.
- Their use-inspired and applied research can be useful in addressing real-world issues.
- The results of their research efforts could inform sustainable development.

Learning: Science and sustainability literacy.

This integrated research and education experience with a focus on a social-ecological issue (i.e., water) and using an interdisciplinary approach for delivery helps answer the call by NSF and other agencies to improve research and education. Specifically, this approach offers opportunities to integrate research and education, increase interest in science, builds literacy, and provide insights on socially important issues (NSF, 2006; National Academy of Sciences [NAS], National Academy of Engineering [NAE], Institute of Medicine [IoM], 2007). Furthermore, in building science and sustainability literacy, this work enhances individual well-being by preparing students for the workforce and civic engagement.

Other significant findings related to education also came out of this study. Cross-listing this course between NRM and LAS and having the course fulfill oral and writing intensive course requirements brought diverse students together in the course and created an interdisciplinary community of learners (i.e., students from the sciences and social sciences enrolled in the course). The course was also attractive to women (i.e., all of those enrolled were women) and perhaps the interdisciplinary, real-world nature of the course (i.e., covering both science and social science aspects of water) contributed to this.

Community engagement and adaptive capacity.

This study provides a working model institutions of higher education can use to work on important societal issues and benefit communities. The work looks to affect community well-being by increasing human and social capital to enhance community adaptive capacity. This type of capacity development, if refined, made highly effective, and embraced by universities, could be extremely valuable. If institutions of higher education take up this work with their constituent communities *widespread* capacity development is possible. The refined model lays the groundwork for future work in this area.

The other significant outcomes of this work are the tools generated for use in the study. First, the work described how social and human capital (i.e., aspects of adaptive capacity) increase through a research process (Figure 5.5). Second, a new adaptive capacity index to characterize change in community adaptive capacity (i.e., human and social factors) as the result of an external research project was created (see Chapter 4). These tools may be useful for others interested in theoretical and applied aspects of adaptive capacity and its development.

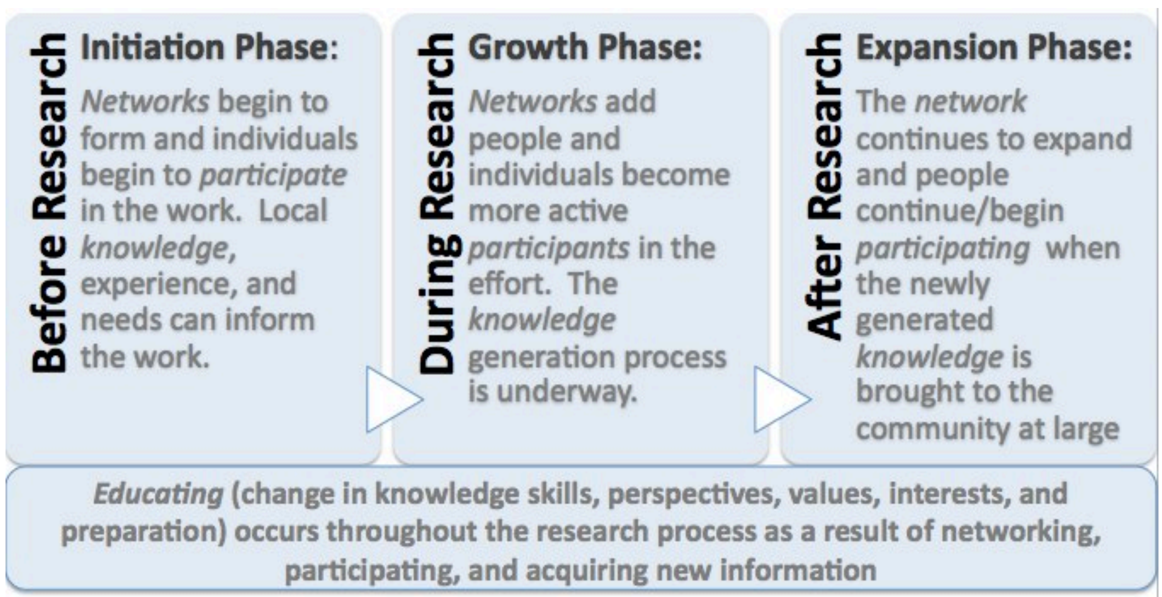

Figure 5.5. How social and human capital can increase during the research process. This figure shows how social (i.e., networking and participation) and human (i.e., knowledge) capital increase during the process of conducting research.

Sustainability science.

As previously described, this work informs the individual fields of watershed science, education, and adaptive capacity, but perhaps of more significance is that this work informs the field of sustainability science. It does this by addressing a known gap in the literature base in which educational science and sustainability science inform one another (Barth & Michelsen, 2013). The lack of educational science informing sustainability science discourse has limited theoretical ideas and efforts to apply these ideas in this field. An outcome of this effort is that it has led to new theoretical and applied models that provide insights for the field of sustainability science.

An important outcome of this study is that, to the best of my knowledge, it contributes a distinctly new perspective on the field of sustainability science by presenting a new conceptual model of sustainability science (Figure 5.1). This model builds on existing ideas of what it means to do sustainability science by offering a conceptual model that includes learning as key component. This model indicates that sustainability science is a field of research that is informed by and informs learning (i.e., individual or social, formal or informal) and community in pursuit of a more sustainable future.

This thesis is also significant for its contribution to sustainability science because it takes this theoretical concept of how to do sustainability science and offers a concrete model to illustrate what this can look like in a post-secondary setting. This study provides a working model of how higher education can *do* sustainability science (Figure 5.4). This is important because to do sustainability science there must be a structure in place that facilitates research, learning, and community engagement. While the model depicted here has a specific focus on water in the undergraduate curriculum and community adaptive capacity the model can be generalized for other uses.

It is important that the model can be generalized for a variety of needs and applied at course, programmatic, and institutional levels. Individual instructors can use this as a model to design their courses. For instance, instructors can use this model to design courses based around social-ecological issues (i.e., WEHAB targets <u>W</u>ater, <u>E</u>nergy, <u>H</u>ealth, <u>A</u>griculture, and <u>B</u>iodiversity; UN, 2002; AAAS, 2009) and civic engagement (SENCER, 2013). Departments can use this model to think about the content and structure of the programs they offer (i.e., types of classes and their scheduling). This model may also be useful at the institutional level in thinking about course requirements for students (i.e., sustainability, civic engagement) and in determining appropriate criteria for those required courses. This work might also inform infrastructure at the institutional level (i.e., the need for an office for community-based research and learning). Furthermore, while this model, was designed for use in undergraduate education it could be modified for use in graduate programs or secondary schools.

Institutions and program leaders should consider adopting this type of framework for at least three reasons. First, this research-based model is based on *best practice.* It incorporates characteristics that have been identified as the most important attributes in strong undergraduate science, technology, engineering, and mathematics (STEM) programs. The following characteristics of high quality learning experiences have been identified by Project Kaleidoscope (PKAL) and are built into this model (PKAL, 1991; PKAL, 2006):

- Learning that is experiential, inquiry-based, investigative, and has research opportunities beyond the classroom and campus.
- Learning that is personally meaningful, makes connections to other fields (interdisciplinary), and has practical applications.
- Learning that takes place in diverse communities of learners where students are collaborating partners.

Second, through this sustainability science model, higher education can meet its tripartite mission or cooperative extension goals in one process. By integrating research and education, institutions can generate knowledge and disseminate that new understanding through formal and informal educational experiences. By partnering with communities before, during, and after the research the institution can help meet community needs (Carnegie Foundation, 2013).

Third, by working on important societal issues through the inherently positive framework of community adaptive capacity institutions have an opportunity to contribute to building sustainable communities . Community health, well-being, and sustainability require that communities plan for and address social-ecological issues (e.g., water, energy, food, ecosystem services). Using this framework, to build a comprehensive program that addresses many social-ecological issues, institutions of higher education can help communities understand these systems. This study is essentially a proof of concept project for a single social-ecological issue (i.e., water) but the model can easily be refined and expanded to address other critical issues as part of a larger community well-being framework.

Currently, a growing number of institutions of higher education are mobilizing to address sustainability but as the University Leaders for Sustainable Future (ULSF) remarks this is not an easy endeavor. The concept of sustainability offers a tremendous challenge for higher education. It requires education institutions to rethink their missions and to restructure their courses, research priorities, community outreach, and campus operations (ULSF, 2009). Identifying proven models is important if higher education wants to answer the call. This study could be potentially transformative in offering theoretical and concrete examples of how higher education engages students and communities in sustainability science.

Opportunities for Further Research

This study was a pilot test of the model so a number of additional studies are needed to follow-up on the ideas and conclusions reported here. Further work could be done in four main areas. First, additional research could be done in the individual areas of watershed science (Chapter 2), science and sustainability education (Chapter 3), and adaptive capacity (Chapter 4). Second, studies that attempt to generalize the applied model would be useful. Third, studies relevant to broader impacts of the work would be very informative. Finally, research focusing on the conceptual model would be useful. Each of these is discussed here.

Additional studies relevant to watershed science revolve around implementing and studying the refined model. Would more time, team teaching, banks of potential project areas, or working on collaborative projects improve student research? In general, further studies need to look at what the best strategies are to reduce constraints within the classroom so that students can conduct and produce the high quality research.

There is a need for further research in science and sustainability education. One area in which the data produced inconclusive results relates to how the integrated research and education experience impacted students' attitudes and this is an area where another study would be useful. Relevant research questions are suggested in Figure 5.5. Another area of interest could focus more closely on what types of acquired and participatory learning experiences best facilitate specific learning goals. A final and important area where additional work would be helpful would be to simply conduct more studies to ensure that the perceived and demonstrated learning gains shown in this study can be reproduced.

- How are students' attitudes affected by various acquired (e.g., multimedia) and participatory experiences?

- How do different types of learning experiences affect students' *interest* and *confidence* in civic engagement?

- What types of learning experiences lead to increased confidence in civic engagement?

Figure 5.6. Possible research questions related to learning and student attitude. This figure lists possible research questions that focus on how learning experiences impact students' attitudes.

Additional work using the refined model would also be useful to see if community adaptive capacity could be *significantly* improved. Other interesting studies could focus on the use of organization-based projects in undergraduate research and better understanding community perceptions on how their adaptive capacity is affected by a university-based research projects.

Along with research in these individual areas, it would be exceedingly useful to simply conduct more iterations of this work to confirm the findings produced here. Furthermore, it would be useful to generalize this model and apply it in different contexts to see what results are obtained. For instance, one could design a new class on a different social-ecological issue (e.g., energy, food security) using this model or to test the model in other geographic and educational (e.g., national, international, urban, cooperative extension) settings.

Studies that focus on broader impact areas of this work would also be interesting. For instance, in this pilot study, all of the students in the class were women and it would be useful to know if classes of this nature tended to attract groups (i.e., women) under-represented in the sciences. It might also be useful to conduct work to see if this type of class could have any positive outcomes (i.e., recruitment, retention) for indigenous students by allowing them to conduct research in their home communities or by incorporating local or traditional knowledge into their research.

Finally, it would be very informative to study a series of different applied models that all use the research, learning, and community conceptual model to identify what strategies and methods best facilitate this concept of sustainability science. Gaining a better understanding what *best practice* is for the field of sustainability science would benefit the field as whole.

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