Chapter 13
Socio-scientific Issues for Scientific Literacy – The Evolution of an Environmental Education Program with a Focus on Birds

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13.1 Introduction

> *Perhaps the greatest threat is losing our connection with the natural environment. Too many children are now raised indoors with no knowledge or appreciation of nature and no incentive to retain any part of their natural environment. Who will carry on the fight to reduce atmospheric and oceanic pollution, to conserve productive farmland and clean water, and to work toward slowing the rising sea levels?* – Chandler Robbins (Strycker 2012, p. 19)

Birds and humans share common spaces the world over. There are over 9800 species of birds worldwide and just under 1000 species within North America (Clements 2007). The United States Fish and Wildlife Service conducts regular national surveys related to wildlife-associated recreation activities, and observing wild birds is the leading non-consumptive wildlife related activity (United States Fish and Wildlife Service, USFS 2013). The 2011 survey indicates that over 46 million people engage in birding and bird watching. Birds are one of the most accessible groups of animals by students and teachers. Students' connections to birds may range from casual observations in the schoolyard to keeping birds as pets or engaging in bird identification projects, and it is common for outdoor classroom areas to feature gardens that attract birds, bird feeders, and nesting structures. Many organizations such as the American Birding Association (ABA 2015) and Cornell University (eBird 2015) have been actively building youth outreach programs for some time now. Given this natural familiarity and for many students' inherent interest, birds are an animal group with great potential for science education.

In this chapter, we discuss a program that provides opportunities for high school learners to interact with birds through a citizen science initiative. The work is presented from the perspective of Andrew, the first author, who created the program.

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The chapter begins with a brief review of the literature on citizen science around bird monitoring and habitats, and then presents early versions of the avian citizen science program at Andrew's school. After several years with the initiative, Andrew was looking to improve the program with the goal of impacting student learning and experiences with science in more profound ways. He started working with Troy, the second author, and together they considered how the bird research experiences might be coupled with a socio-scientific issues (SSI) approach. The chapter focuses on how the program evolved to engage learners in science research on natural populations, ecology, and meaningful SSI.

13.2 Research Experiences for Students Through Citizen Science

A major challenge for science teachers is finding methods that engage students in scientific investigation that allow for exploration of science content and practices in settings that are authentic (Schwab and Brandwein 1962). Asking students to follow instructions in a lab handout to a scripted end rarely leads to meaningful experiences that embody science. Most students do not experience research opportunities until they move beyond their secondary education (Feldman et al. 2013).

Citizen science dates back to the 1800s in the United States. Science educators began exploring the concept of citizen science in the 1990s as a way to make school science more relevant to children's lives. Citizen science varies widely in its implementation. Generally it can be described as a collaboration between members of the public and scientists investigating and collecting data on real world problems (Wiggins and Crowston 2012). Dickenson and colleagues emphasize that citizen science also "addresses broader societal impacts in a profound way by engaging members of the public in authentic research experiences" (2012, p. 291). Oberhauser and Lebuhn (2012) present citizen science as a way to enhance education through data collection, research opportunities, and class projects. These projects have also been described as 'Public Participation in Scientific Research' (PPSR) (Bonney et al. 2009; Cooper 2012). Bonney and Cooper have extensive background with citizen science and informal science education and described three categories of PPSR:

A. Contributory – Designed by scientists, in which the public primarily collects data.
B. Collaborative – Designed by scientists, with public collaborators given some freedom to refine, analyze data, or communicate results.
C. Co-Creative – Fully collaborative in which the public and scientists design and participate together in most aspects of the project. (Bonney et al. 2009; Cooper 2012)

Most citizen science/PPSR projects fall within the contributory category (Bonney et al. 2009). Gray et al. (2012) suggest a rationale for this may include the lack of common frameworks available for researchers and other participants to engage in collaborative or co-creative PPSR.

The vision for citizen science/PPSR in classroom settings promotes the idea of building scientific literacy, especially among youth and the public. Scientific literacy is a broad concept with diverse, sometimes conflicting interpretations, and yet is often referenced as a goal of science curriculum design and instruction. Roberts addresses the concept of scientific literacy as a way of conceptualizing outcomes of science education in his chapter in the *Handbook of Researchon Science Education* (Roberts 2007; Roberts and Bybee 2014). He proposes two broad visions of scientific literacy at opposite ends of a continuum. Vision I refers to scientific literacy with traditional science content and practices that focus on the internal knowledge of science products and processes. This type of literacy is often decontextualized from specific events or issues. In contrast, Vision II refers to external sources of scientific literacy. An example of this type of literacy might involve students in the context of societal issues impacted by scientific phenomena. In other words, the complex and sometimes controversial issues of science are illuminated by understandings of scientific processes and content woven together. Both ends of this scientific literacy continuum have relevance to citizen science and PPSR.

Mueller et al. (2012) expand the definition of citizen science and envision that CS/PPSR serves as a means for more democratic science to affect change for future generations. Mueller and his colleagues ask educators to:

> Find ways to include youths not only in pedagogy that heightens epistemic development, but also in schooling where they have opportunities to engage real issues through their activism. Thus we promote youth activism through citizen science as a pedagogy in which teachers and their students gather information to make the most informed decisions about potential consequences and collaborate with others to increase the degrees of confidence surrounding these choices (p. 11).

13.3 Andrew's Evolution with Citizen Science and Bird Banding

My first experiences with research occurred during my undergraduate work in biology, working briefly in a laboratory and later in the field. Following college graduation, I worked for two years on a variety of ecological research projects and became adept at bird banding, nest searching, conducting bird surveys, as well as habitat analysis and water quality techniques. One of the most influential moments was at Whitefish Point Bird Observatory in the Upper Peninsula of Michigan where part of my job was to provide banding demonstrations for the public. Introverted with no prior teaching experience, I dreaded that part of the job at first. In fact on the morning of my first public banding demonstration, I faced 15 birdwatchers and stumbled through an interpretive demonstration about the purpose of bird banding and research in general. During this first teaching experience, I gravitated towards a little girl whose body language suggested that she and I were equally uncomfortable with the lesson. I knelt in front of her with a Cedar Waxwing that had been banded. She touched the bird. I asked whether she would like to hold it herself. As her demeanor softened, she agreed. Her face vibrantly lit up as she held the bird for the first time and safely released it. It was clear that she had connected to that bird and the natural environment as never before. This was an experience that changed both of us. It was in that moment, that I realized the power of a bird in the hand as well as sharing my passion for science and research with young people. I decided to become a teacher and returned to school to complete a master's degree and initial teaching certification with the goal of finding a way to innovatively teach science with birds and share that moment of discovery.

During the early years of my teaching career, I kept looked for ways to continue working in research and share my passion for research with my students. In 1998, I earned a bird banding certificate and partnered with the Institute for Bird Populations (IBP) in Point Reyes, California to establish a local research station as part of the IBP's Monitoring Avian Productivity and Survivorship (MAPS) program (DeSante et al. 2008). I entered into a partnership with leading ornithologists and established a bird-banding program based on their researchprotocols (DeSante, et al. 2008). I had previously worked on several bird banding projects such as MAPS as a field biologist, and I knew that I could use this as a platform for teaching core ecology and research techniques.

In 1999, I created a summer Field Research class for high school students with bird banding as the central element. A regional Environmental Protection Agency (EPA) grant provided funds for purchasing equipment. I offered my class as a summer school course in which students documented 120 hours of work toward science credit. The class was situated almost entirely in the field with work beginning at sunrise and extending into mid-afternoon. The banding station was situated on my family farm, providing a safe venue on private property to run mist nets and perform habitat analysis. The goal of this project was to engage students in actual science research projects so they could come to think of themselves as citizen scientists and apprentice researchers in stark contrast to the scripted, predictable nature of laboratory events traditionally used in typical science instruction. I expected students would gain ornithological and botanical knowledge in addition to research skills.

I taught the class alone for the first two years with 6–10 students each year. The class focused only on ornithology in the early years, banding for six consecutive hours at least once every ten days throughout the summer. Our research together was often unpredictable and unscripted. Students were not simply following directions in a laboratory manual but rather using content knowledge in conjunction with problem solving skills to complete daily research. For example, when students captured and analyzed birds (following the bird banding protocol) they identified the species, sex, aged the bird using skull ossification and plumage characteristics, and made basic measurements for statistical analysis. I guided students through the research protocols and gradually faded these supports as students became more proficient with the science. Each day presented different challenges, and we worked through them together to achieve the goals of our partner agencies and, just as importantly, to develop a greater understanding of the science ideas and processes.

My students and I learned much as we battled rainouts, severe weather, early morning starts, and hot summer weather. I was excited as a young teacher, and feedback from the students was positive despite the physical hardships.

In my third year running the program, a chemistry teacher colleague, Alan Reed, joined me to teach the field course. Alan suggested adding water quality monitoring as a new component of the course by using the guided protocols from the Missouri Stream Team (Missouri Department of Conservation, MDC 2007). These protocols are similar to many other state programs and feature a combined biological and chemical assessment of water quality. Students surveyed stream invertebrates, which provided insights into the long-term conditions of the stream. Water chemistry assessments provided a snapshot of immediate stream health. Our students responded well to the water quality monitoring component and working in the streams provided a convenient way to deal with the summer heat. Alan and I continued to fine-tune the bird and water quality research until his retirement in 2004. For example, we developed a portfolio assessment design for grading with a summative public presentation of our research findings to the parents and school administrators.

Another colleague from physics and technology, Brandon Kovach, joined me after Alan retired. Brandon brought a strong physics background to the class, which afforded the addition of astronomy and geo-orienteering components to the curriculum. The program picked up momentum during this time with enrollment increases and tremendous support from the community. Much of the success for the program was due to a desire to continuously analyze and improve the course on our part. We employed a reflexive approach to the class by continuously examining our goals and reflecting on outcomes from students. Students were actively engaged in meaningful learning experiences, and pre/post testing documented significant gains in science knowledge. At the same time, it was clear that students perceived bird banding, stream quality, orienteering, and astronomy as disconnected contents. Perhaps, this was due in part to the compartmentalized approach for science instruction that students have grown familiar with in the traditional classroom model at our school. I was dissatisfied with this disconnect and turned to the empirical literature to inform my instruction.

13.4 Best Practices for Citizen Science

Classrooms in the United States and abroad often feature science inquiry activities that are oriented to be "hands-on, but infrequently minds-on" (Burgin et al. 2012, p. 440) based on the assumption that involving students in inquiry activities is adequate for effective instruction. Thus, creating learning experiences in the midst of doing science should allow for productive science learning. However, this notion may inadvertently inhibit realizing more extensive student gains. Empirical studies of citizen science programs and other approaches for engaging students in inquiry suggests that incorporating explicit foci on learning goals within these programs can significantly increase the extent to which these goals are actually achieved (Sadler et al. 2010). Some students who are naturally introspective and analytical may indeed learn target outcomes from more traditional, implicit approaches. However, in order to maximize the significant effort and financial expenditure that goes into the curricular design and implementation of citizen science projects, it is better to make learning goals explicit. In other words, it is better for teachers to be purposeful in their design and implementation of these programs and to communicate these goals with their students (Sadler et al. 2010). With these thoughts in mind, I identified two areas of improvement for the field research program: Increasing the epistemic involvement of students in research processes and engagement with reflective practice.

13.4.1 Epistemic Involvement

Ryder and Leach (1999) introduced *epistemic involvement* as a way of thinking about the extent to which learners, involved in research, are engaged in the meaning-making dimensions of science. The construct helps to distinguish between low epistemic activities such as recording data, to high epistemic activities, such as generating research questions. Sadler and his colleagues (2010) later used the idea to interpret authentic research experiences as contexts for learning. Consider the following,

> Involving students in ongoing research projects such that they follow established routines may be the most practical way of engaging the relative novices. However, if the participant's experience doesn't include a range of epistemically demanding practices…learning gains on higher order outcomes will likely be limited. (Sadler et al. 2010)

Education research shows students' understandings about the nature of science (NOS), science content, and interest in science careers increase when students are actively engaged in analyzing data, developing and refining hypotheses, and questioning their findings. In the beginning stages of a student research program it is necessary to guide students through protocols, but efforts should be taken to scaffold students into more epistemically active roles. If possible, they should be allowed to explore research problems on their own with independent projects. In the case of my field research program, it was important to me to maximize students' epistemic involvement and ownership of their research.

13.4.2 Reflection

Reflective practices often are peripheral in science classrooms. When engaging students in citizen science projects, reflection activities should be designed into the projects to maximize educational benefits garnered over time. Consider several studies that promote building reflection activities into science apprenticeships. For example, Schwartz, Lederman, and Crawford identify reflective journal writing and seminar reflection as having the greatest impact on NOS understandings (2004). Stake and Mares (2005) use a mixed-methods analysis to document the impact of reflection that occurs following an apprenticeship. White et al. (2009) write extensively about the valuable role reflection plays in metacognition in science inquiry. These scholars promote the idea of infusing metacognitive practices into scientific inquiry, specifically reflectivepractices, in order to address science content knowledge, NOS, and development of autonomous learners and communities (2009). Reflective journals also encourage creative expression and can provide instructors unique insights into student's perceptions.

Increasing student's epistemic involvement and using reflexive practices in our class are best practices that maximize the potential impacts of teaching through citizen science projects. A significant challenge remained: How to unify and conceptualize the disparate components of the class? Socio-scientific issues provide a context around which the curriculum can be connected.

13.5 Why Socio-scientific Issues?

Socio-scientific issues (SSI) are complex, open-ended and often controversial issues blending science content and practices with complex societal issues (Zeidler 2014). SSI-based instruction has been presented as a way of conceptualizing science content and practices within social issues and problems, such as hydraulic fracturing (fracking), climate change, genetic engineering, nuclear power, among others (Zohar and Nemet 2002; Sadler 2011; Zeidler 2014). Interweaving SSI with the unique opportunities presented by citizen science projects can capitalize on the strengths of both pedagogies. We briefly explore three areas in which the SSI approach has been shown to benefit student's science knowledge and practice.

13.5.1 SSI & Science Content Knowledge

Citizen science projects often engage students in novel learning experiences, which by their nature set the stage for gains in content knowledge. Students in my field research class have an opportunity to interact with birds directly and learn unique ornithological and ecological content knowledge through interacting with meaningful research. SSI instruction has been shown to promote gains in science content knowledge. For example, Dori et al. (2003) engaged students in controversial biotechnology cases and documented improvements in knowledge and understanding of these topics as well as higher order thinking skills. Several studies have examined genetics and related concepts taught through SSI instruction and show gains in student understanding of the content (Dawson et al. 2010; Lewis and Leach 2006;

Zohar and Nemet 2002). Additional SSI research has documented improvements in environmental, ecology, and chemistry content knowledge (Barab et al. 2010; Klosterman and Sadler 2010; Sadler et al. 2011).

13.5.2 SSI and the Nature of Science

The nature of science (NOS) is generally agreed to be "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman 2007, p. 833). Both of Robert's visions of scientific literacy require understanding NOS (2007). Sadler et al. (2010) examined the literature for impacts of authentic research opportunities on student understandings of NOS. In their review they found 16 empirical studies showing gains in student understandings of NOS. Recently, Burgin and Sadler found that engaging students in highly authentic investigations can "support student learning of some NOS aspects and that coupling these opportunities to "do science" with explicit NOS instruction including reflecting on the ways in which students' research experiences connect with more general NOS themes maximizes NOS learning outcomes (Burgin and Sadler 2016, p. 22). SSI based instruction also has been shown to support NOS understandings. For example, two studies examining the impact of NOS instruction with high school students within SSI investigations around the topic of global climate change reported gains in NOS understanding (Khishfe and Lederman 2006; Sadler et al. 2004).

13.5.3 Citizen Science Through SSI to Improve Vision II Science Literacy

In the previous two sections we examined the documented SSI gains in content and NOS understanding. These are primarily vision I perspectives as per Roberts (2007), and Roberts and Bybee (2014). We position SSI as a means to elevate citizen science projects beyond the basic contributory category (based on Bonney and Cooper's categorizations of citizen science). Furthermore, we advocate that utilizing SSI instructional approaches within citizen science projects may provide the potential to improve scientific literacy around science content and NOS in a social context. The social factors of SSI allow students to engage in vision II scientific perspectives finding meaning and understandings of science within larger social contexts (Zeidler et al. 2009). The complexity inherent in measuring vision II scientific literacy perspectives does not negate their importance. "Vision II emphasizes an approach that is broader in scope, involving personal decision-making about contextually embedded issues. These 'real life' situations relate to science and are influenced by other perspectives such as social, political, economic and ethical ones" (Sadler and Zeidler 2009, p. 910). We advocate that utilizing SSI instruction within citizen science projects may address the struggle instructors have elevating projects beyond the contributory category. We propose that SSI may serve as a framework for addressing these issues and provide a vehicle through which citizen science projects can be elevated to collaborative or co-created models of instruction. The implementation of an SSI approach within my environmental education field research class is presented as an example.

13.6 Citizen Science SSI (CS-SSI)

My first step in incorporating an SSI orientation into the field research course was to identify socio-scientific themes, which connected with the bird research and water quality monitoring citizen science. Two frameworks for SSI instruction provided guidance to shape instructional revisions. (Friedrichsen et al. 2016; Presley et al. 2013).

So how does this work? The selection of a central SSI is critically important. The issue must feature complex and contentious societal components with substantive connections to science. We recommend instructors be very intentional with issue selection considering the specific science content and practices of their curriculum, the context of their student population, and state and national standards. The issue is introduced at the beginning of the instructional sequence and this socio-scientific issue itself becomes a context for students to explore fundamental science concepts (see Fig. 13.1). Science concepts and practices are explored along with the social connections associated with the issue. These connections are made at the research site while students perform avian and water quality research. Additionally student research of the SSI through use of information and communications technology (ICT) such as researching the issue in print and electronic media and interviewing stakeholders provides opportunities for connections with the science and social issues. A culminating experience provides an opportunity for students to synthesize their ideas, perspectives, and research related to the issue being explored.

My field research class occurs in the Missouri Ozarks. This is a geologic area featuring karst topography. Karst geology is composed of porous limestone and dolomite and is characterized by numerous caves and sinkholes which create extensive surface and groundwater connections. This complexity presents a myriad of socio-scientific issues through which to explore water quality and connections to the ecosystem. Consider, for example, where the high school building for my students is located. During construction the building required significant geologic siting in order to avoid multiple sinkholes on the property. We are able to examine this situation together and talk to the architect who designed the building and discuss the challenges involved in construction in Karst ecosystems. Students commute between the research site and the high school building on a highway that literally transits through the middle of a small sinkhole. Most students in the district obtain potable water from wells and have on-site septic wastewater treatment systems. Clearly,

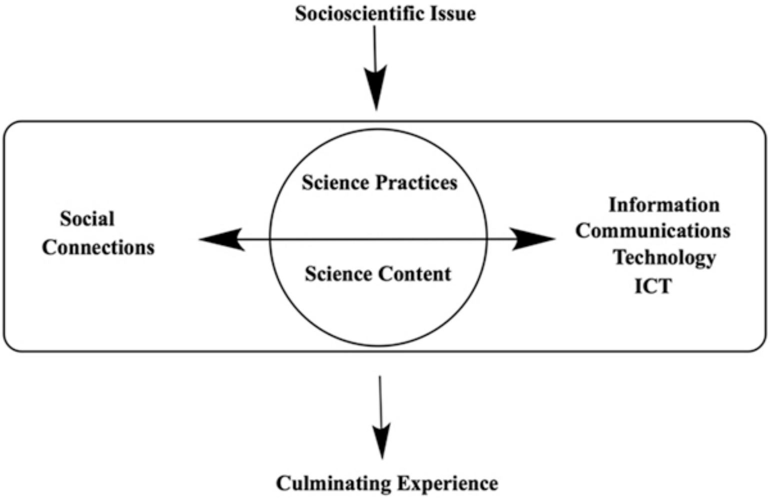

Fig. 13.1 Model for SSI Instruction, adapted from (Friedrichsen et al. 2016)

karst topography is everywhere in these students' lives and yet most are unaware of the significance and fragility of these systems.

Karst topography became a logical way to begin exploring SSI infusion in my field research class during the summer of 2015. The issue needs to be as realistic as possible and place-based within the local community. Interestingly, a timely local issue occurred when developers proposed the construction of a groundwater based ethanol plant several miles from the high school. This proposal provided the perfect opportunity to explore science through a local SSI.

I seeded the ethanol plant proposal early in the instructional sequence. The overall instructional sequence is shown in Fig. 13.2. The ethanol plant SSI was revisited throughout the month long class. We visited the test well that was drilled and discussed the implications of commercial scale use of groundwater in the Midwest. Throughout the course, students engaged in bird banding and water quality monitoring. The bird banding station sits within a riparian corridor and the birds that are banded there are important biological indicators of water quality and forest health (Latta et al. 2015). Students engaged in purposeful ICT explorations of science concepts around karst topography, ethanol production, potable water wells, wastewater treatment as well as societal issues such as subsidies and planning and zoning. Students completed personal reflection journals approximately twice weekly, where they were given specific prompts to help summarize their learning, identify questions and areas of confusion, and validate learning and its importance. There were two related culminating activities for the course. Students created PowerPoint and Keynote presentations of the bird and water quality research and presented these to parents and the school administration. The SSI was presented as a feature of the class in which they were tasked making a recommendation to the community on the feasibility of the proposed ethanol plant.

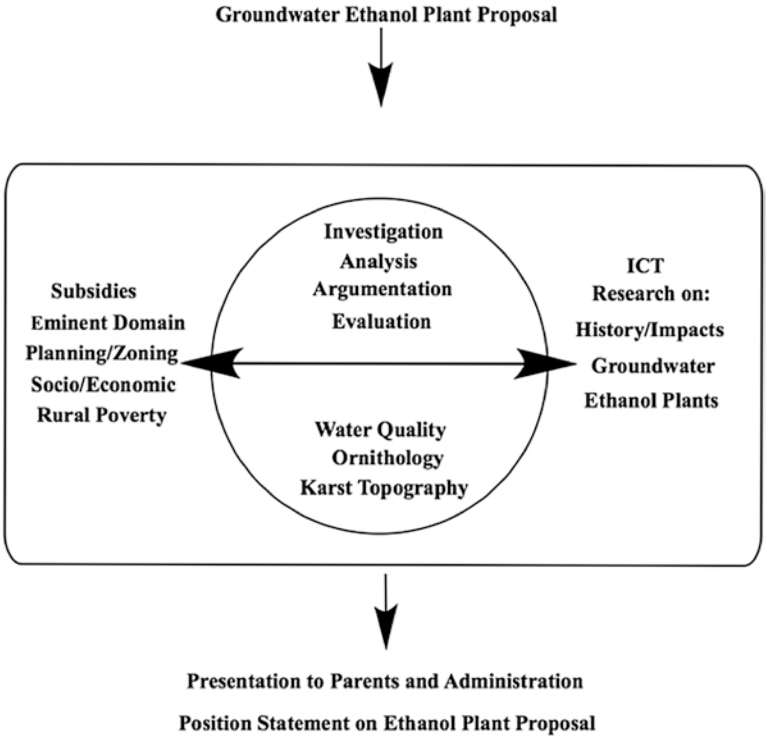

Fig. 13.2 Model for SSI Instruction, adapted from (Friedrichsen et al. 2016)

The class was unanimous in recommending against a groundwater ethanol plant situated in the Ozarks. Students also completed a summative reflective journal activity in which they were asked to reflect on the totality of their class experiences and specifically asked to address how the bird bandingresearch connected to the water quality monitoring and the ethanol plant proposal.

13.7 The Power of a Bird in Hand

In the 17 years since I gave that little girl a bird to hold in her hand, I have gained so much from working with students and birds. I look back with great satisfaction and drive to continue exploring citizen science through SSI. Involving students in authentic research and working with animals is a powerful platform to teach science concepts and practices. Holding a wild bird and connecting with its fragility and power as a learning experience is a powerful moment for student and instructor. SSI reciprocally strengthens citizen science engagement and provides a vehicle for contextualizing investigations of science content and practices within the larger interwoven social and political world we live in.

Fig. 13.3 Student Drawing. Used with permission from Berea Flatness (2007)

Consider several excerpts from student reflection journals and summary projects. These excerpts provide evidence of students forming connections between the ornithology research, water quality monitoring, and the SSI. *(Note: Student names provided here are pseudonyms.)*

> What I learned today matters because I now understand how something small can affect the whole watershed and the animals like the birds that depend on it. I can use it to inform others about the importance of keeping all waterways clean, because you never know what it connects to. (Mandy)

> Missouri's karst topography is the reason for all of the problems with runoff. But as long as smart practices are kept in place our water will be safer for all in the watershed, the birds, and our wells. (A.J.)

> It is especially important to understand karst landscapes to be aware of waste treatment and not pollute your water supply. In the Ozarks, acres and acres of farmland, residential, commercial are all connected through water systems and it is imperative to be working with your natural surroundings. (Eric)

> The birds are amazing to hold. You can feel their heart beat and how delicate and fragile they are. They are like the bugs we study in the streams, like larger (water quality) indicators because they feed on the bugs. Everything that happens to the stream happens to the birds also. (Tamara)

A drawing from a students' journal is shown in Fig. 13.3. The drawing illustrates a connected viewpoint of the various elements of the class (bird banding, stream quality, orienteering, and astronomy).

The environmental issues we face today and in the future require citizens with a solid grasp of science and equally the ability to negotiate the complex issues that shape our society. These citizens need the passion and drive to make a difference. Science experiences situated within socio-scientific investigations provide a vehicle for students to develop the understanding and passion to affect positive change. Our future depends on those who have deep and profound connections with the Earth. These connections do not come easily from a textbook. They do, however, present themselves readily to a group of young people early in the morning in feathered form.

Photos

Photo by A.D. Daniels

Photo by Dawn Huber

Photo by Andrew Kinslow

Photo by Troy Sadler

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