Cult Stud of Sci Educ (2017) 12:7–31
DOI 10.1007/s11422-016-9757-1

ORIGINAL PAPER

Learning in and about rural places: Connections and tensions between students' everyday experiences and environmental quality issues in their community

Heather Toomey Zimmerman[1] · **Jennifer L. Weible**[2]

Received: 1 October 2015 / Accepted: 31 October 2015 / Published online: 27 September 2016

Abstract Guided by sociocultural perspectives on the importance of place as a resource for learning, we investigated 14- and 15-year old students' understandings of their community and water quality during a school-based watershed unit. Methods included a theory-driven thematic analysis of field notes and video transcripts from four biology classrooms, a qualitative and quantitative analysis of 67 pairs of matched pre- and post-intervention mindmaps, and a content analysis of 73 student reflections. As they learned about water quality, learners recognized the relevance of the watershed's health to the health of their community. Students acknowledged the impacts of local economically driven activities (e.g., natural gas wells, application of agrichemicals) and leisure activities (e.g., boating, fishing) on the watershed's environmental health. As students learned in and about their watershed, they experienced both connections and tensions between their everyday experiences and the environmental problems in their community. The students suggested individual sustainability actions needed to address water quality issues; however, the students struggled to understand how to act collectively. Implications of rural experiences as assets to future environmental sciences learning are discussed as well as the implications of educational experiences that do not include an advocacy component when students uncover environmental health issues. We suggest further consideration is needed

Lead Editors: L. Avery and D. Long.

This paper is part of the special issue Cultural Studies of Rural Science Education.

✉ Heather Toomey Zimmerman
heather@psu.edu

Jennifer L. Weible
j.weible@cmich.edu

[1] Learning, Design, and Technology Program, Penn State University, University Park, PA 16803, USA

[2] Teacher Education and Professional Development Department, Central Michigan University, Mount Pleasant, MI 48859, USA

on how to help young people develop action-oriented science knowledge, not just inert knowledge of environmental problems, during place-based education units.

Keywords Science education · Place-based education · Environmental education · Informal–formal connections · Community-based learning

In the 205,000-square-mile area of the Appalachian region of the United States, rural residents are asking questions about the impacts of local economically driven activities (e. g., natural gas wells, application of agrichemicals to farm crops) on their communities' environmental health. For example, the natural gas development process called fracking thrusts chemicals, sand, and water into shale rock common in Pennsylvania to fracture the rock and release gas. Use of this technique to extract natural gas has brought new income to rural families while at the same time raising concerns about pollution affecting drinking water, as identified in the documentary Gasland (Fox 2010). Energy is not the only contested socioeconomic activity in rural Appalachia. With increases in biotechnologically altered crops that are resistant to certain pesticides, residents wonder if this new technology will increase the use of agricultural chemicals within their communities and, if so, what will be the long-term impact on water and soil. Compounding these socioeconomic concerns is the reality that those in rural Appalachia (over 10 million people) face poverty at higher levels than the rest of the US with localized conditions of high levels of unemployment, poor dental and healthcare access, and educational inequity (Appalachian Regional Commission, no date).

While many rural citizens are living on lands that have belonged to their family for generations, new issues about these lands are emerging. The current agricultural and energy economic activities bring up issues related to runoff from one property onto another, pesticide/herbicide spread to neighboring lands, and ownership of underground mineral estates (also known as mineral rights) related to oil, coal, and natural gas. These new economic activities challenge traditional ideas of land ownership, especially related to shared resources such as underground minerals and water. Furthermore, sustenance and recreational hunting and fishing are socioeconomic topics debated nationally in terms of declining animal populations and rights to harvest. Finally, in addition to contested activities, Appalachian residents engage in leisure activities in the vast forested spaces—including swimming, boating, and hiking. These leisure activities are revenue sources as well, given the number of tourists interested in spending time in the outdoors.

Although these socioeconomic and leisure activities occur in places with complex environmental sciences underpinnings, it is not clear how or when the Appalachian communities engage with the science embedded within their everyday activities related to water quality. The impact of these rural leisure and socioeconomic activities on young people's science learning within the school day is even less clear. To address these questions, we focus on how young people from one Appalachian community engage with place-based socioeconomic topics (e.g., gas drilling, hunting, fishing, and farming) as well as ecological concepts related to watersheds. We investigate how learners connect their experiences in rural places to water quality to decipher how their everyday experiences support or hinder scientific meaning making.

In the present video-based study, 14- and 15-year old students' understandings of the environmental sciences were examined during a watershed unit. This unit connected to the students' rural community through including a water quality assessment of a stream feeding the school's drinking water reservoir. We answer two research questions:

1. How did youths' knowledge of the indicators of watershed ecology change from the beginning to the end of a place-based science unit that focused on understanding their community's water quality?
2. How did students make use of their rural experiences during the watershed unit to support (or hinder) science learning about environmental quality?

The first research question examines how and if local experiences affect classroom-based meaning-making after a scientific stream study that was part of a three-week unit on watersheds. Before and after the watershed unit, students developed mindmaps on the evidence that they would look for to determine whether a stream was healthy. We used quantitative and qualitative techniques to examine these mindmaps for any changes in expressed content and vocabulary. This question addresses directly the science content learning resulting from a place-based curricular approach. The second research question examines how high school students connected their local experiences within the watershed to support or hinder scientific meaning making in the classroom. The second question is answered by a thematic analysis of field notes, video records of the students in the classroom and stream study, and the students' summative reflections about watersheds. This second question addresses how direct experiences within a specific place influenced students' learning about their community and the quality of its water.

Learning environmental knowledge through participation in the cultural practices of science

Our theoretical framework draws upon a sociocultural conceptualization of learning with a specific consideration of place to understand how students' rural experiences intersect with school-based learning. First, we start with the assumption that learning is a fundamentally social and cultural process (Vygotsky 1987) of participation in cultural practices. Second, we build on the importance of place in science-related meaning making, which can lead to the development of various kinds of environmental meanings as learning outcomes. Four types of meanings could be outcomes from this unit (Jensen 2010): knowledge about the environmental problem, of the causes of a problem, about individual and collective strategies to address the problem, and about future alternatives and other people's perspectives.

Learning as participating

We take a practice view of learning, where people learn as they participate in everyday activities with the things and people around them. People engage in multiple practices within multiple cultural communities (Gutiérrez and Rogoff 2003). These multiple practices can come from communities with divergent worldviews, which can cause borders for students to navigate as they learn new practices related to science (Aikenhead 1996). Taking this practice perspective on learning, we presume that a cultural community's activities may include practices that serve as barriers (Anderson, Thomas and Nashon 2009) and resources for science learning in urban (Moll, Amanti, Neff and Gonzalez 1992) and rural classrooms (Avery 2013).

Participating in places

Place-based education is a pedagogical perspective that incorporates discipline-specific practices with community-specific practices to engage people in educational activities that connect academic content to a local setting. Place-based education in science education often focuses on the learners' meanings of the place to establish a pedagogy that is both ecologically and culturally appropriate via on-site fieldwork (Semken 2005).

Studies of science education have adopted a place-based perspective in the design of curricular materials by using students' local experiences to connect to broader concerns in science and society. Notably, Steven Semken (2005) developed a curriculum that attended to the diverse meanings that a place has for learners and teachers through creating and teaching a course called Tsé na'alkaah (Indigenous Physical Geology) on the Navajo Nation. Indigenous Physical Geology focused on fieldwork experiences with authentic artifacts and representations. Recent examples have taken these placed-based pedagogical ideas and applied them to other types of environmental learning settings. For example, Pedro Membiela, Renée DePalma, and Mercedes Suárez Pazos (2011) created classroom lessons on food that tied to the local agriculture of the Galicia community in Spain. Leanne Avery and Karim-Aly Kassam (2011) focused on rural environmental education issues to understand youths' local ecological knowledge. They asked elementary-aged students to take photographs of their daily life experiences as a means to bring the students' local experiences to the attention of a schoolteacher responsible for science instruction.

The multiplicity of community and institutional meanings for places

Place-based learning in education considers places as more than just geographic locations associated with a specific time; place also includes the geographic, temporal, and ecological elements alongside the sociopolitical histories and meanings (Lim and Calabrese Barton 2006). Michiel Eijck and Wolff-Michael Roth (2010) argue that current conceptions of place in education need further theoretical development to reflect the multiplicity of meanings of a place held by members of dominant and non-dominant cultural groups. Eijck and Roth provide an in-depth example of how multiple meanings exist for the location called both the SNIT₵E and the Tod Inlet in Canada because place-based learning is a "bidirectional, dialogic transaction" (p. 896) between multiple peoples.

Economic status and divergent place meanings

Other research advances studies that examine how issues related to economic privilege intersect with people's multiple meanings of a place. Researchers Shari Levine Rose and Angela Calabrese Barton (2012) studied low-income urban middle-school-aged youths participating in an afterschool community-based program focused on social activism in environmental issues related to energy decisions that could affect their community. For example, Rose and Calabrese Barton focused on the two young people who realized a connection between air pollution and asthma that affected friends, family, and others in their neighborhoods. They found that learners' use of science in decision-making focused largely on the tension between economic concerns around energy sources and environmental health issues. Carrie Tzou, Giovanna Scalone, and Philip Bell (2010) used ethnographic methods to study young people learning about environmental education issues in two programs. Tzou and colleagues found that the youth constructed place narratives that were influenced by their experiences in their poverty-impacted community. For example, the researchers reported on how one program's environmental educators associated walking in one's community rather than driving a car as an environmentally-friendly practice. This pro-walking meaning conflicted with the youths' experience in their community because the local area had recently experienced a drive-by shooting. This shooting resulted in families discouraging youth to walk through their community. The conflict that Tzou and colleagues document between the educator and youth reiterates that place-based learning can be ineffective if there are not conversations about a place and its diverse meanings.

Rural science education and people's perspectives of place

Daniel Shepardson and colleagues (Shepardson, Wee, Priddy, Schellenberger and Harbor 2007) conducted a study of the conceptions of watersheds held by 915 Midwestern students from 25 classrooms through a draw-a-watershed protocol. Sixty percent of the students in their sample were rural learners. The study concluded that the rural students had a deeper understanding of watersheds than the urban or suburban learners. Shepardson and colleagues' interpretation of students' drawings showed that the urban or suburban students relied primarily upon textbook representations of watersheds for their understandings rather than their lived experiences. These students included landforms in their draw-a-watershed task that were not present in the midwestern region where they lived. Heidi Carlone, Sue Kimmel and Christina Tschida (2010) conducted an ethnographic inquiry of a newly created math, science, and technology elementary magnet school in a rural community in the southern United States. They found that place-based perspectives were key in how the community came together to find common meaning for school-based science. Science in the magnet school built on a shared meaning of their local place as a community with the "state's natural resources and history as a farming community" (p. 470). Not all rural science education research has found shared meanings between communities when investigating the role of sense of place in learning. For example, Kai Schafft and Catharine Biddle (2015) conducted ethnographic research on the impact of the Marcellus shale natural gas fracking issues on education in multiple Pennsylvania Appalachian counties. They found that even when the socioeconomic issues in the local community were not formally part of the curriculum, these issues entered the school as young people were deciding whether to pursue higher education or to seek employment in the transient, but high-paying, energy-related job sector. Schafft and Biddle's work points out tensions in differing timescales—short-term economic development and high-wage employment compared to long-term decreased employment potential due to lack of higher education once the gas well development phase ends.

Meanings developed from place-based environmental education programs

Bjarne Jensen (2010) suggests that there are four kinds of meanings that learners develop as they engage in environmental education: knowledge (a) about the environmental problem, (b) of the causes of a problem, (c) about individual and collective strategies to address the problem, and (d) about future alternatives and other people's perspectives. He posits that learner-centered, action-oriented education is the key to learning about environmental issues so that people can make a difference in their community:

> *an action should be directed at solving a problem* and it should be *decided upon by those preparing to carry out the action.* In other words, an action is targeted at a change: a change in one's own lifestyle, in the school, in the local or in global society. This approach implies that action in environmental education embraces indirect as well as direct actions; for example, demonstrating against traffic conditions is as valid an approach as cleaning up litter. p. 326 (italics in original).

Jensen argues that environmental learning can encourage environmental sustainability, yet schools often do not teach environmental topics in such a way as to foster knowledge of stewardship actions. Teaching to support sustainability actions, therefore, needs to be central to environmental education. We build on Jensen's perspective to investigate individual and collective sustainability actions in this environmental education experience.

To understand how science content knowledge and environmental sustainability actions are related, Anja Kollmuss and Julian Agyeman (2002) analyzed factors shown to have an effect on pro-environmental behaviors. They found that extensive education about environmental issues increased student knowledge about the content, but increased knowledge was not always correlated with increases in students' pro-environmental behaviors. In addition, when studying college students participating in projects directed at increasing involvement in environmental causes, Katja Brundiers and Arnim Wiek (2011) found most students did not include action-specific strategies—even when these strategies were required. These findings indicate the difficulties in structuring student learning to facilitate environmental science knowledge related to future action, in order to provide students with the resources with which to propose and carry out actions aimed at solving environmental problems.

Theoretical framework summarized

Given the focus of place-based education on multiple meanings, we designed our study to gather and analyze data from multiple perspectives—individual, community, economic, and institutional. We also use a framework from Jensen (2010) to understand the way youth's meaning can be used (or not) as youth participate in practices across aspects of their lives.

Methodology

Setting and participants

The study occurred at a high school in the Mid-Atlantic USA (in Pennsylvania) classified by the U.S. Department of Education (2011) as a rural, poverty-impacted school. The school is classified as rural due to the small population and its low population density; the area near the school includes farmland and forests with streams and lakes and a small town of fewer than 6000 people. Top employers in the school's county include a hospital, the K-12 school district, a small number of retail stores, and a few industrial metal shops. In 2010, the year when the study occurred, the USA census listed the school's county with a slightly higher unemployment rate than the state and national average.

The research participants were 74 (out of 80) consented and assented ninth- and tenth-grade students (aged 14–15) from four high school biology classrooms. These students had indicated that they were college-bound; these four sections were called "academic biology" for students interested in college after high school.

Watershed unit

The science education context of the study was a three-week-long watershed unit that included a stream study. One teacher had participated in this field study in past years; she collaborated with the two authors to engage the students in scientific inquiry connected to their community. The teachers and researchers posited that by utilizing the principles of place-based education, the students would increase their knowledge of environmental issues associated with watersheds—especially related to water quality. Furthermore, the teacher-researcher partnership sought to support the learners in forming connections within their community as well as developing an action-oriented mindset focused towards issues impacting their personal source of water.

In accordance with the study's theoretical framework of place-based science learning, the teachers selected a stream for the study that fed the town's drinking water reservoir. In the stream study, the youth collected data to investigate the water quality of the stream. Because the reservoir chosen served the school and the town with drinking water, the health of the watershed and the quality of the water were made relevant to the students' lives. The two partnering teachers presented the unit as a structured inquiry (Windschitl 2003) with pre-established questions to investigate: (1) How would you know if the stream that feeds your drinking water reservoir was healthy? and (2) What evidence would you need to collect and how would you analyze it? The watershed unit was oriented to solve these two questions using established scientific procedures used by local water quality monitoring agencies.

The watershed unit was designed to foster engagement in science practices in several ways. First, the students utilized local maps to delineate the school's watershed using authentic topographic maps. The learners created topographic maps on paper and as a 3-D model. These maps and models were customized with local landmarks, favorite recreational areas, farms that they knew, and familiar industrial sites. The map and 3-D model were used to illustrate possible sources of watershed pollution that the teachers used to engage the students in discussions about environmental responsibility, runoff, and point versus non-point sources of pollution.

Second, students were given instruction within the classroom on how scientists measure water quality; these procedures were linked to the watershed inquiry experience. Students were explicitly taught four protocols commonly used for stream monitoring during class time using water samples collected by students from their homes. Teachers modeled how to interpret the results, and students determined whether their water samples contained the chemicals and macroinvertebrates that were predictors of a healthy stream. Although students were introduced to all four areas in the classroom, during the field experience they only collected data in two stations either (a) biological parameters and chemical parameters or (b) stream mapping and physical parameters. By having the students become specialists at Community Stream, researchers and educators believed that students would have ample time to collect data and to make inferences about the health of Community Stream. The groups of students posted their data and interpretation of the results on an online wiki page that was shared with the community scientists leading the watershed tour. All students had access to all groups' data and results in order to make a determination of the health of the watershed area. The researchers also suggested adding student-taken digital photographs of the stream and the stream study, so that digital artifacts were available to the students to use as evidence in their classroom to support the development of place-based understandings.

The field study was held at Community Stream that fed into a human-made lake that served as a drinking water reservoir for the town. This lake was also used for recreation (i.e., boating, fishing). Community Stream ran through farmland and forestland used by some of the students for recreational and subsistence hunting and fishing. To foster connections with the local community, the field study was led by ecology educators and scientists; these individuals currently monitor the health of the stream and watershed as a part of their employment or as a volunteer member (e.g., Trout Unlimited, Rails to Trails). These community members led sections of the stream study (see Table 1) because of their environmental knowledge and willingness to support students' engagement in science. Students participated in a walking tour of the reservoir led by community educators and scientists. In the walking tour, students were exposed to perspectives meant to foster a connection to both science and to place at Community Stream. Issues of the ecological system, human's current uses of the place, historical influences and uses of the place,

Table 1 Four areas of student investigation, plus walking tour, in the watershed unit

Science activity	Activities at community stream and classroom study	Place-based connections
Biological parameters	Youth prepared to and then sampled the stream for macroinvertebrates (i.e., insects, crustaceans, mollusks, etc.) using a kick net. They identified and quantified the macroinvertebrates	These macroinvertebrates were identified in relationship to the health of the water and to everyday connections (in some cases)
Chemical parameters	Youth learned to conduct various tests for the water's health. Students brought water samples from areas they frequented for testing in class. Onsite, the youth investigated the stream's levels of dissolved oxygen, hardness, turbidity, pH, alkalinity, iron, and nitrates	Nature walk discussions focused on sources for pollutants or other chemicals indicated by water samples
Stream mapping	Students learned about the natural history and present condition of their local watershed and annotated local landmarks, industries, or activities familiar to each student. Onsite, youth mapped more than 30 meters of the stream bed and calculated the slope. The same area is mapped annually and the data are entered into a database, so the youth can analyze any stream changes	Nature walk discussions about stream mapping indicating the erosion of the streambed over a period of time. Students were asked to project forward what would happen to the stream if conditions stayed the same
Physical parameters	Youth collected the stream and air temperature on-site and took measurements of the stream's width, depth, and velocity to estimate the water flow volume	During the nature walk, students learned about the interconnection of multiple elements of the stream and how various industries influence the stream's parameters through erosion and run-off
Walking tour of reservoir	Environmental scientists and educators led youth on a guided tour of lands surrounding the town and school's drinking water reservoir. The tour focused on the influences on the stream by agriculture, industry, recreation, and other factors	Discussions occurred about experiences of students and community members in the local watershed such as fishing or boating, recreational use, and economic and environmental impacts from the various causes and sources of soil erosion and runoff

governmental regulation, and personal choice were discussed during the walk. For example, community members pointed out soil patterns that indicated a fire approximately 100 years ago.

After the field study, each small group posted to an online wiki (a) the procedure for each investigation, (b) data that were collected, and (c) their interpretation of the data related to water quality. Finally, each student was asked to write an individual water quality analysis of the stream as part of a reflection. The reflections were also to include his or her refined ideas about watershed health; there was no explicit instruction on how to discuss next steps for action.

While the unit was developed from the idea of acknowledging individual, community, and institutional meanings, we also considered how the discussion and activities would develop different kinds of environmental knowledge. Community scientists incorporated discussions related to how individual and community actions influenced the health of the stream, particularly during the nature walk around the Lake. On the walk, the scientists directed students' attention to the visible evidence of socioeconomic influences and sustainability decisions made by community and industries in their local ecosystem. For example, the scientists pointed out gas lines that intersected with streams and visible road run-off that increased sediment. One park ranger focused discussions with the students on immediate actions that they could take such as picking up litter and sustainable fishing. Through explicitly articulating the connections between the man-made structures surrounding the local watershed and environmental issues, the teachers intended for the students to develop an action-oriented mindset focused on the local watershed and their community. Also, because the students are required to take a semester-long class on civics during the ninth or tenth-grade year, many students had been exposed to the processes utilized in local governments to resolve concerns. The team posited that after explicit in-school instruction about the legislative process and the field study discussions about relationships between local industry, recreational activities, and energy issues, students would develop an action-oriented mindset. As such, there was no explicit instruction within the watershed unit on how to create a community-level action plan or possible steps at the level of town, state, or federal government.

Data collection

Data were collected over the 3-week school-based unit on watersheds and daylong community-based field study. The data sources consisted of (1) pre- and post-unit mindmaps, (2) youth-taken photographs from the field study, (3) individual reflection essays about the health of the watershed (completed at the end of the unit), and (4) video-recorded science instruction and small group work. We focus this analysis on the mindmaps, the reflective essays, and field notes and video records from the watershed field study, the watershed walking tour, and classroom discussion of the field study and tour.

Seventy-four students were consented and assented into the study for videotaping purposes; 67 of 74 students completed both the pre- and post-unit mindmaps, and 73 of 74 completed the end-of-unit reflection on what they learned. The students each wrote two pages of concept maps, which comprised 134 pages of text for analysis and between 0.3 and two pages of text for their reflections, which resulted in 96 pages of text for analysis. When presenting the mindmap data and the reflection data within this paper, the learners' original spellings (i.e., misspellings) are maintained throughout; we use brackets to clarify words as needed.

Data analysis

Given that our interests are on how a place-based learning experience influenced various environmental meanings and scientific knowledge, this paper presents two analyses to answer our research questions. The first analysis takes a traditional approach—what Eijck and Roth (2010) referred to as science education's ecological place-based curricular approach. The second analysis addresses the role of place, with a focus on youths' experiences in rural Appalachia, in meaning making.

Analysis of students' knowledge of watershed health

We coded the mindmaps' structures in a qualitative analysis software environment (ATLAS.ti) so that the students' pre- and post-mindmaps could be compared for: (1) number of ideas (nodes) about watersheds, (2) structure of ideas (level of hierarchies), and (3) connections youth drew across their ideas. The research team coded the first 16 maps together, refining the coding strategy and elaborating codebook definitions until all codes were stable and easily applied by both authors. The second author coded the remaining maps. We analyzed the counts using repeated measure t tests in the statistical software (Minitab) to compare the summed scores from the pre- and post-mindmaps. We next analyzed the scientific language on the mindmaps based on the four water quality inquiry area (i.e., biological, chemical, and physical parameters, and stream mapping).

Sense of place thematic analysis

For the second analysis, we conducted a thematic analysis of the field notes, students' reflections, and video logs. Prior to writing the reflections about what they had learned, students were given back their pre- and post-test and their pre- and post-unit mindmap. The thematic analysis included the researchers' field notes and video logs as well. The video logs analyzed represented approximately 15 h of video from: the learners' experiences in the four inquiry stations; the walk around the reservoir at the end of the field study, in which students and environmental scientists broke into small groups to see how the study stream fed into the human-made lake; and classroom-based data following the field study. Through a thematic analysis, we analyzed how and when students' daily, rural experiences were discussed in the classroom or during the field study. We looked for tensions between meanings of a place (e.g., economic, recreational, familial) and when learners could balance their understandings of their community from different lenses.

To conduct the second analysis, we used an a priori qualitative approach to coding that relied on place-based education theory to orient us to learners' multiple meanings for a place in four categories: (a) personal meanings, (b) meanings across timescales, (c) conflicting meanings for uses and misuses of a place, and (d) community and institutional (scientific) meanings. After the data had been coded, the data were reread to add a finer-grained coding layer that emerged based on the segments' content. The research team members created and shared analytical memos of the emergent coding work. As initial claims were developed, the data set was reread to look for additional confirming and disconfirming evidence (Erickson 1985). The analytical memos were refined based on this further data interrogation and researchers' conversations. The analytical themes that intersected place, science education, and rural experiences were selected for this article.

Table 2 Mastery of ecological concepts as illustrated by the mindmap structural analysis

	Number of nodes*	Levels of hierarchy*	Number of connections†
Pre-unit map	11.5	2.152	0.318
Post-unit map	17.5	2.712	0.773

(n = 67 matched pair mindmaps)

* Change significant at $p < 0.001$; † significant at $p < 0.05$

Findings and results

Youths demonstrated increasingly complex ideas about their watershed

With analyses of pre- and post-unit mindmaps' structure and content related to watershed ecology, we found indications that the youth could express complex knowledge about the evidence of stream health in their watershed. To complete the quantitative mindmap structural analysis, we compared the number of ideas (represented as nodes) about watersheds, the organization of students' ideas (hierarchy of nodes), and the connections made between watershed concepts, as shown in Table 2.

After participating in the watershed unit, learners increased the quantity of informational nodes about ecology on their mindmaps by 50 %, changing from an average of 11.5 ideas on their pre-field-study mindmap to 17.5 ideas at the end of the unit. The increase in the number of nodes (about six new ideas about ecology) was significant when compared through a repeated measures *t* test ($p < 0.001$). According to Hay, Kinchin, and Lygo-Baker (2008), this increase in the number of nodes can be indicative of meaningful learning as students elaborate their understandings.

Learners not only increased the quantity of ecological information on their map, but they also re-organized their ideas. This finding is notable because one could imagine that the local community's dependence on industries that can pollute water (e.g., natural gas drilling, agricultural endeavors which produce runoff) could hinder learners' scientific sensemaking through making students resistant to knowledge that casts a negative light on industries providing employment for their town. Learners added, on average, an additional half level of hierarchy (statistically significant at $p \leq 0.001$ with a repeated measures *t* test) to their maps. We interpret this statistic to mean that one out of two learners reorganized their map with a more complex organization. Increasing hierarchical organization has been taken by researchers (Novak and Cañas 2008) to show that learners are developing deeper understanding about the relationships between and among ideas within a discipline. This means that after the unit, approximately half of the learners showed a more sophisticated understanding, which has been argued to be imperative to science learning (Duschl et al. 2007).

Learners also doubled the number of connections they made between nodes from 0.318 connections to 0.773 connections. Although this was statistically significant at $p \leq 0.05$ with a repeated measures *t* test, we interpret this finding less than optimistically. While the youth added new details to the existing nodes as a means of elaborating their original perspectives (Hay 2007), the students also made less than one new connection between their initial 'big ideas' and a new big idea. Examining the maps to look for connections between new categories is important because a change in the connections between big ideas, or nodes, has been shown to signify meaningful learning (Hay 2007). This result

Table 3 Scientific knowledge through content analysis of 67 pairs of mindmaps

	Pre-unit terminology	Post-unit terminology	Pre-unit nodes (SD)	Post-unit nodes (SD)
Biological parameters*	"Animal life"	"# And type of organism" "sensitive species"	0.742 (1.316)	1.924 (1.658)
Chemical parameters*	"Chemicals" "how clean and clear the water is"	"Iron" "nitrates" "Phosphates" "dissolved Oxygen" "turbidity"	1.909 (1.496)	4.636 (4.505)
Stream mapping[†]	"Location"	"Type of stream"	0.136 (0.388)	0.485 (0.980)
Physical parameters[†]	"Test water" "soil around it"	"Depth" "velocity" "temperature" "cobble"	0.409 (0.764)	1.121 (1.554)
Broad biological concepts	"Garbage" "poisons" "parasites" "lots of plants"	"Pollution surrounding" "soil–how fertile" "diversity of life"	6.424 (5.099)	7.000 (5.954)

* Significant at $p < 0.001$; [†] significant at $p < 0.05$

suggests that overall these students were still challenged to connect categories of watershed topics.

Learners adopted scientific terminology to describe indicators of watershed health

We found (Table 3) that learners advanced their understanding of environmental sciences constructs after the watershed unit through a qualitative analysis of the changes in learners' scientific ideas. Learners increased their understanding of environmental health in four categories: physical, biological, chemical, and human impacts.

Learners significantly increased the number of categorized ideas related to the four stream study inquiry areas (through a repeated measures t test; $p < 0.05$), as shown in Table 3. The learners employed an increasingly scientific terminology, as shown in the second and third columns of Table 3. Everyday words such as "critters" were found on both pre- and post-unit maps, but after the unit more learners adopted scientific terms such as "sensitive species." Notably, the learners showed the strongest gains the chemistry terminology. When describing the chemical aspects, learners moved from descriptions of the water as "clean" and "clear" to descriptions of the "dissolved oxygen," "phosphates," and "nitrates" in the water. The students also showed increased sophistication of vocabulary related to physical parameters of water quality (e.g., velocity, temperature).

Considering the structural and qualitative analysis of the mindmap results above with perspectives on place-based education, the learners reflected on the human activities within their watershed including economic and recreational pursuits as well as developed scientific meanings related to their local stream and watersheds in general. Given that using scientific language is an important part of seeing one's self as connected to science (Gee 2000–2001) and of learning to be a scientist (Lemke 1990), during this investigation the students engaged in science practices as they appropriated the environmental discourse. Science vocabulary increased; however, we found little terminology employed that could be taken as evidence of students' rural experiences on the mindmaps—the youth did not include words related to personal activities on their maps. Although Avery and Kassam (2011) used photo-elicitation to allow youths to document their rural experiences in the science curriculum, the mindmap did not serve this role in our study. We posit that students took this mindmap to be a school-like assignment that did not allow for personal experiences, even though that was not explicitly stated to the students. Related to Jensen's framework for kinds of knowledge (2010), the learners' developed knowledge about the watershed and the environmental problems that the watershed was facing within their second post-unit mindmap. The students identified knowledge of the causes of the environmental problems (e.g., runoff) but, in this analysis, the learners did not show knowledge about individual and collective strategies to address any water quality problems.

Seeing their community differently: Developing new meanings of a place

The strongest influence on developing new meanings about the watershed and Community Stream came from the walk during the fieldtrip. During the walk, community members supported the learners in interpreting the science inquiry findings from the stream study with the visual evidence at the Community Stream site. For example, a local Conservation District employee Steve monitored the erosion within the county's watershed. Accordingly, he first directed his group's attention to the areas of erosion along the streambed. He and the students discussed logging further up the hillside and how different methods of tree selection and road construction could impact the runoff from the site—and subsequently, how logging and road construction impacted the quality of the water in the stream. After walking farther upstream, the students discussed other factors that could impact runoff such as paved roads, farms, and Amish outhouses. Finally, Steve pointed out a gas well beside Community Stream; he asked students to consider the benefits of natural gas as an energy source as well as the dangers of the location of the well.

Another walk guide was a Park Ranger named Sandra. Sandra involved the students in explicit discussions about how human actions can impact on the health of the stream. Sandra asked students to reflect on how they utilized the dam and the stream that flowed into it. After discussing leisure pursuits and subsistence hunting and fishing, the group proposed improvements they felt would support additional human activities. The group walked around the dam as they discussed the students' ideas. With each idea related to developing the stream site, Sandra asked them to consider the tradeoffs required. For example, a student suggested paving the parking area in place of the gravel lot; Sandra asked the group to consider the effects of this action. Students discussed runoff from the lot, the increased need for facility upkeep, and the potential for increased numbers of visitors. Discussion included the idea that with increased development, less funding would go directly to maintaining the stream and dam. The discussions exposed the students to issues related to the recreational use of community resources.

The walking discussions allowed learners, with guidance from community members, to observe unique aspects of their local stream and the effects of the pollutants streamside. Students used their knowledge of and from their rural community—including agriculture, hunting, fishing, energy industries, and recreation—to connect the stream to the science presented. A weakness of this walk was that there was no explicit instruction about current political issues that surround water quality and access, in spite of the teachers' requests. In addition, while the science community members discussed tradeoffs of development, the community members did not explicitly discuss actions that could be taken by the students to support their community as a whole to improve the problems that the students identified during their walk.

Rural activities used to make sense of watershed health

To further understand the intersection of youths' experiences in Appalachia and environmental sciences knowledge, we examined the dataset for how students made meaning of their own activities in relation to water quality. Students often identified a large set of activities that rely on and affect their watershed; importantly, most learners included drinking water during this unit. Drinking water is an especially valued commodity in this community. The town and school have municipal water supplies; however, many people living in the outlying areas that depend on wells for water. During recent droughts, many families' wells ran dry, requiring water to be brought in from outside sources. Teachers in the school also reported to the research team that a small number of students in this community live in homes without indoor plumbing or an in-home source of potable water.

In their end-of-unit reflections, industry, recreation and tourism, wildlife, and food for humans, along with drinking water production, were common categories listed as activities that happened in the watershed. For example, Julie and Teagan were representative of the other learners who identified activities in their community that rely on and affect the watershed and drinking water:

> We as humans use watershed for many things: drinking water, industrial purposes, and we even use them as a source of food.—*Julie*

> When watersheds are affected, drinking water, vacation spots and even wildlife are changed for humans. The affects that can ruin these things for humans are things like pollution in the water, like oil or trash. When dams are built in watersheds to stop the flow, the ponds and lake are affected by loosing the wildlife—*Teagan (note: learners' original spellings are maintained throughout this document)*

We found some students, such as Julie, just identified the human activities and uses of the watershed. While others, such as Teagan, listed both human activities and the negative effects that these activities can have in her Appalachian community's water, resulting in industrial, commercial, and residential pollution.

Throughout the unit, students also brought up hybrid economic-recreational activities as important within the watershed: fishing and hunting. Hunting is important in the community and to the high school students; the first day of deer hunting season is designated as a school holiday in this community. Local butchering businesses depend on hunters' patronage for income, and many families use the available wildlife as food sources. In fact, 16 students listed fishing and hunting in their reflections as something important to their family. Some students described hunting and fishing in their rural community as providing a fun family hobby. Others rely on hunting to provide needed food for their families, as shown in two students' comments below:

> Watersheds affect the life of animals and fish in an area. This affects me because I like to hunt and fish. If there was nothing to hunt or fish, my family and I would be disappointed because that is one way we spend time together.—Sarah

> [watershed damage means] hunters would not be able to get much for them to eat.—Bobbi

Multiple students discussed that the health of the stream in their watershed affects the health of the animals because the animals depend on clean, potable water and need a healthy watershed to provide them with healthy food to eat. And, if animals were not healthy, human activities of fishing and hunting would be negatively impacted.

Other economic activities the learners mentioned as happening within the watershed and as relevant to its health were related to energy. Students wrote about electricity and gas production related to gas wells and electrical lines, as shown when a student, Teagan, wrote: “every time a gas well is drilled, or a tower is put up, the water if [is] affected.”

Many learners mentioned the influence of agriculture on the watershed. Students discussed productive farming relying on a healthy watershed and how some farming practices (i.e., fertilizer, pesticides) can have negative effects on the water and soil. Students also mentioned pollution from industry or factories as being present in the watershed. This community has multiple powdered-metal facilities and several metal and machine shops within its borders. Most students expressed surprise that industry did not show as many markers of impact in their stream study. Instead, most pollutants visible or measured in their study came from nonpoint source pollution (e.g., erosion, runoff from roads, fertilizer, animal waste from agriculture, and human waste from outhouses).

Nearly every student listed on their end-of-unit reflection that recreational activities were human activities that could affect or would be negatively affected by changes to the watershed. For example, most students wrote that they participated in canoeing, hiking, swimming, spending time in nature, and camping at or near Community Stream. These students wrote that these recreational activities affected the watershed health *and* would be affected by the watershed’s health, as shown by these three selected excerpts from the written reflections:

> Before I looked at a lake or stream as a place to fish or to have a nice picnic, but I never really thought of it as a necessity for so many creatures including us human beings.—Mark

> I also did not realize how much recreational activities affect the watershed. As humans, we can cause great damage to a watershed with our waste, pollution, and simple carelessness.—Suzie

> I now don’t see a stream that needs to be jumped in for the fun of it. I see an aquatic habitat for many organisms that should not be disturbed.—Dave

Like their peers, Dave, Suzie, and Mark were surprised to think that their normal activities (e.g., picnicking, swimming, fishing) could potentially harm the quality of water in their watershed. Through their writings, these three students and their peers began to express that their recreational activities were connected to a place’s wellbeing rather than separable from it.

Seeing new connections, seeing conflicted meanings

By the end of the unit, most learners articulated that they saw connections between the water within their watershed, the environmental health of their community, and their everyday activities. Not all students reported new connections: when reflecting what they learned, seven of the 73 students wrote only factual reports that focused on the new vocabulary words without writing details of a personal connection to the watershed. One student wrote that this watershed unit was only another “mandatory school project:”

> Even though this trip has been fun and informative, it doesn’t have any impact on my daily life. This trip has not motivated me to do or change anything about the watersheds. It was very informative, but it lacked in making me want to do anything

> to protect or change the lake. In conclusion, the trip was fun and very enlightening, but in the end it was just another mandatory school project that i had to do.—R. J.

In contrast, 66 of the other high school students wrote in their reflection that they learned to see their community's natural areas and bodies of water differently. The four examples below demonstrate how the majority of the students felt a new or greater connection to the watershed:

> Before this I wouldn't think twice about a gas line in the middle of a stream but now that I realize that that gas line is destroying the streams' buffering capabilities. I might look into it more.—Sean

> I would more vividly look at what surrounds it and make my own determination of how healthy it is. I would look for those creatures we found, vegetation surrounding the area, possible pollutants… I now think deeper about the life that exists in watersheds and not just how much fun I can have in that area.—Tammy

> Now when I drive past lakes, streams, and ponds I look at it differently than I did before the trip… The other day my mom said she only likes swimming in water she could see the bottom in, I told her that means there is no life in the water.—Chelsey

> From doing this project we found out that [Community] lake is contaminated by many things. It is contaminated by run off, litter, oil, and even pesticides. I find this disgusting. Not only are we drinking this water but so our animals that live there. I am also a hunter so this would affect the deer and that would be affecting the sport.—Max

When analyzing the reflections, our evidence from the change of viewpoint of the watershed was bolstered by how many students used the words "different" or "differently" to describe how they thought about Community Stream and reservoir. We were also struck by how many emotional words and adjectives the students used to describe their new environmental beliefs: "vividly" and "disgusting" are two examples from the above excerpts. Tammy thought more about the life that a watershed supports and the impacts pollution can have on plants and animals. Most students, like Chelsey and Sean above, appropriated scientific vocabulary when describing the watershed and their participation in the practices of science. Chelsey, in particular, noted that she now could observe the stream in a more scientific ways— showing that she adopted the scientific way of knowing about a body of water alongside viewing the water aesthetically. Six students, including Sean above, used the words "destruction" or "destroy" in relation to the future of the environment health due to human actions. Sean saw a negative connection between the natural gas industry and the stream's health. Notably, even though he remarked on the stream's lowered buffering capacity (the decreased ability of the stream to balance its pH), he did not make an argument against natural gas drilling in his community. Instead, he wrote more neutrally, "I might look into it more." No student who participated in this unit suggested a change in law or policy affecting the use of water in their community. Likewise, no student suggested a new policy or policy change to protect the water quality in Community Stream or other nearby places.

As the learners saw divergent meanings for the watershed health; they often acknowledged the conflict that various meanings caused. For example, Chelsey learned that water that appears clear might not be healthy; however, she noted that her mother did not see the clear water as a negative indicator of the stream's health. Commonly, students acknowledged an intergenerational difference in how the watershed and its care were viewed. Maddie wrote, “When I see garbage on the road now, I’m tempted to ask my dad to pull over so I can get out and get it.” Maddie felt an inclination to act to clean up trash, but that she did not ask her father to stop the car. Max, a hunter, saw a connection between the quality of his drinking water and the sport of hunting—both were affected by the nonpoint source pollution. Although he stated what water quality should be, like his peers, Max did not suggest an action or a diversion of course from his community’s current water-polluting practices. Given the national conversations about drinking water quality, fracking, and fishing/hunting, the research team also noted that not one student mentioned media coverage of water quality issues (i.e., Internet, news, movies).

Timescales of a place—history and future of stewardship

In their reflections and on-site conversations during the walking tour, students were surprised that the history of the stream was still visible. Students were awed that they could see ash, charred wood, and soot from a forest fire about 100 years ago in the soil layers. For many students, seeing these century-old objects prompted them think that there may be evidence of what they leave now—such as litter—for people to see in the future.

Related to the future, students often claimed that what they learned in the watershed unit would change their future behaviors. This behavioral change was motivated by the evidence that one stream in their watershed was affected by nonpoint source pollution, and this polluted stream flowed into their drinking water reservoir. The students’ suggested changes in behaviors were often changes related to proper trash disposal (e.g., the experience will “stop me from littering”—Melly), as in these examples:

> We can use less electrical lines all through the forests. We can pick up litter from the roadways and remove harmful weeds.—Lamar

> Instead of throwing a wrapper out the window of our cars, we can wait until we get to our destination. Or, something as simple as picking up a bottle from the ground and putting it in a recycling bin can help a lot. Maybe even walk to the places that are within a mile or two from your house.—Dina

> Before I think about littering or saying “thats not mine I don’t need to pick it up” I will remember that it does affect our water which will harm fish and plants and could eventually affect me as well.—Hannah

Other students wrote that they had not previously thought of littering as so harmful. One correctly wrote that throwing gum down on the ground (versus in a trash can) can have a negative impact on wildlife. Another wrote that she had not realized how bringing a boat from one area to another could inadvertently transport invasive species.

Within these students’ reflections, learners mentioned the need for changing economic (especially energy-related) choices for the entire community, as shown in Lamar’s statement above about the need for less electrical lines in forestlands. However, as the young people learned how economically driven activities could affect the future health of streams, the students did not advocate new energies for their community (such as solar or wind energy). Students’ reflections provided evidence that although they saw the tensions between divergent perspectives on watershed health, these teenaged students felt powerless to make the changes needed at this time in their lives. In some cases, such as Maddie’s and Chelsey’s perspectives shared earlier, students remarked that this was because their new ideas about the watershed conflicted with their parents' ideas. Some learners wrote that they saw a need to share their perspectives and address the conflicting views, as Lacey wrote (see below) when she is "an adult."

> It made me think that watersheds are very important seeing how only a small percent of fresh water is accessible throughout the world. I will admit the watershed won't be the same in the next 5 years do [due] to large amounts of drilling for natural gas and other ways to get recourses [resources] now.—Cherilyn

> When I get older, i hope to help out with the community and stop littering everywhere.—Paul

> I know we need to take care of them [watersheds], for there will be a huge impact on the rest of my life if we don't.—Mike

> I now know about all that harms a watershed I mostly can't stop that. At least I am able to know and that will impact my future decisions that I make as an adult.—Lacey

> if this pollution and harming of watersheds continues, my generation could experience major issues with the health of waters.—Brooke

Students such as Mike, Lacey, and Brooke above lamented that they saw changing the quality of the water as a key issue for their future. Paul, Mike, Lacey, Brooke, Lamar, and other students did not see a near-term, individual- or community-level solution. In fact, multiple students said that they would need to wait until they were adults before they could make an environmental health intervention. Even though several classes of the students created a wiki, publically available on the Internet, about the watershed health, not one student suggested sharing the results of their investigation with the local community or their parents.

The finding that students saw the need for change yet did not identify individual or community changes to support an increased health of the watershed was an unresolved tension in our study. The intention of the curriculum was to foster understanding of environmental issues in ways that were aligned to the lived experiences of these high school students. While this goal was met, it was not aligned to fostering environmental stewardship actions. This result is similar to the finding of Tzou, Scalone, and Bell (2010), which found tensions between the environmental educator's intention and the urban experiences of the youth. In our study, individual students wrote about stopping their own littering, yet they did not feel they could enact change at the level of community to address issues related to nonpoint source pollution. We posit this tension was unresolved for two reasons. First, because the environmental scientists raised trade-offs with streamside development as well as local economic and recreational pursuits but did not talk about policy implications, the learners did not have information about collective actions. The teacher who organized the field study asked for community policy to be raised by the scientists on-site, but her request was not addressed. Second, given the earlier finding of lack of personalized activities on the mindmaps (e.g., no "my fishing trips"), we feel that the structure of schooling may have interfered. Civic engagement and political actions are considered the domain of another school subject in high school—social studies. It may be that the learners did not include civic solutions to environmental health issues raised because this investigation was part of their science unit. We assert that the because the answer for collective and individual answers are outside of what is normally considered within school science, the students need explicit coaching to consider civics or governmental solutions during school science units.

Discussion and implications

With the orientation towards place as an important school-based learning resource, we examined when, how, and with what result rural students leveraged their lived experiences in their community to understand the watershed unit in their high school classrooms. Overall, our study's analyses found that these students engaged deeply in the place-based exploration of their community's watershed in ways that were scientifically normative (through the mindmap analysis) and personally meaningful (through the qualitative analysis). With industries that could pollute (energies, agricultural) as key economic forces in their community, students acknowledged socioeconomic impacts on water quality, but this information did not hinder learners' understanding of the health of their watershed. Across our analyses, two themes emerged that can inform science education generally and rural science education more specifically. First, we found that the place-based education investigation at Community Stream was successful as a tool for these rural young people in relationship to engaging in science practices and to gaining scientific knowledge. The learners leveraged their rural funds of knowledge (Moll, Amanti, Neff, and Gonzalez 1992) in contextualizing the investigation within their community. The unit's place-based approach supported the youth in thinking about watersheds in general and specifically the community's water quality. Second, the youth recognized conflicting meanings of place—the water within their watershed was a required resource for multiple employment, leisure, and subsistence pursuits (Schaftt and Biddle 2015). As multiple water-use stakeholders were identified, students' expressed an unresolved tension about what are reasonable next steps to improve their community's environmental health. By the end of the unit, the students raised issues and concerns that were beyond the scope of the information normally addressed within school science. As a result, students were unsure how to suggest individual or community-level sustainable actions; the students' unresolved need for action suggests some further work for science educators and researchers, which we discuss below.

The investigation at community stream and learners' knowledge outcomes

Returning to Jensen's (2010) four kinds of knowledge produced through participation in environmental education programs, we found that learners readily gained knowledge of the problems facing their community as well as identified causes of the mediocre water quality. Through mindmap analysis (Tables 2 and 3), we found that learners gained concepts related to watersheds. The students appropriated the scientific meaning of watershed through participating in the practices of environmental science. The students adopted technical knowledge about watersheds, scientific measures, and water quality. Some students organized their ideas in ways congruent with ecological, systems thinking about a watershed (Shepardson, Wee, Priddy, Schellenberger, and Harbor 2007) as consisting of humans, plants, animals, abiotic factors, groundwater, surface water, and precipitation (especially in regard to causing run-off). Students expressed that the health of animals' and plants' habitats depend on the health of the watershed, and the health of the watershed depends on plants and animals (including humans).

The qualitative analysis also revealed that learners (e.g., Sean, Cherilyn, Max) realized that human activities related to the production of energy, farming, and transportation affected their watershed in negative ways, and eventually this impacted their community's drinking water. The students acknowledged that economic factors, especially related to energy production, created a level of pollution within the watershed that affected animals, plants, and humans. Most reported that they felt this present amount of pollution and destruction were not acceptable to maintaining the activities they like to do, including hunting, fishing, spending time in nature, and drinking clean water.

Consequently, the research team concluded that for the majority of students, their experiences in rural places were assets to their meaning-making related to understanding the environmental problem and its causes. Activities such as hunting, fishing, farming, and recreational camping, hiking and boating provided connections for the students to bodies of water in their watershed. These activities were important to everyday family life, and consequently the protection of the places where the activities were based became important to nearly every student. Importantly, there was no evidence that the community's industries and energy sources that were debated locally became a barrier for student engagement in the water quality testing or ecological understandings. In short, learners' rural experiences were assets to provide a fundamental understanding of place, which was enhanced and extended in the unit.

Conflicting meanings for the watershed and definitions of its health

In addition to demonstrating their knowledge of the water quality problem and its causes, the students included knowledge of the strategies for change as suggested by Jensen (2010). The learners felt changes were warranted because they believed that the status quo of the water quality was in conflict with their views of what the quality of water in their community should be. As a result, most students readily identified personal strategies for change, which were actions that they could take now. For example, Dina, Lamar, and Hannah identified that they would not litter and they would pick up other people's litter. A few students wrote in a pessimistic manner, however, expressing their feelings that a decline in watershed health was inevitable.

Learners such as Cherilyn, Paul, Mike, and Lacey pointed out tensions in their new environmental knowledge that were in conflict with others in their community. Cherilyn and Brooke believed that their generation would experience major environmental health issues because of current standards allowing for pollution emissions and energy production. Some learners suggested that they needed to wait until they were adults to make changes in how decisions affecting watersheds are made. Chelsey and Maddie, for example, expressed that their views about water quality were different from their parents' views.

Students wrote powerful statements that they were "disgusted" and saw "destruction" of their local ecosystem; however, none suggested *collective* indirect or direct actions (Jensen, 2010) to address the community-level activities that impacted water quality. While the watershed mattered to these high school students, none proposed any collective action that their Appalachian community could adopt together to address their new knowledge of water quality problems and causes. While the students acknowledged the need for potable water for a variety of activities, the students did not discuss what next steps their community would need to work on together. Even given the national attention about the environmental impacts of certain economically driven activities, the students did not raise questions about current legislation, environmental oversight, or the possible need to exclude certain socioeconomic activities in their community. Importantly, students did not defend the value of these socioeconomic activities to their community either. The learners identified the conflicts present in their community, but they remained silent on what the solution should be. The students had knowledge of a vision for their future individual actions, but not a vision for the future collective actions of their community.

In sum, the majority of the learners developed revised senses of place, as demonstrated through their own meanings expressed in their reflections and through the recognition of the divergent meanings for water quality and watershed health that existed in their community. In acknowledging the divergent meanings, an unaddressed tension arose about collective actions that their community should undertake. The students did not presently feel the ability or the empowerment to act together as stewards. Students identified their own individual actions (e.g., pick up litter, walk more), but no one in our study identified how the community could act together to support goals of ecological sustainability.

Our analysis did not identify the reasons that the students proposed no collective action, but we have two possible suspects based on our data and our reading of the literature. First, the lack of collective action proposed may be due in part because a lack of "bidirectional, dialogic transactions" (Eijck and Roth 2010) about and with their community. Environmental educators, scientists, and teachers were involved in the watershed unit, but students' parents and other community members were not. To move towards collective action, perhaps more members of the collective needed to be involved. Given the learners were engaged with an online wiki, they could have sought out other communities engaged in similar dilemmas within Pennsylvania or neighboring states and created links to these on their webpage—creating community resources. Second, while science practices were modeled in this unit, the practices of civically-engaged, scientifically-literate citizens were not. In research with volunteers working on water quality monitoring in citizen science watershed projects, Abby Kinchy and Simona Perry (2011) identified knowledge gaps and uneven knowledge distribution about watershed topics and pollutants' influence on water quality. The researchers found through participating in water monitoring activities, similar to this unit, the adults gained local knowledge about their community but not information that was aligned to global understandings of watershed systems or collective civic action. David Sobel (1996) posited that education with too much emphasis on global issues could leave students un-empowered for local environmental action. We followed theoretical recommendations in this study with our focus on Community Stream that was used to understand the global science of watersheds. Nevertheless, even with such a local focus, the students still felt unsure of the proper course of action for their community.

We posit that if the unit enhanced students' action-oriented knowledge through direct connections to civic concerns and by providing models of civically-engaged, scientifically-literate citizenry, these youth may have felt empowered to have additional conversations with others in their community about water quality. In his work, Jensen (2010) suggests not differentiating between individual and collective action; however, our study's findings about the lack of development towards knowledge of collective actions suggest otherwise. If a goal of science education is sustainability, more refinement of pedagogy is needed for students to develop collective actions. Relatedly, if we take seriously the need for education to create engaged scientifically literate citizens in their own communities, explicit connections between science, social studies, and other school subjects are necessary. While many of the students took, or were taking, a civics class, just co-mingling ideas was not sufficient for students to imagine collective actions. In other words, our findings support the assertion that environmental education has to be more than just science education—civics education needs to be linked to science education to fully realize the sustainability goals of environmental education.

An implicit assumption of the environmental scientists involved seemed to be that the learners would be able to enact stewardship and conservation actions, if they were exposed to the science—even when stewardship and conservation actions were not explicitly stated. Yet, our results show that learning science content alone is not enough to prompt students to collective environmental education action as engaged, scientifically-literate citizenry. Additional explicit instruction is needed for students to apply refined environmental understandings and new senses of place to support their rural community. As such, we argue that the students need action-oriented knowledge (taken as an integrated understanding of causes, strategies for change, and alternatives to address environmental problems). Models of civically-engaged, scientifically-literate citizenry need to be explicitly included alongside the environmental sciences content and practices to evoke behavioral changes related to sustainability. For example, the learners can read a case study of another community whose members monitored its environmental health and then advocated for change of local policies. Cross-curricular experiences could also have provided resources; learners can be assigned a non-fiction book or set of historical readings in their English or social studies classes related to communities' reactions and actions about environmental health topics. As our society works together to address issues like water quality, global warming, and alternative energy, more educational research is imperative to understand how to support learners to gain more than just knowledge of the problems facing their communities (Jensen 2010), but also how to enact local solutions to environmental dilemmas.

Conclusion

This analysis presented a case of how, when, and whether young rural Appalachian residents engaged with place-based understandings of their everyday activities and community as they learned about watershed health and water quality in school-based science. As students learned in and about the rural places in their communities, they experienced both connections and tensions between their everyday experiences and local environmental problems. Our analyses show that the young people saw the impacts of rural leisure and socioeconomic activities on the local watershed and water quality; the students were able to leverage their rural experiences as they engaged in the science during the school day, during the fieldtrip, on mindmaps, and in their reflections. The students offered initial individual actions that might reverse the degradation of water quality in their Appalachian watershed. By examining how these young people connected their local experiences with hunting, fishing, and farming, as well as their understandings of industry pollution, energy needs, and nonpoint source pollution, we found that their everyday experiences supported science meaning-making related to water quality. However, the students' understandings of the intersection of the watershed with their community left them with unanswered questions about what their community could or should do next. For example, as the students learned about nonpoint source pollution affecting their water, they found that it was not *one* problem to solve, but community-wide pollution that came from nowhere in particular and everywhere at the same time. With the sociocultural perspective on learning as reliant on place, we found that these 14- and 15-year-old students increased their understandings of multiple concepts related to water quality, yet by the end of the unit they were no more likely to suggest a collective action to support the health of their own local watershed.

Given that the socioeconomic issues facing their Appalachian community were acknowledged by the students, but without any sense of what to change, our analysis suggests that education focused on scientific concepts alone is not enough to support young people to become stewards of their community. As a result of our findings and similar studies of watershed monitoring with adults (Kinchy and Perry (2011)), we posit that learning how and when to evoke action-oriented environmental sciences knowledge required explicit models and cross-curricular support. The learners needed support in methods of presenting evidence and arguments to convince key stakeholders in their lives, such as parents, teachers, and other members of their rural community. Although a study of learners in afterschool programs on alternative energy with urban learners (Rose and Calabrese Barton 2013) has shown that youth can take on an advocacy role if a social justice perspective is taken, more research effort is needed on how to translate the advocacy findings to formal school-based units. As the science educators engage youth in informal and formal learning experiences about freshwater quality, climate change, and habitat destruction, more focus on action-oriented environmental sciences knowledge is warranted. Learners need support to become an engaged scientifically-literate citizenry, rather than a disillusioned citizenry. Research is also needed on how to prepare science teachers to create learning communities that produce action-oriented science knowledge, instead of inert knowledge of environmental problems, during place-based education units.

Finally, given the Eijck and Roth (2010) study's conclusion about the importance of dialogues about places, more research is needed on how to engage rural community members in school-based science experiences when the action-oriented environmental sciences knowledge challenges current economic activities that are relied upon for income. This dilemma is currently under-examined in the literature in rural science education and place-based education. Few resources exist for teachers and for students about how to discuss future community development and local policies that support both the economic and environmental health of a community. Within our local school-research partnership, a possible solution is for the high school students to take an American government and local civic engagement social studies course at the same time as the biology class that contains the watershed unit. In this way, the environmental science concepts and practices can be aligned with the accepted procedures for action across multiple fields to provide students with the understandings and support to they need to develop action-oriented environmental knowledge that is sustainable now and in the future.

References

Aikenhead, G. S. (1996). Science education: border crossing into the subculture of science. *Studies in Science Education, 27*, 1–52. doi:10.1080/03057269608560077.

Anderson, D., Thomas, G. P., & Nashon, S. M. (2009). Social barriers to meaningful engagement in biology field trip group work. *Science Education, 93*, 511–534. doi:10.1002/sce.20304.

Appalachian Regional Commission. (no date). *The appalachian region.* Retrieved January 10, 2015, from http://www.arc.gov/appalachian_region/TheAppalachianRegion.asp.

Avery, L. M. (2013). Rural science education: Valuing local knowledge. *Theory into Practice, 52*, 28–35. doi:10.1080/07351690.2013.743769.

Avery, L. M., & Kassam, K. A. (2011). "Phronesis": Children's local rural knowledge of science and engineering. *Journal of Research in Rural Education*, *26*, 1–18. Retrieved, from http://jrre.vmhost.psu.edu/wp-content/uploads/2014/02/26-2.pdf.

Brundiers, K., & Wiek, A. (2011). Educating students in real-world sustainability research: vision and implementation. *Innovative Higher Education, 36*, 107–124. doi:10.1007/s10755-010-9161-9.

Carlone, H. B., Kimmel, S., & Tschida, C. (2010). A rural math, science, and technology elementary school tangled up in global networks of practice. *Cultural Studies of Science Education, 5*, 447–476. doi:10.1007/s11422-009-9233-2.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school*. Washington, DC: National Academies Press.

Eijck, M., & Roth, W.-M. (2010). Towards a chronotopic theory of "place" in place-based education. *Cultural Studies of Science Education, 5*, 869–898. doi:10.1007/s11422-010-9278-2.

Erickson, F. (1985). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 119–161). Chicago: MacMillan.

Fox, J. (2010). *Gasland [documentary film]*. Brooklyn, NY: International WOW Company.

Gee, J. P. (2000–2001). Identity as an analytic lens for research in education. *Review of Research in Education, 25*, 99–125.

Gutiérrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher, 32*, 19–25. doi:10.3102/0013189X032005019.

Hay, D. B. (2007). Using concept maps to measure deep, surface and non-learning outcomes. *Studies in Higher Education, 32*, 39–57. doi:10.1080/03075070601099432.

Hay, D., Kinchin, I., & Baker, S. (2008). Making learning visible: The role of concept mapping in higher education. *Studies in Higher Education, 33*, 295–311. doi:10.1080/03075070802049251.

Jensen, B. B. (2010). Knowledge, action, and pro-environmental behavior. *Environmental Education Research, 8*, 325–334. doi:10.1080/13504620220145474.

Kinchy, A. J., & Perry, S. L. (2011). Can volunteers pick up the slack? Efforts to remedy knowledge gaps about the watershed impacts of Marcellus Shale gas development. *Duke Environmental Law & Policy Forum, 22*, 303–339.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behaviour? *Environmental Education Research, 8*, 239–260. doi:10.1080/13504620220145401.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.

Levine Rose, S., & Calabrese Barton, A. (2012). Should great lakes city build a new power plant? How youth navigate socioscientific issues. *Journal of Research in Science Teaching, 49*, 541–567. doi:10.1002/tea.21017.

Lim, M., & Calabrese Barton, A. (2006). Science learning and a sense of place in a urban middle school. *Cultural Studies of Science Education, 1*, 107–142. doi:10.1007/s11422-005-9002-9.

Membiela, P., DePalma, R., & Pazos, M. S. (2011). A sense of place in the science classroom. *Educational Studies, 37*, 361–364. doi:10.1080/03055698.2010.506340.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: using a qualitative approach to connect homes and families. *Theory into Practice, 11*, 132–141. doi:10.1080/00405849209543534.

Novak, J. D., & Cañas, A. J. (2008). *The theory underlying concept maps and how to construct and use them, technical report*. IHMC CmapTools 2006-01, Rev 01-2008, Florida Institute for Human and Machine Cognition.

Schafft, K., & Biddle, C. (2015). Opportunity, ambivalence, and youth perspectives on community change in Pennsylvania's marcellus shale region. *Human Organization, 74*, 74–85. doi:10.17730/humo.74.1.6543u2613xx23678.

Semken, S. (2005). Sense of place and place-based introductory geoscience teaching for American Indian and Alaska Native undergraduates. *Journal of Geoscience Education, 53*, 149–157.

Shepardson, D. P., Wee, B., Priddy, M., Schellenberger, L., & Harbor, J. (2007). What is a watershed? Implications of student conceptions for environmental science education and the national science education standards. *Science Education, 91*, 554–578. doi:10.1002/sce.20206.

Sobel, D. (1996). *Beyond ecophobia: reclaiming the heart in nature education* (Vol. 1). Great Barrington, MA: Orion Society.

Tzou, C., Scalone, G., & Bell, P. (2010). The role of environmental narratives and social positioning in how place gets constructed for and by youth. *Equity & Excellence in Education, 43*, 105–119. doi:10.1080/10665680903489338.

U.S. Department of Education, National Center for Education Statistics. (2011). *The condition of education 2011 (NCES 2011-033)*. Retrieved online September 19, 2011, http://nces.ed.gov/programs/coe/indicator_sde.asp.

Vygotsky, L. S. (1987). *Thinking and speech*. New York: Plenum Press.

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education, 87*, 112–143. doi:10.1002/sce.10044.

Heather Toomey Zimmerman is an associate professor and the program chair of the Learning, Design, and Technology program at Penn State University's College of Education. Her research focuses on STEM learning within informal spaces, science learning that spans informal and formal spaces, and technology-enhanced science learning with mobile computers. Her professional work experiences include being a museum educator, wetland educator, and learning scientist.

Jennifer L. Weible is an assistant professor of Educational Technology in the department of Teacher Education and Professional Development at Central Michigan University. She has taught chemistry and physical science for over 20 years, as well as working in a technology leadership role in a K-12 school district. Her research examines how digital technologies can support learning in Science, Technology, Engineering, and Mathematics (STEM) education with a focus on participation in science practices.