Scientific Fieldwork: An Opportunity for Pedagogical-Content Knowledge Development

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ABSTRACT

This study documents the effects of a scientific fieldwork-based model of instruction on enhancing pedagogical-content knowledge of in-service teachers engaged in an NSF-funded, three-year professional development program for earth/environmental teachers entitled Earth-View (ESI-9911850). We focused on data collected through concept maps and videotaped interviews that dealt specifically with the two areas of participant knowledge germane to enhancing PCK (i.e. content and pedagogical). The videotaped interviews were used to examine how the structure of the program (i.e. specifically, scientific fieldwork) facilitated the development of PCK in the context of instruction designed to increase content and pedagogical knowledge. The concept map evidence supports the assertion that the treatment experienced by Earth-View participants promotes construction of earth/ environmental science content knowledge. We also demonstrate the capacity of the program activities (i.e. primarily scientific fieldwork) to promote pedagogical and pedagogical-content knowledge.

INTRODUCTION

The frequency with which K-12 teachers are placed in science classrooms and expected to use instructional strategies they have not personally experienced (e.g. scientific fieldwork-based instruction) to teach subject matter in which they have had little to no formal training (e.g. earth/environmental science) is considerable (Henderson et al., 2006). One of the primary means of addressing the lack of content and pedagogical understanding of these teachers is through pre-service and in-service professional development programs. According to Mason, however, the problem is that such programs "…stress unilaterally either content or pedagogy, often merely providing future and current teachers with an array of noncontextualized, unconnected activities, concepts, and demonstrations" (1999, p. 277). While most programs may be effective in construction of content or pedagogy to varying degrees, few have demonstrated effectiveness in developing teachers' pedagogical-content knowledge (PCK).

Shulman described pedagogical-content knowledge as one of three different types of knowledge, grouped with subject matter and curricular knowledge. This specific type of knowledge was thought of as going "beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986, p. 9). The implication was that educators must have a complete knowledge of the subject matter, such that they can discern what aspects are essential to the teaching of the subject. Then, they must maintain an array of methods by which to teach those aspects, knowing under what circumstances and with whom to use them. Furthermore, they must understand the subject matter and pedagogical theory well enough to be able to identify particular points within the subject matter that learners find easy or difficult, and go on to explain why in each case. Such knowledge leads to the educators' understandings of student preconceptions and misconceptions and how one would successfully address them (Shulman 1986).

PCK has endured alterations that range from semantics to its very nature. Some share very similar views of PCK, applying different terms, such as "craft knowledge" (Van Driel et al., 1998), to the same basic concept. The majority of the literature tends to focus on specific aspects of PCK, such as student misconceptions, rather than tackling the entire concept. One of the primary reasons for the avoidance of discussing PCK in its entirety could possibly be that its very nature is unresolved (Gess-Newsome, 1999). In fact, its existence as a separate knowledge has been questioned, as seen in the Integrative model. The concept of an Integrative model, which denies the existence of PCK entirely, takes the stance that an educator's knowledge of teaching is merely the combination and interaction between three types of knowledge, namely subject matter, context, and pedagogy. The Transformative model stands in contrast by declaring that there is only one type of knowledge that is important in the practical application of education, and that is PCK. Proponents of the Transformative model justify the existence of only one type of knowledge by asserting that once all three other knowledges have been assimilated, which is usually a function of the quantity of teaching experience, that one distinct, practical, and functioning knowledge materializes - PCK (Gess-Newsome, 1999). These are of course the two ends of the PCK spectrum. The variations in degrees of acceptance and the application of the notion of PCK are seemingly infinite. However, the discussion of teacher cognition in recent literature is increasingly embedded with the idea of PCK, even if it is not identified by that term (Van Driel et al., 1998). Still other researchers incorporate PCK into frameworks involving other forms of knowledge (Frykholm and Glasson, 2005).

The concept of PCK has become one of ever-increasing popularity and import; yet most professional development designers continue to consider PCK an unrealistic and unintentional outcome of programs. Major reasons for this common view include: 1) most professional development programs are not sustained in instruction and support; therefore, designers feel that sufficient time for PCK construction does not exist, and 2) particular components of professional development most effective at developing PCK remain unidentified.

Scientific Fieldwork - One example of a teaching strategy consistent with constructivist-based learning theories and inquiry-based reform efforts is that of fieldwork-based inquiry (Howarth and Slingsby, 2006). "While the rationale for fieldwork is broadly that for other styles of practical work, field experiences also provide a range of learning opportunities that laboratories cannot supply" (Lock, 1998, p. 633). Hodson (1996) points out three areas in which this is true: learning about science content, learning about the interactions between science and society, and doing complex science. It is argued that first hand experience of scientific phenomena makes the learning of science more accessible for more students. In addition, the complex processes of science and their relationships with other systems (political, social, etc.) are better understood through investigative activities conducted by the students themselves. This is of particular value when considering environmental and environmental science education. Lastly, the opportunity to do science possesses the potential to profoundly affect the student's concept of the nature of science, by exposing the tentative state of scientific knowledge as well as the complexity of variables that exist in the environment (Helms, 1998; Hodson, 1998; Knapp, 2000; Lock, 1998).

Research Question - Due to the urgent need across the nation for effective professional development in Earth/Environmental Science, the need for research on a wide variety of approaches to professional development is crucial. The use of scientific fieldwork in professional development has emerged as one of the more promising approaches, but more empirical evidence is needed regarding its efficacy. As a result, this study addresses the question, "what are the effects of a scientific fieldwork-based model of instruction on enhancing pedagogical content knowledge of in-service teachers engaged in professional development?"

METHODS

In an attempt to study the issue of PCK construction as a calculated outcome of professional development, the program Earth-View: Leadership in Earth/ Environmental Science for North Carolina Schools was selected because of its sustained involvement with its participants and its use of current research regarding models of professional development and adult learning (see for example Fraser-Abder, 2002; Loucks-Horsley et al., 1998). Earth-View (ESI-9911850) was a three-year, National Science Foundation funded, fieldwork-based program that involved forty-five earth/environmental science teachers from across a single state in the southeast region of the US. Primarily through inquiry-based fieldwork experiences (i.e. participants posing and answering their own questions about the environment through the use of scientific processes), these teachers become experts in content and pedagogy, while growing as leaders in their field, eventually providing professional development opportunities for their peers. The research agenda embedded in the project included questions about what teachers learned and how they continue to organize and use the content and pedagogical knowledge they possess. Over the course of the three years, a variety of methods regarding a number of research questions yielded a range of data sources, including pre and post-tests, questionnaires, videotaped presentations by teachers, videotaped interviews, videotaped classroom observations, surveys, artifacts, and concept maps. In order to address the research question posed in this study, we focused on data collected through concept maps and videotaped interviews that dealt specifically with the two areas of participant knowledge germane to enhancing PCK (i.e. content and pedagogical). The videotaped interviews were used to examine how the structure of the program (i.e. specifically, scientific fieldwork) facilitated the development of PCK in the context of instruction designed to increase content and pedagogical knowledge.

Concept Maps - The assessment instrument implemented after the second summer of the program consisted of a post-concept mapping activity about streams - defined as, any flowing body of fresh surface water. Prior to the participants being asked to construct a concept map regarding streams, they were given instruction on concept map construction and purpose. The pre-concept mapping activity occurred before the stream fieldwork exercises at the beginning of the second summer session, while the post-concept mapping was conducted approximately three months after the fieldwork at a follow-up session. Scoring of the concept maps consisted of tallying the number of connections made between concepts. These connections were divided into three categories: 1) an appropriate relationship explicitly described (i.e. verbs describing connections were present), 2) an implied appropriate relationship (i.e. verbs were not present to describe connections), and 3) an explicit misconception. Sums were calculated from the number of appropriate relationships described (explicit and implied) to form totals. Explicit misconceptions were not included in the totals (i.e. they were scored as 0). The number and nature of those misconceptions were recorded and analyzed for pre to post increases (i.e. change in total number from pre to post) and resilience (i.e. did they describe the same misconception in the pre as they did in the post). Summary statistics for the Pre-Concept Map Totals, the Post-Concept Map Totals, and the Paired-Differences Totals were calculated (Novak, 1998).

Videotaped Interviews - The data obtained through the videotaped interviews were collected over a seven-month period involving both experienced and novice earth/environmental science teachers participating in the program. An experienced teacher, Jill (pseudonym), was interviewed and deemed experienced based upon her years in the classroom, the number and variety of Earth/Environmental Science workshops which she had attended, the leadership roles she had assumed, and awards and grants she had received. Additionally, thirty other Earth-View participants were interviewed during the second summer session. The videotaped semi-structured interviews were transcribed and coded and categorical aggregation was used to identify themes and make assertions (Bogdan and Biklen, 1998; McMillan and Schumacher, 2006).

In short, the concept maps were used to demonstrate any change in content understandings. The videotaped interviews were used to identify the relationship between changes in content understandings and

Measure	Pre-Concept Map (N = 35)	Post-Concept Map (N = 25)	Paired Differences (N = 23)
Mean	10.97	30.8	19.83
median	10	29	21
Mode	10 (Frequency 6)	No Significant Mode	28 (Frequency of 3)
Maximum	26	77	31
Minimum	2	14	3
Standard Deviation	4.85	12.37	8.55
First Quartile	8	22	11
Third Quartile	13	37.5	26
Outliers	Yes (26)	Yes (77)	No

Table 1. Summary statistics of concept map data.

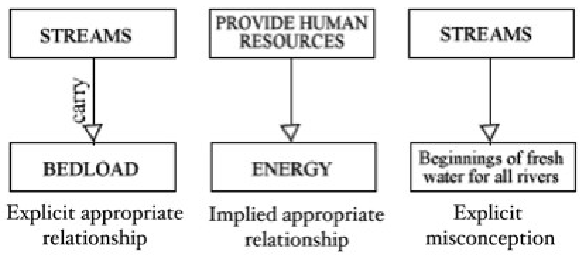

Figure 1. Concept map scoring rubric.

scientific fieldwork. The interviews were also used to identify any changes in pedagogical knowledge and PCK, while also illuminating what role scientific fieldwork played in those changes.

RESULTS AND CONCLUSIONS

Content Knowledge: Concept Maps - Summary statistics of the pre and post-concept maps are shown in Table 1. The statistical evidence supports the assertion that the treatment experienced by Earth-View participants promotes construction of earth/ environmental science content knowledge. All participants showed an increase in their pre to post-concept mapping activity scores. The paired differences from the pre and post- concept maps yielded a mean of 19.83 implied and explicit appropriate connections, including a maximum of 31 and a minimum of 3 implied and explicit appropriate connections. The wide range in the number of appropriate connections is expected, based in part, on the participants' experiences with teaching earth/environmental science, the extent of their academic backgrounds in the areas of earth/environmental science, and their varying levels of physical and mental participation in the program. Of the participants that completed a pre and post-concept map, twenty-one out of twenty-three demonstrated either no change or a decrease in the number of connections representing misconceptions. All of those misconception connections that demonstrated no change were instances in which no misconceptions were ever identified. The misconceptions that were identified in the post-concept maps (n=4) fall into one of two categories: 1) streams form drainage basins or 2) limnological nomenclature (e.g. streams are older and younger than creeks and rivers respectively). These misconceptions also appeared the individuals' pre-concept maps. Further research is needed to ascertain the origin and impact of the participants' misconceptions, along with whether these concepts possess unique characteristics that support their resiliency. To illustrate how the maps were scored, note the following example (Figures 1, 2, and 3).

The participants were engaged in activities that required them to directly measure the temperature, pH, depth, and velocity of water in several mountain streams. Words and phrases associated with Earth-View Summer II Activities were common in virtually all the participants' post-concept maps, and relatively rare in the pre-concept maps. The organization of thoughts appeared to change from pre to post-concept maps for many participants, as well. For example, in the post-concept mapping activity, several participants used words and phrases like, "stream orders", as major categories from which their maps developed. The use of more hierarchical vocabulary signified a shift from the earlier use of more loosely structured organizational schemes. In addition, the change in topics used in the concept maps suggested an increase in the participants' abilities to integrate various content from a number of disciplines and sources. For instance, in the post-concept maps, teachers integrated content associated with Summer I Activities (coastal environments), Summer II Activities (mountainous environments), and Fall Follow-Up II (environmental health) appropriately.

Pedagogical Knowledge: Videotaped Interviews - Case Study Interview - Jill underwent changes in her ideas about teaching that led to a more frequent implementation of inquiry-based activities in the field. These ideas revolved around the concept of providing the students with an opportunity to "do science". She cited several new ideas she had developed in regard to the concept of "doing science" and described how they affected her students' learning in positive ways. For example, the subject implemented activities that were only slightly modified from fieldwork exercises in which the Earth-View participants engaged. The modifications were of a logistical nature and did not alter the fieldwork procedures. She discussed how the process of conducting scientific fieldwork herself led to her decision to implement the activities in her own classroom and utilize similar instructional strategies more often.

Summer II Interviews - Other Earth-View participants interviewed during the Summer II session articulated similar sentiments and described how their pedagogy was impacted by the scientific fieldwork experiences. Most indicated that they intend to or have already implemented fieldwork activities with their students

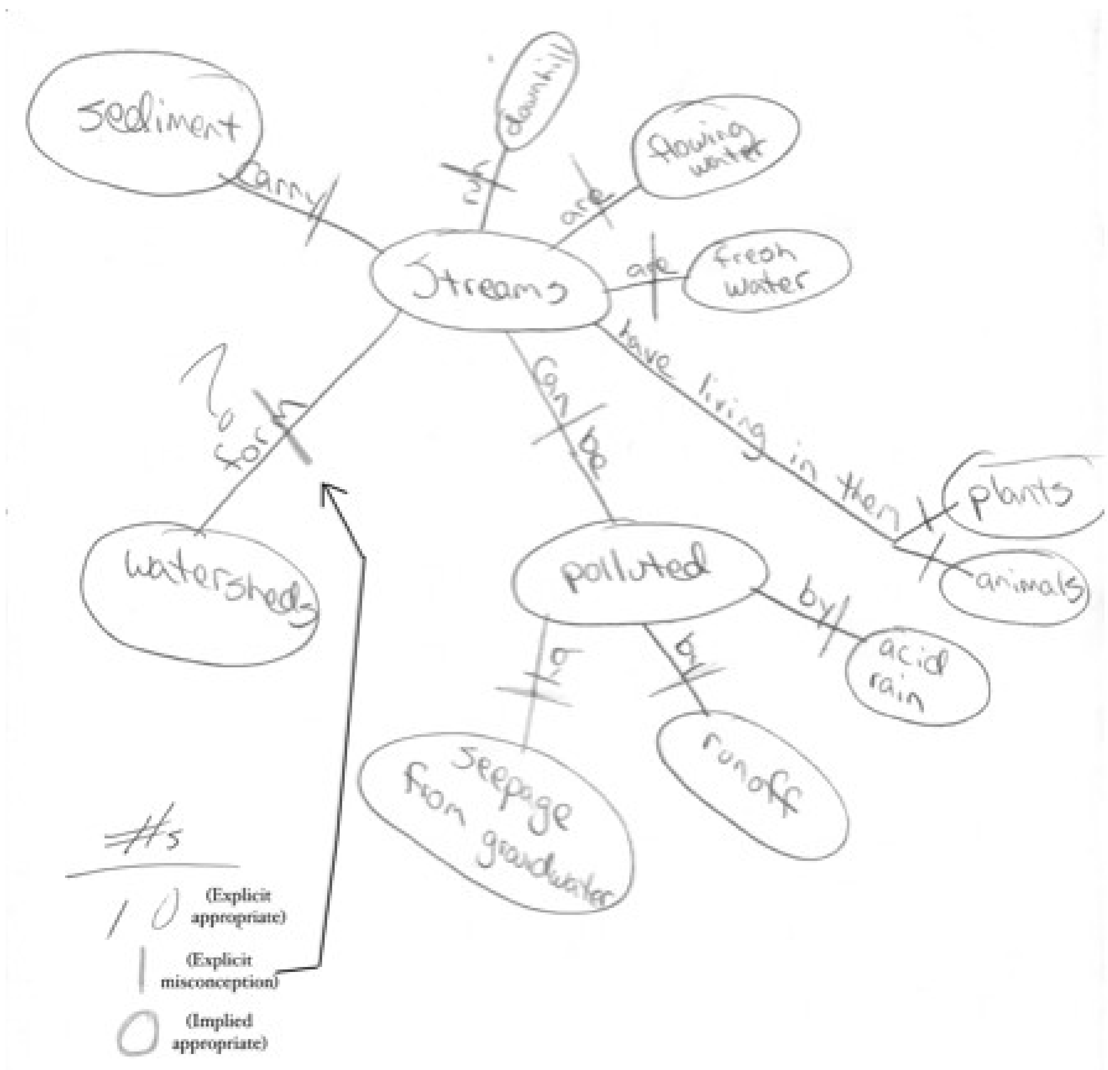

Figure 2. Example participant pre-concept map.

that closely imitated those they personally experienced during the course of the program. For example, participants stated,

From dawn to dusk, we [Earth-View participants] hiked through and we learned so much that I turned around last year and took my kids on what I thought was as close to the trip as thought I could get.

I was doing hands-on…and I was learning and what I was doing in the field I could do with my students.

…hands-on, great ideas for labs. I make it part of my program. What we did the other day on the streams. I will use that exact lab in my classroom this year.

Pedagogical-Content Knowledge - The interviews with Jill yielded descriptions of instances where newly created content understandings allowed for the implementation of improvised activities and improvisation served as evidence for the existence of PCK. For example, the participant described how she had taken her class to the beach to conduct an activity about weathering and erosion and sediment transport that she experienced during Earth-View instruction. She was unable to execute it as she had planned because of a multitude of fishermen in the study area. Instead of canceling the fieldwork and going back to the classroom, however, she improvised by walking down the beach with the students, addressing the original lesson's goals using content knowledge obtained through Earth View. She noticed a rock jetty and used it as the focal point of her lesson asking students to make observations about the beach regarding the types and distribution of sediments while leading the students through an impromptu three-part learning cycle. Jill made use of both 1) inquiry-based scientific fieldwork pedagogy and 2) content knowledge regarding weathering and erosion of parent materials and transport of sediments in low-energy, barrier island environments to meet student needs in the face of an unexpected challenge. She stated,

> That comes back from Earth-View because we talked about those things last summer…. I've never seen it in a book anywhere as far as sitting there looking at this handful of sand and looking at these rocks that don't belong there, but are there. And those kids have probably climbed on those rocks many times and never realized that they weren't from around here. A lot of that came from pulling from what we were exposed to last summer.

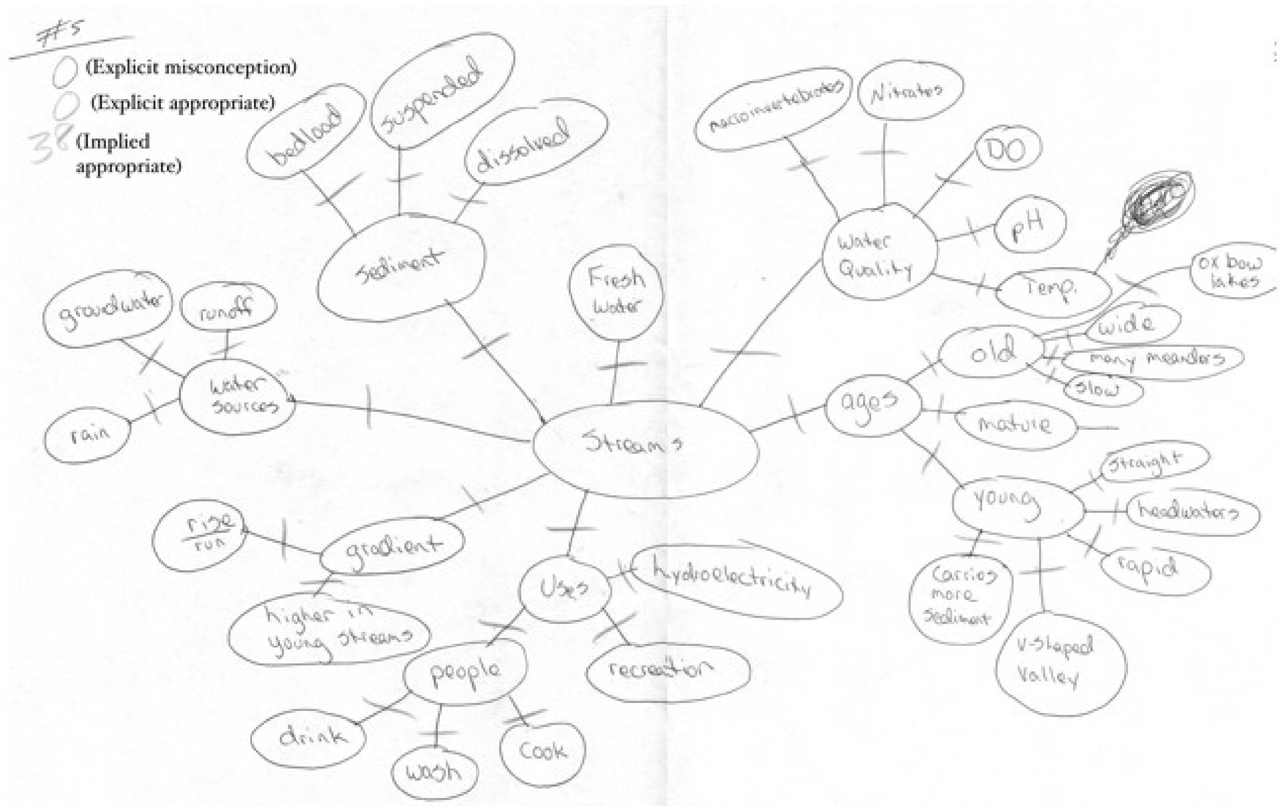

Figure 3. Example participant post-concept map.

Jill's ability to successfully improvise during the lesson demonstrates her ability to integrate her newly constructed content knowledge with her pedagogical understandings in a specific context.

The construction of PCK Jill experienced is further evidenced by the change in what she considers to be important concepts within the subject matter, coupled with the pedagogical steps she takes to teach those concepts. For example, the importance of data collection and interpretation rose dramatically for her as she developed more coherent ideas concerning the nature of science. Jill learned that doing science through fieldwork requires more than a one-shot hands-on demonstration of a fieldwork exercise. In order for students to learn about the nature of science and the methods and processes involved, they must engage in those methods and processes over and over again.

I think having students go over there and do measurements every month, well, it's the first time I've carried on anything for the whole semester. Then they have a basis of understanding that ninety-nine percent of the voting public doesn't have.

[We do the beach survey] once a month…this is my first year to do it. This is one of the things that is a result of the class last summer [Earth-View Summer I], getting out and really doing fieldwork … after what we did last summer, I see the value in repeating and that every lab that they do doesn't have to be mind-boggling. If they're going to work like scientists they have to collect that data and they have to do it over a period of time…

Jill explicitly stated that she had altered her teaching in light of her newly constructed content understandings regarding the nature of science and used scientific fieldwork as the instructional strategy to teach those concepts. Not only did she incorporate activities directly from Earth View, she also purposefully modified lessons she used in the past to more effectively couple content with what she considered the most appropriate and effective pedagogy for that particular content and her particular population of students. Her rationales for the selection of content and pedagogy were consistent with recommendations contained in science reform documents (e.g. National Science Education Standards and Benchmarks for Scientific Literacy) (AAAS, 1993; NRC, 1996).

IMPLICATIONS

Scientific fieldwork-based instruction has the potential to serve as a potent catalyst for the growth of PCK in secondary earth/environmental science teachers. Implications include the use of fieldwork-based instructional strategies in professional development programs for similar populations. Although the evidence provided supports our assertions that the use of scientific fieldwork played a positive role in enhancing content knowledge, pedagogical knowledge, and PCK with this population, we recognize that other variables exist which may have impacted the results and that there are limits to our ability to generalize.

Since the use of scientific fieldwork constituted the central element in the professional development program, we speculate that the associated structure and execution of Earth View played a significant role in the process of enhancing participants' PCK regarding earth/environmental science. The following represent some of the components of the program that we consider to be key in the process of developing teachers' PCK.

First, Earth View used complex scientific content in instruction that was focused primarily on building teacher content understandings and environmental awareness and understanding. We provided sustained instruction and support for participants. We primarily used collaborative, inquiry-based hands-on scientific fieldwork exercises designed to increase teacher content and pedagogical understandings that were also flexible enough to be either directly incorporated into a classroom setting or modified at the teacher's discretion. Earth View program leaders made considerable efforts to model effective instruction. Lastly, program leaders facilitated the development of cohesive teacher teams that constructed content and pedagogical expertise over time in an environment that supported reflection. While determining the efficacy of the program requires additional research efforts, the value of this study rests in the findings that support the notion that scientific fieldwork can effectively meet the goals of enhanced teacher content knowledge, pedagogical knowledge, and most importantly, PCK. As such, the use of scientific fieldwork is worthy of consideration by anyone whose aim is to improve the PCK of earth/environmental science teachers.

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