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BUILDING INTEREST AND KNOWLEDGE IN GEOSCIENCES THROUGH PLACE- & FIELD-BASED TEACHER PROFESSIONAL LEARNING PROGRAMS: A COMPARATIVE MULTI-CASE STUDY

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Dedication

To future generations- may you never give up hope that you can make your community and world a better place, where all living things can thrive.

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List of Abbreviations

Crosscutting concepts (CCCs)

Disciplinary core ideas (DCIs)

EarthCache™ (EC)

Earth Science Literacy Principles (ESLP)

Earth and space science (ESS)

Great Lakes Stewardship Initiative (GLSI)

Michigan Teaching Excellence Project (MiTEP)

Michigan Integrated Technology Educational Competencies for Students (MITECS)

Nah Tah Wahsh Public School Academy (NTW)

Next Generation Science Standards (NGSS)

Place-based education (PBE)

Place-based stewardship education (PBSE)

Professional development (PD)

Science and engineering practices (SEPs)

Underrepresented groups (URG)

Virtual Geosite Investigation Program (VGI)

Virtual reality (VR)

Abstract

The focus of this study was to develop and evaluate a geoscience professional development model that would improve K-12 teachers' capacity to effectively build geoscience literacy and interests in students from a variety of settings and cultural groups. The research compared the application of a geoscience professional development model realized through multiple case studies of varying settings and scales. The study investigated the capacity of each approach in improving teachers' geoscience background knowledge, awareness of local geologically and culturally significant examples, and ability to integrate place-based, field investigations into standards-based curricula. By using both qualitative and quantitative methodologies, the study not only measured the successfulness of each approach but also identified the underlying reasons for specific outcomes. Cross-case study comparisons were made to identify emergent patterns utilized to improve the geoscience teacher professional development model. The outcome is a refined professional development model that can be universally applied to a diverse range of K-12 school communities. The ultimate aim of this work is to improve geoscience literacy, to develop a society with greater capacity to make informed decisions and to sustainably manage natural resources in the 21st century.

1 Unifying Chapter

1.1 General Overview

The broad aim of this study is to improve geoscience literacy and interests in Michigan K-12 students by increasing students' access to activities throughout their educational pathway that enhances geoscience interests, engagement, and learning. To achieve this objective, we developed a model for inservice teacher development (PD) that improves participant geoscience knowledge and pedagogical practices, and ultimately increases the enactment of geoscience related learning experiences in their K-12 classrooms. This approach was taken because of the: (1) ongoing challenge that geoscience is de-emphasized in both teacher education and the K-12 science classrooms; (2) potential effect that engaging teachers have to impact many students, especially when sustained over time; and (3) limited examples of geoscience teacher professional development that focus inclusion of place-based strategies, especially in multiple settings.

Figure 1.1 provides an overview of the steps in this dissertation. To begin, a comprehensive teacher PD model was visualized based on previous geoscience and educational research. The PD model was designed to support teachers of all grade levels and subject areas. Implementation of the PD model was tested through five PD projects in three distinct settings and scales within the state of Michigan, including the: MiTEP EarthCache™ (EC) Program; Western U.P. Virtual Geosite Investigations (VGI) Program; and Nah Tah Wahsh (NTW) Summer Youth Kids Zone, Interdisciplinary Fayette Historical State Park Lessons, and Geoheritage Field Investigations Programs. A case-study approach was applied to understand the effectiveness of the PD model at meeting its intended outcomes and to explore the implications of the program design in each setting. Each research goal was measured by multiple measures to support the validity of the findings through the convergence of information and ensure different perspectives are not overlooked.

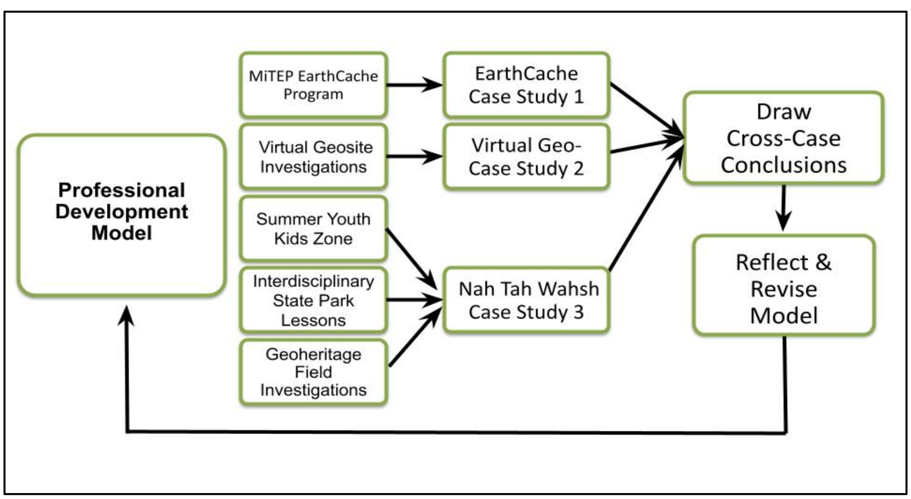

Figure 1. 1. This figure provides an overview of the comparative multi- case study design.

The following chapters describe in detail, and provide empirical evidence for, how the geoscience teacher PD model was realized through five individual programs. The setting, participants, and scale of engagement (i.e., facilitator or community partner effort and time, number of districts, participant time commitment) varied for the PD program. The five programs were organized into three different case studies that are reflective of the partnering school districts. Major conclusions drawn from the cross-case analysis are presented in this chapter, including limitations and considerations for future efforts. Special attention was placed on meeting the unique needs and complexities of school communities that serve large populations of students who are historically marginalized or underrepresented in geosciences. The purpose of this work was not to "prove" empirically that the PD model "works," but rather to uncover which PD design characteristics, if any, impacted teachers' geoscience understandings, pedagogical abilities, or classroom enactment of geoscience instruction.

1.2 Background

1.2.1 Nature of the Problem

Understanding geoscience concepts and the interactions of Earth system processes in one's own community has the potential to foster more-informed decision making for environmental, economic, and social well-being (American Geological Institute, 2008). The term literacy has been extended beyond its original usage of referring to the ability to read and write. Geoscience literacy encompasses knowledge, skills, and attitudes needed to solve problems (Earth Science Literacy Initiative, 2009). The integration of science and community within education can build enduring public science literacy (Roth and Lee, 2004).

Scientific literacy is especially important for communities with large populations of underrepresented groups (URG) in geoscience such as Indigenous, Black and Hispanic peoples (US Department of Education, 2019). These communities lack degreed scientific expertise that may understand the unique challenges faced by those that live there. Yet the negative health and environmental impacts of geoscience industries, such as resource extraction and disposal, disproportionately impact URG communities. There is a range of geoscience issues, including natural hazards, water quality, and climate change, that are inextricably linked to topics of race, equity, justice, and marginalization of communities (Crushing et al., 2015; Gray and Crofts, 2022; Islam and Winkel, 2017).

1.2.2 Integrating geoscience education in school curricula

Community schools are an ideal place to engage K-12 students in the geosciences because the vast majority of youth have access to public education. National science standards give equal weight to Earth & Space Science (ESS) from kindergarten through graduation (National Research Council, 2012). Geoscience is an interdisciplinary science that combines many concepts, traditions, and disciplines in science. Yet, geoscience learning continues to be inadequate in most K-12 student experiences (Banilower et al., 2018). While there likely exist many nuanced causes for the lack of inclusion of earth science content in standards-based classrooms, one obvious factor is the low percentage of educators with geoscience backgrounds (Wilson, 2014).

Teachers play a crucial and influential role in the lives of students as they help to shape students' critical thinking skills and attitudes about the world around them. Educators have the potential to increase the geoscience literacy of all young Americans. Research shows that, if properly trained and resourced, teachers have a profound effect on student learning and engagement (Darling-Hammond et al., 2020). In spite of that, geoscience is limited in teacher education (Banilower et al., 2018). Even geoscience careers are limited among science teachers and school counselors (Sherman-Morris et al., 2013; 2019). There is a clear need to enhance the limited geoscience content knowledge and available career opportunities of many classroom teachers. This challenge is exacerbated by the limited experience that many inservice teachers have applying pedagogical strategies that engage diverse populations of students. Much is known about the types of educational experiences that can contribute to student engagement. For example, previous research points to a number of strategies, such as place- (Riggs, 2001; Semken, 2017), field- (Unsworth et al., 2012), and inquiry- (Marshall & Alston, 2014) based instruction, that have been shown to positively affect URG students' knowledge and motivation.

1.2.3 **Field-Based Instruction**

Learning outdoors has many distinctive benefits for student achievement beyond what is possible in the classroom or laboratory setting (King, 2008). Teaching and learning through direct experience with nature and through discussions with colleagues in outdoor settings are important components of traditional geoscience instruction at the university level (Mogk & Goodwin, 2012). Unlike classroom and virtual settings, students are able to directly observe processes and experience resulting landscapes, while developing spatial abilities and interpretation skills (Orion, 1993) needed for understanding geoscience literacy principles (e.g., geologic time, Earth systems). Additionally, field-based learning emphasizes inquiry and discovery, promotes higher-order thinking and problem-solving skills, and requires metacognition and the application of knowledge and skills from across the geoscience curriculum (Mogk and Goodwin 2012; Whitmeyer et al., 2009). Learning in the field, connects to the psychomotor domain of learning, aiding the acculturation of novices to the common set of practices that characterize scientific 'habits of mind' (i.e., question asking, evidence-based reasoning) (Kastens & Manduca, 2012) as well as developing objective note-taking, 3-dimensional mapping, and other skills distinctive to geoscience (Mogk & Goodwin, 2012).

The field environment is particularly rich in learning experiences that connect affective and social aspects to cognitive learning. In geologically significant settings, students experience awe and wonder about natural phenomena and are consequently motivated to learn more about the natural environment (Dillon et al., 2006). Learning in the field engages human senses, contributing to memorable experiences and long-lasting learning (Mogk & Goodwin, 2012). Additionally, field-based learning has a strong social component that can break down typical peer-peer and teacher-student relationships through shared field experiences, thus, improving students' group work abilities (Fuller et al., 2006; Petcovic et al., 2014). Field activities can build cooperative learning skills while establishing or strengthening relationships between participating educators (Nugent et al., 2012). If students are properly prepared and the experience is purposefully integrated into the school curriculum, field-based experiences improve knowledge, skills, and interests in geosciences (Birnbaum, 2004; Mogk & Goodwin 2012; Orion 1993; Orion & Hofstein 1994; Riggs 2005).

1.2.4 Place-Based Education

Place-Based Education (PBE) is a particularly useful educational practice in helping link geoscience concepts to societal issues and other disciplines. Broadly speaking, PBE has been defined by Sobel (2004) as "the process of using the local community and environment as a starting point to teach concepts in language arts, mathematics, social studies, science and other subjects across the curriculum. (p. 4)". A PBE approach fits most examples where students learn concepts in the context of significant places and engage in multidisciplinary learning, spanning several academic study disciplines.

Other descriptions of PBE are inclusive of specific elements, such as critical thinking and understanding real-world problems (Smith, 2013), building community and school partnerships (Nagel, 1996), and inquiry-based methods (Woodhouse & Knapp, 2000) as part of student learning. Some literature focuses on time outside in the environment as an essential component of PBE (Leather & Nicholls, 2016). Whereas research applying PBE to augmented reality games (Godwin-Jones, 2016; Squire & Jan, 2007) engages students in problem solving centered on community context using a technological interface. Other PBE advocates insist that action must be a component if ecological and cultural sustainability are to be results (e.g., Gruenewald, 2003b). Further examples of PBE literature include student agency and civic engagement as essential pieces of the PBE model (Lowenstein et al., 2018). Semken et al. (2017) note that PBE should promote student voice and choice to encourage contributions from diverse groups of learners.

The variation of elements that exist in the diverse definitions for PBE could lead to stress for those attempting to engage PBE as a strategy. The Great Lake Stewardship Initiative (GLSI) developed a helpful framework for PBE that is intended to support practitioners to strengthen their practice of PBE over time. The guiding principles and rubric were adopted in this work as a collection of indicators to measure the progress of learning experiences towards the application of place- and inquiry-based methods.

1.2.5 Benefits of Place-Based Education

The widespread benefits of incorporating PBE strategies into schools have been documented in the literature. PBE strategies have been shown to have positive influences on academic achievement, such as scoring better on standardized tests, earning higher grades (Howley et al. 2011; Lieberman and Hoody, 1998), as well as student gains in place attachment, civic competencies, and environmental behaviors (Gallay et al., 2016; Semken et al., 2017). Improved motivation to learn and engagement in courses that employ elements of PBE methods have been well documented (Athman & Monroe, 2004; Bartosh et al., 2010; Goodlad & Leonard, 2018; Powers, 2004). These benefits are also noted in marginalized communities and those with large populations of URG. PBE has been cited to increase student engagement among students from Indigenous communities (Riggs & Semken, 2001) and students in urban areas (DeFelice 2014; Endreny, 2010). Gains in student confidence in science and communication (Semken et al., 2017) and increased career awareness (Billig, 2000) have been less extensively reported for PBE.

PBE has also been shown to have potential benefits for teachers, schools, and communities. Previous research demonstrated that educators who have implemented PBE have: displayed higher levels of mastery of knowledge and skills of their subject matter (Gibson & Puniwai, 2006, Semken & Freeman, 2008); collaborated more with other educators (Powers, 2004); and became more confident (Meichtry & Smith, 2007), energized, and engaged (Bartosh et al., 2010). Also, it has been noted that school districts have benefited from PBE efforts due to their ability to address multiple priorities (Chin, 2001) and build stronger connections with community partners (Powers, 2004). PBE benefits communities including retaining population and preserving heritage (e.g., Brennan and Barnett, 2009) and local systems (Semken, 2005).

1.2.6 Place-Based Education in the Geosciences

The PBE approach has come into use across multiple academic contents. Smith (2002) describes five thematic patterns in his review of PBE efforts, including: (1) cultural studies, (2) nature studies, (3) real-world problem solving, (4) internship and entrepreneurial opportunities, and (5) introduction into the community decision-making process. While not explicit in Smith's review, PBE has emerged as a strategy for learning in the field of geoscience. There is a natural fit due to the inherent transdisciplinary nature of the geoscience discipline as well as the connection of Earth features, processes, and topics related to geographic locations & societal needs (Semken & Freeman, 2008).

Examples of place-based geoscience learning have been well noted in the literature. Published research includes topics related to: sampling and monitoring programs (Dalbotten et al., 2014); geotechnical applications (Gibson & Puniwai, 2006); Earth systems processes and cultural themes (Palmer et. al., 2009); and watershed and ecosystem services (Meichtry & Smith, 2007). Many of these studies have been undertaken at the postsecondary level, which includes research with undergraduate students (Tedesco & Salazar, 2006; Palmer et al., 2009) or pre-service teachers (Adams et al., 014; Lowenstien et al., 2018). Other studies have focused directly on K-12 education (Gibson & Puniwai, 2006; Kuwahara, 2013; Riggs & Semken, 2001) or a combination of both K-12 and postsecondary students (Dalbotten et al., 2014). However, literature on PBE for inservice geoscience teacher education is more limited (Chinn, 2007; Kastens and Manduca, 2012; Russ et al., 2015; Williams & Semken, 2011).

1.3 Geoscience Professional Development Model

Professional development is an ongoing process of education that includes improving teaching practice and providing support activities. There are a wide variety of common PD activities, such as multi-day workshops, single sessions, in-class observation, working with a coach, technology enhancement, and professional learning communities. A 2017 report on the elements of effective professional development (Darling-Hammond et al., 2017), indicates that PD programs should: (1) focus on the teaching of specific curriculum content, (2) engage educators in active learning, (3) support collaboration, (4) showcase models of effective practices, (5) include coaching and expert support, (6) build in time for feedback and reflection, and (7) be of sustained duration over time. Additionally, Bruce et al. (2010) concluded that the PD should be situated within the school and is characterized by a cycle of planning, practice, and reflection.

A teacher professional development model (see Figure 1.2) was developed by combining elements effective of PD with other influential literature on geoscience education and field- and place-based education, as described in detail in the preceding sections. The intended participants of the PD model are educators from all disciplines and K-12 grade levels, not only those charged with earth science standards. The PD model includes two multi-step, overlapping phases: 1) engage schools and teachers and 2) teacher-designed lesson cycle. Each phase is cyclical to create an ongoing system of continuous learning and support, which leads to meaningful learning experiences for all students. The intended short-term goals are to enhance practicing educators' geoscience pedagogical abilities, content knowledge and their enactment of geoscience learning and interest-building opportunities for students (Yoon, 2007; Gulamhussein, 2012). The intended, long-term goals of the PD model are that all students graduating from public schools are geoscience literate and some students choose to pursue a geoscience career.

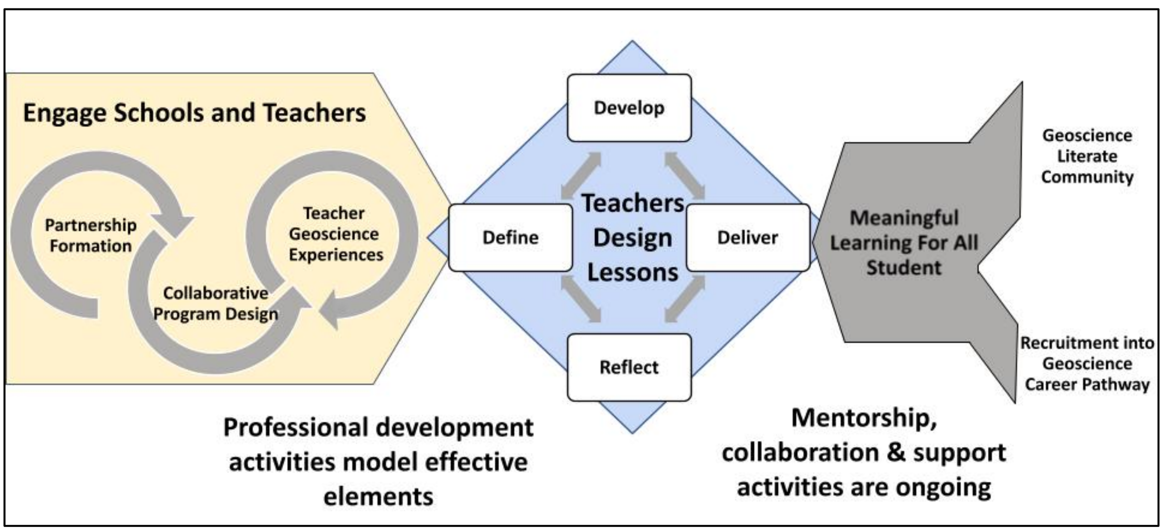

Figure 1. 2.A representation of the proposed geoscience professional development model which creates meaningful geoscience learning for all K-12 students. The PD model includes two multi-step overlapping phases: 1) engage schools and teachers and 2) teacher designed lesson cycle. The intended long-term goals of the PD model are that all students graduating from public schools are geoscience literate and that some students choose a geoscience career pathway.

1.3.1 Phase 1- Engage Schools and Teachers

The goal of the first phase of the professional development model is to engage school and community members in the development and implementation of geoscience professional development. This phase is separated into three steps, beginning with partnership formation, followed by collaborative program design, and concluding with the implementation of a teacher geoscience field experience. These steps are intended to repeat regularly during a periodic timeframe, building off new understandings and interests developed throughout the entire process.

Partnership Formation**:** Establishing mutualistic relationships is an essential component of PBE and is fundamental for building a network of support to ensure that the intended instructional change will be ongoing and sustained over time (Bouillon & Gomez, 2001; GLSI, 2016). Thus, partnership formation, prior to the design or delivery of PD activities, is the first step of the PD model. Involving community partners from the onset of the process can help build understanding in the schools about community needs. Additionally, this step provides PD providers opportunities to understand the infrastructure of the schools and the unique needs of the students, teachers, and community. Potential avenues to engage students in geoscience learning should be identified for various subject areas and grade levels as well as natural opportunities arising within the community. Partnership formation can and should continue throughout the entire PD model, including those identified by teachers while designing lesson plans and by the students through their inquiries in later phases of the PD model.

Collaborative Program Design**:** The next step is to collaboratively design a program that is unique to the school setting and meets the overlapping objectives of the partners. A leadership team is established to lead the design of the PD program. The leadership team is formed from the cooperating partners, including geoscience and educational experts as well as members of the school community. Research on essential elements of PD, PBE, and geoscience learning should create the foundation for the scope and design of the program. Yet, the design must also be synergistic with available community support, school improvement priorities, and what the intended participants perceive as meaningful learning (Darling-Hammond et al., 2009; Riggs, 2005). The collaborative design process may require substantial time and effort, especially at first. Nonetheless, the initial investment is necessary for engaging and supporting instructional change for a wide variety of educators within a single educational setting.

Teacher Geoscience Workshop*:* The final step of the first phase of the PD model is to enact geoscience learning experiences for educators. One goal of this step is to engage teachers as active learners in similar content and strategies as desired in their instruction (Bates & Morgan, 2018; Darling- Hammond et al., 2017). Educators should be provided significant time to engage in these activities outside of the school day (Luft & Hewson, 2014), primarily occurring during the summer and on inservice days within the school year. The teacher workshop is primarily outside of the classroom, in a field-based setting. However, classroom and online learning experiences are also interwoven to practice scientific techniques and other general preparations prior to the outdoor experiential learning (Orion & Hofstein, 1994; Orion 2003; Riggs, 2005).

The specific workshop content is selected based on the identified needs of the individual educators, school, and local community. In this work, both the Next Generation Science Standards (NGSS, 2013) and the Earth Science Literacy Principles (ESLP, 2009) serve as useful guides for participating science and non-science educators (Wysession et al., 2012). The selected content is presented through the context of significant places within the community and region through field experiences. The focus is on local landscapes that are meaningful and accessible to teachers and their students. Utilizing an Earth system approach, content and skills from multiple disciplines are coherently applied to authentically study the interactions and connection between Earth's natural subsystems and the human cultural system (Orion, 2002; Riggs 2005). Discussions with experts and community members are incorporated into the teachers' learning experiences to examine the role of these significant places in the community's history and the present-day way of life of community members (GLSI, 2016). Connections between scientific and Indigenous knowledge are emphasized where appropriate (Riggs & Semken, 2001).

The learning experience is initiated by a problem or series of challenges related to topics of local significance (Almquist et al., 2011). Open-end 'driving' questions, custom data, and other resources are provided to create a learner-center experience. New geoscience content is gained by utilizing process skills (e.g., research, reasoning, computational thinking) to formulate clarifying questions, design investigation, discover new concepts and apply knowledge to address the posed challenge (Larmer & Mergendoller, 2010). In this way, learning becomes self-directed and adapted to the participating educator and the unique setting. The workshop should include explicit opportunities for educators to discuss with each other how the content and strategies that they are learning might fit into their own classroom curriculum (Mansour et al., 2014).

1.3.2 Phase 2- Teachers Design Lessons

The second phase of the proposed geoscience professional development model focuses on supporting teachers to iteratively design student experiences inclusive of concepts and strategies similar to those that educators experienced during the teacher geoscience workshop. Tailored mentorship and other PD activities are provided outside of the school day, to enhance teachers' design expertise (Huizinga et al., 2014). The Teachers Design Lessons phase is separated into four steps: define, develop, deliver, and reflect. Each step has a distinct purpose with specific end products, yet the phase is cyclical where one step builds upon the achievement of the previous step. The process is cyclical through continuous improvement iterations. The design of successful student experiences depends on this phase being ongoing, with iterative refinements based on evaluation and changes in the school system. It should also be noted that it would require educators many years to master the understandings, skill sets, and strategies outlined in the PD model (GLSI, 2016). Thus, it is essential that mentors help educators select a few new learning goals or strategies to attempt each iteration of the Teacher Design Lessons phase.

Define: Educators begin by defining the outcomes of the student learning experiences. Cognitive, affective, and behavioral learning outcomes are all possible in place- and field-based approaches. The desired outcomes should be based on the needs and assets of the classroom setting, students, and community. Thus, the scope of the learning and type of learning achievement will differ for each individual or team of educators. Ideally, educators are interested in defining lessons with extended learning opportunities, which build geoscience content knowledge and skills sets. However, increasing awareness of geologically significant places or careers may make more sense for non-science educators to connect to their classroom standards.

Develop: In this second step, teachers move into developing the student learning experiences. Starting from the learning outcomes defined in the previous steps, teachers use a 'backward design process' to develop meaningful assessments and learning plans (Wiggins & McTighe, 2006). Multiple opportunities for assessments should be included to collect sufficient evidence that students have achieved the desired learning. For example, performance-based assessments could be combined with multiple-choice items to provide robust evidence of gains in students' cognitive knowledge. Whereas a place-attachment or motivation survey could be applied to measure changes in the affective learning domain. Once the assessment tools are identified, teachers should shift into planning the student learning experiences. A number of specific frameworks could be potentially useful for supporting the development process. However, the learning framework must be inclusive of geoscience and place-based elements, such as driving questions, engaging with community partners, and field-based learning. A framework might be selected based on district policies or educational experts' advice during the initial phase of the PD model. For example, in the Nah Tah Wahsh PSA case study, the district had no specific guidance for lesson planning and so the BSCS 5E Instructional Model (Bybee et al., 2006) was selected because of its prevalence in the collaborating university's educational programs. The 5E Instructional Model serves as a flexible learning cycle that engages students with concepts in multiple contexts through inquiry-based approach and supports student understanding as it develops over time.

Deliver: Once learning experiences have been developed, the PD model provides ongoing support for classrooms during the delivery of the student learning experiences. This support will occur via two mechanisms designed to complement each other: mentorship and financial support. The extent and nature of this support are dependent on the needs of the teachers and students. For many, field-based learning may be brand new, and teachers may benefit from having an experienced outdoor educator to support the experience. In other cases, scientific, technological, or cultural expertise may be essential for students and educators as they are engaging in the learning experience for the first time. Whereas other classrooms may need physical resources such as equipment or funding for travel and substitute teachers to lower constraints to implementation. In all cases, mentors provide encouragement to educators to follow through with the instructional changes occurring during this step.

***Reflect*:** Reflection is the final step in the lesson design phase of the PD model. Structured time for reflection is provided and managed through activities such as learning journals or facilitated discussions. Intended reflective responses include impacts on teachers' own learning, their students' learning and the broader benefits to the community (Randel et al, 2016). Opportunities for individual and group reflection have been shown to be an integral approach to deepen learning and enhancement of professional practice (Moon, 2013).

1.3.3 **Phase 3- Meaningful Student Learning**

The third and final phase of the geoscience professional development model emphasizes the importance of fostering a system where students can access meaningful geoscience learning experiences throughout their K-12 educational careers. The aforementioned phases of the PD model are designed to create educational experiences that can contribute to student engagement and interest in geoscience. The PD model is designed to be inclusive of teachers at all grade levels and subject areas to ensure that student geoscience learning occurs at multiple grade levels and within a wide range of contexts. The ultimate goal is to develop a "pathway" for students to become geoscience literate and have the skills to pursue a geoscience career.

1.4 Study Design

Using a multi-case study design, the following questions were addressed. What is the proposed teacher geoscience professional development model's:

1. Impact on teachers' geoscience pedagogical and content knowledge
2. Impact on teachers' inclusion of geoscience and interest-building activities in classrooms
3. Effectiveness in different settings and scales using multiple case studies

1.4.1 **Methods**

Applying a systematic, comparative, multi case-study design (Bogdan & Biklen, 2007), the outcomes of the individual programs are compared to draw conclusions to identify successful design characteristics. Special attention was placed on meeting the unique needs and complexities of school communities that serve large populations of students who are historically marginalized or underrepresented in geosciences. Major conclusions drawn from the cross-case analysis are presented in this chapter (see Figure 1.1).

From 2011-2021, the geoscience teacher PD model was tested through five individual programs including the: MiTEP EarthCache™ (EC) Program; Western U.P. Virtual Geosite Investigations (VGI) Program; and Nah Tah Wahsh (NTW) Summer Youth Kids Zone, Interdisciplinary Fayette Historical State Park Lessons, and Geoheritage Field Investigations Programs. The setting, participants, and topics varied for each PD program. The five programs were organized into three different case studies reflective of the partnering school districts and the scale of engagement (i.e., effort and time commitment). By coming to know each project through an in-depth analysis, this study was able to answer the research questions, as well as draw significant comparisons across the cases and against the research literature.

Each case study utilized a mixed-methods approach similar to those described by Fraenkel et al. (2012). A suite of qualitative and quantitative instruments was employed to measure each program goal to support the validity of the findings through the convergence of information and ensure different perspectives are not overlooked (Morse, 2009; Patton, 2002). The measurement instruments included surveys, content tests, interviews, and archival content analysis. Table 1.1 displays the primary differences in how the methods are applied in the three case studies. The specific protocols, instruments, and schedules were uniquely designed for each situation and in accordance with collaborating schools and other program partners. The details on the collected data and copies of the instruments for each case study are described in more detail in the subsequent chapters and supplementary materials. All aspects of the project research were conducted in accordance with protocols approved by the Michigan Tech Human Subjects Review Committee (see citations in each of the chapters relevant to the work presented).

Table 1.1. Displays the qualitative and quantitative methods utilized in each case study under the corresponding goal. Emergent themes unique to each case study are listed in the final column

Case Study	**Teacher Geoscience Content**	**Teacher Science Skills & Practices**	**Teacher Pedagogical Practices**	**Changes in Classroom Curriculum**	**Other Themes Unique to Study**
MiTEP EarthCache™ Program	Pre/Post & Delayed Post Survey, Interviews, Artifact Analysis	Pre/Post Surveys, Interviews	Pre/Post & Delayed Post Survey, Interviews, Artifact Analysis	Post Survey, Delayed Post Survey, Interviews	Benefits to Public, Artifact Analysis
Virtual Geosite Investigation	Pre/Post Surveys	Pre/Post Surveys	Artifact Analysis, Pre/Post Surveys	Artifact Analysis, Pre/Post Surveys	Technology Competencie s, Platform Benefits,
Nah Tah Wahsh Pathways	Pre/Post Surveys & Tests, Interviews, Artifact Analysis	Interviews, Big Spring, Fayette, Field Notes	Pre/Post Surveys, Interviews, Artifact Analysis, Field Notes	Pre/Post Surveys, Interviews, Artifact Analysis, Field Notes	Effects on Teacher Motivation & Student Learning

The researcher was often a full participant in the implementation of the PD programs as well as in some portions of the data collection process. On occasion, such as in the participants’ classroom, the researcher placed herself in a more distinct position as an observer. It was impossible for the researcher to separate their identity as an instructor from the learning that was observed, so they used the knowledge discovered to enhance and inform their own teaching of the professional development program.

1.4.2 Data Collection and Analysis

The data collection process for each case study was similar and connected to the following phases: (a) pre-program, (b) teacher workshop experiences, and (c) student learning activities. During the pre-program data collection phase, general information about the school and community was collected through qualitative methods including document analysis, field notes, and informal interviews. A pre-survey was also employed prior to the teacher's geoscience learning experience. Surveys included a demographic questionnaire to obtain background information about the participants’ experiences and a mix between Likert-type and open-ended questions. All Likert-type questions in the study asked teacher participants to indicate their agreement with items on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). In the Nah Tah Wahsh (NTW) programs, a pre-content test was also administered to gain a baseline of target content knowledge. The content test was a mixture of multiple-choice and free-response questions.

The teacher workshop data collection phase was conducted during and after the conclusion of the teacher geoscience field experiences. The purpose of this phase was to gain insight into the impacts of the experience on participants. Post-workshop surveys were designed to measure perceived impacts on teacher geoscience-content knowledge, target technical skills, pedagogical abilities, and in some programs, participants' interests. A mixture of Likert-type and open-ended items was used. Field notes were collected throughout the workshop which included participant observations and responses to informal interviews. In the NTW case study, a post-workshop content test was employed to measure changes in targeted content knowledge from participating in the educator field experiences.

The third phase of data collection occurred during or after PD participants implemented student activities developed as part of their participation in the study. In some cases, field notes from classroom observations were conducted during student-learning activities designed as part of the PD model. Additionally, documents developed by the participants, such as instructional plans, field-based learning artifacts and their students' work were collected. Multiple sets of group and individual post-interviews were conducted in both the EC and NTW programs. Interviews took place after lesson implementation to assess participants' perceptions of the projects’ effect on student learning and other research goals. In all cases, interview schedules were prepared as a result of the analysis of surveys, facilitator feedback, and field notes. All interviews were voluntary, lasting between 20-60 minutes and were recorded then transcribed later for analysis.

In all case studies, some data analysis was conducted during the PD programs with the remaining bulk of the analysis occurring after the conclusion of the intervention. The pre-post Likert-type responses were converted into numerical codes (-2, -1, 0, 1, 2) and displayed as frequency distributions. Likert-type survey items were combined into a single composite Likert-scale score for statistical analysis where appropriate (Field, 2009). Open-ended survey questions were coded & grouped. Each interview transcript was analyzed separately using an initial set of codes related to the research questions and allowing additional codes to emerge. Themes or patterns were established based on the codes. A table was developed for each case study to display frequent and co-occurring themes that could support analysis across projects.

Archival analysis was conducted for all three case studies. Documents developed by the participants (e.g., instructional plans, field-based learning artifacts, students work), field notes, and open-ended unstructured interviews were collected and systematically reviewed (Savenye & Robinson, 2005). In the VGI and NTW case studies, a rubric was designed to systematically identify, analyze, and rate the strength of the project at meeting its goals, as observed within the collected materials (see sections 3.4 and 2.4 in the supplemental materials). Each project was scored separately and a table was developed to display the results for further cross-project analysis (see Figure 3.4 and Figure 4.3).

1.5 Case Studies

An overview of the three case studies are presented below. The findings from the individual case studies are then compared and summarized across the research questions.

1.5.1 Case Study: Michigan Teacher Excellence Project (MiTEP) EarthCache™ (EC) Program

MiTEP was enacted in 2011-2014 through a National Science Foundation’s Math and Science Partnership Program. The project goal was to empower urban K-12 teachers to lead their schools and districts through the process of systematically improving earth science education. Four cohorts of participants from three large, urban Michigan school districts engaged in the program, each over a three-year period. MiTEP included both summer and academic-year components and used a variety of on-site, residential, field, and distance delivery methods (Klawiter & Engelmann, 2011). Participants were compensated with stipends and course credit. Following the second year of implementation, the MiTEP EC Program was developed to strengthen the connection between the 2-week field-based summer workshop, including the use of handheld GPS units, and the teachers’ classroom curricula. This case study mainly focused on the addition of the MiTEP EC Program into approximately 9 days of activities during the field course and school year sessions. Participants developed and published educational EarthCache^{TM} activities, in addition to earth science lesson plans. There were 35 educators from the 2nd, 3rd, and 4th cohorts that took part in the case study activities (see Table A.1).

During the beginning of the summer course, participants were introduced to GPS technology, EarthCaches™, and the geocaching website. Over the next two weeks, the educators visited many geologically significant places, learning content from experts framed by the Earth Science Literacy Principles (ESLP, 2009). Inquiry-based lessons were created and published as ECs at three of the field sites. In small groups, the teacher used handheld GPSs and ECs to locate features, apply earth science concepts, and answer logging questions. Then each participant identified one location that they visited during the summer field course to develop into their own EC publication. Teachers were provided with a template and instructor support to develop and publish the EC asynchronously after the end of the field course. The MiTEP ECs met all GSA and geocaching guidelines (Geological Society of America, 2013), but also included additional requirements to foster connections to K-12 standards-based classrooms. Later, during a fall inservice day, the participants used Google Earth (http://earth.google.com) to develop virtual learning experiences focused on the teacher-developed ECs and other geo-significant places they visited during the summer. The MiTEP EC program concluded with a reflection session during a final spring session. Teachers were asked to complete a series of surveys, engage in one or more interviews, and turn in program artifacts (see Table 1.1). Many continued to interact with ECs visitors through the geocaching website well beyond the end of the program. A final follow-up survey was administered in 2021 to understand perceived long-term effects of the program.

1.5.2 Case Study: Western U.P. Virtual Geosite Investigations (VGI)

The Virtual Geosite Investigations (VGI) program took place from 2018-2021, in part during the Covid-19 pandemic. The program goal was to generate student interest and knowledge in geoscience topics and places. The initiative engaged educators from the Western Upper Peninsula in the study of Earth system processes through outdoor and virtual reality explorations at regional geosites. The professional development program was conceptualized and designed during the 2018-2019 school year. During that time, project partners (see Table C.1) outlined collaborative support systems, secured project funding, and developed exemplary virtual field geo-investigation and other program materials. In the summer of 2019, 15 educators participated in a one-day teacher geoscience workshop. During the workshop, teachers engaged with geoscience content through an exemplar virtual field experience and by investigating local EarthCaches™ in small groups. Using information from their field experience, the participants developed their own virtual field experience with technology readily available to them (i.e., 360-degree camera, app, Tour Creator program, Virtual Reality Classroom Kits). Follow-up PD sessions were offered in the fall of 2019, which reached 45 additional regional educators and provided further learning for those that participated in the initial summer workshop.

Five of the 15 workshop participants and two additional teachers went on to develop VGIs and lessons connecting to their classroom curriculum. The creation and delivery of the teacher-developed VGIs began in the fall of 2019. Due to the disruption caused by the Covid-19 pandemic in March of 2020, the program was extended into the 2020-21 school year. Classrooms were supported through mentoring sessions, field explorations with geoscience and educational experts, further 'on-demand' technical sessions, and other coordinated support mechanisms such as stipends and mini-grants. In the spring of 2021, the teacher-developed virtual geosite investigations were shared among participants and other broader public via conferences, further PD and a regional online showcase of student work. Participants were invited to reflect on their learning through a post-program survey. Teachers were asked to complete a series of surveys and turn in their classroom products for archival analysis (Figure 3.4).

1.5.3 **Case Study: Nah Tah Wahsh Geoscience Pathways Program**

This final case study outlines a geoscience pathway program at Nah Tah Wahsh PSA in the rural Hannahville Potawatomi Indian Community located in Michigan's central Upper Peninsula. Partnership formation and program design occurred during the 2012-2013 school year in conjunction with the author's participation in Michigan Technological University's GK12 Watersheds Fellows program. Partners included educational administrators, educators, tribal community program staff, and university education and geoscience experts. Throughout the planning year, the GK12 Fellow visited Nah Tah Wahsh, Youth Services, and other community programs multiple times each month. Three geoscience PD projects were collaboratively designed and implemented from 2013-2015 for various Hannahville educators. In all three projects, teachers engaged in a field-based geoscience workshop and designed student lessons utilizing the BSCS 5E Instructional Model (Bybee, 2014). Following each project, the participants engaged in a lesson debrief and a revision-and-reflection activity. A brief summary of each project is provided below; further details are detailed in Tables D.3-D.5. All participants were asked to complete a series of surveys, engage in one or more interviews, and turn in program artifacts (see Table 1.1).

The first NTW project provided PD for Summer Youth Employment students, aged 14-18, that were supporting 1st-6th grade students in the summer KidZone Program. Throughout the summer the teenaged youth engaged in the project activities for 1-2 days per week. The first phase of activities included a field-based investigation focused on local water resources and hydrological processes within tribal watersheds. The second phase supported the Youth Assistants to develop and implement STEM lessons to the KidZone 1st-6th graders and the creation of water awareness videos for community members.

The second NTW project engaged 9th-12th grade educators in geoscience professional development and interdisciplinary lesson design activities in the context of Fayette Historical State Park during the 2013-14 school year. The park includes several sites of ecological, geologic, historical, and cultural significance. All participants engaged in one day of field-based activities at Fayette State Park during a fall inservice day. Educators explored six locations in small groups by locating and completing inquiry-based educational tasks similar to EarthCache™ activities. In the concluding activity, teachers explored the area on their own, answering guiding questions designed to brainstorm lesson ideas for their own students based on the geosite and their classroom standards. The teacher geoscience field day was followed by a series of after-school, mini-sessions that focused on the creation of collaborative interdisciplinary lesson development, field trip planning, and reflection activities. Working in five pairs, the teachers developed a three-day learning experience for all Nah Tah Wahsh high school students, including one field day at Fayette State Park. Each interdisciplinary lesson connected classroom curricula from two subject areas to topics related to the various geosites at the state park.

The final NTW project involved 4th-12th grade teachers in the summer of 2014 through the spring of 2015. The focus was on enhancing youth engagement in geosciences and use of geosites within grade-level core-science curricula. During the first phase of the project, eight educators and support staff engaged in a five-day, graduate-level field course. Participants spent time in the field investigating several geosites within 100 miles of their school, with university and community experts. Topics were connected to the Earth Science Literacy Principles and Next Generation Science Standards. Additionally, participating educators had the opportunity to engage in authentic scientific studies including a community water budget analysis and karst spring characterization study. During the second phase, five teachers participated in follow-up mini-sessions and mentorship activities to develop lessons that connected geosites to their classroom standards. Fifty-six students engaged in one of five multi-day lessons which included both classroom- and field-based learning activities tied to the NGSS standards.

1.6 Cross-Case Analysis

In order to address the study's research questions, the complete collection of case studies was analyzed by conducting a cross-case search for patterns of design elements and evidence of effectiveness. It was assumed that the triangulation of data, validation, and reliability measures was appropriate to generate accurate and valid case studies from which to address the study's research questions.

1.6.1 Impact on teachers' geoscience knowledge and competencies

This study sought to understand if the proposed PD model improved the geoscience content knowledge and pedagogical ability of participants. Qualitative and quantitative results from all three case studies demonstrated improvements in geoscience content knowledge, improvements in professional competencies, and pedagogical knowledge.

Post-program interview data from EC and NTW revealed perceived gains across a wide variety of geologic principles and concepts, generally centered in the context of geosites visited during the teacher field experiences. These results are corroborated by post-workshop survey data collected from all three cases. In each case, the majority of participants felt the field workshop activities improved their knowledge of Earth systems processes. However, based on survey data, VGI workshop participants perceived more modest gains in content knowledge and skill. This is likely due to the shorter duration in which VGI teachers engaged in exploratory field experiences compared to the programs highlighted in the other two case studies. Further evidence for the ability of inquiry-based, field experiences to build content knowledge is evident in the results of the NTW pre-post workshop content tests. The results displayed in Table 4.2 (see chapter 4) were produced through the quasi-experimental design of the Summer Youth KidZone Project and demonstrate the field course had a small- to medium-effect size on participant content knowledge. The results included participants with limited to medium levels of previous geoscience coursework. Lastly, while limited to only the EC case study, results from the longitudinal follow-up survey show that participants perceived long-lasting increases in their knowledge gains. Data from across all three case studies adds further evidence to field investigations being an important component to build expertise in geoscience (Luera & Murray, 2016; Schiappa & Smith, 2019) and is effective for participants from a wide variety of educational backgrounds and grade levels. There are some indicators that suggest the duration of the field course may be an important factor for the magnitude of content gains and should be considered during the program design.

While the data set is less robust, it should be noted that post-program interviews from EC and NTW also showed that participants perceived having a greater awareness of regional significant places than before the interventions. Extensive interview data from the EC case study suggests that the variety of locations visited during the course was a key characteristic for building awareness of geosites in and around their own community, and recognizing geosites may be quite small and are not always picturesque. These findings bolster previous PBE publications that demonstrate that local places, including urban areas, provide ample opportunities for students to connect geoscience concepts to their community (DeFelice et al., 2014).

The mixed-methods results also indicate that educators in all three case studies gain geoscience content knowledge during the lesson design phase of the PD model. Both EC and NTW post-program interview data reveal that geoscience content learned in the teacher field experience may be strengthened or expanded through the process of developing and implementing student geoscience lessons. Post-program survey results from the VGI case study suggest that delivering learning experiences situated in geologically significant locations improved the participants' content knowledge, regardless of whether the lessons were field or virtually based. Additionally, analysis of teacher-designed EarthCaches™, virtual field experiences, and lesson plans demonstrate participants' mastery of site-specific content. These findings suggest that by participating in the lesson-design phase educators have further opportunities to increase geoscience content knowledge directly related to their classroom curriculum.

Both qualitative and quantitative evidence supports participants' perception that the professional development activities improved teacher geoscience and professional competencies. The pre-post workshop surveys from all three case studies and EC interviews reveal that most participants perceived that the field course improved their abilities to recognize geologically significant features. Some qualitative and quantitative evidence supports participants' perceived improvement in other professional competencies such as confidence in making observations, collecting data, and other scientific practices. Interview and survey data from all case studies also show strong evidence for improvements in each program's target technological abilities, including: GPS, Google Earth, virtual reality equipment, and 360-degree cameras. Utilizing inquiry-based ECs as part of the field course seemed to be especially effective for building geospatial navigation skills with handheld GPS units in the EC study. Whereas, in the NTW program, building virtual learning experiences during the teacher geoscience workshop was an essential element to improve participants' skills to explore geosites with Google Earth and virtual reality software. These results demonstrate the benefit of the PD model in developing both skill and knowledge for teachers from a wide variety of grade levels, even if they have little or considerable content knowledge prior to the course. Observed gains confirm previous studies showing the importance of learner-centered and field-based experiences to increase knowledge and skill building (Fuller et al., 2006; Mogk & Goodwin, 2012).

1.6.2 Impact on teachers' geoscience pedagogical abilities

In all three case studies, mixed-methods results indicate that many educators who took part in the PD model perceived improvements in their pedagogical skills. Evidence from interviews and post-surveys indicate that the majority of participants felt the field activities enhanced their understanding of how to connect geoscience concepts to geosites and increased their ability to teach earth science through a particular place. Moreover, transcripts from EC and NTW post-program interviews demonstrate the teachers' value for post-field workshop activities to further improve instructional practices, including learning to use Google Earth as an educational tool. The VGI post-program survey showed teachers perceived their participation in the PD program supported them to integrate virtual field experiences into their classrooms. These findings were backed by evidence, collected during artifact analysis of classroom products, which demonstrated that the teacher-designed lessons successfully connected their curriculum to geosites, often through multiple disciplines.

Additionally, interview and survey evidence from all three case studies establish that both novice and experienced educators perceived other pedagogical benefits, although specific gains generally varied by project or participants' previous capabilities. Examples of perceived pedagogical gains included increased use of system models, driving questions, outdoor activities, and transdisciplinary instruction. While the evidence is limited, the EC 2021 longitudinal survey indicates that participants perceived the PD effects on their abilities to teach earth science are long-lasting. These findings substantiate previous educational research that shows that providing ongoing support through curriculum implementation can render desired instructional change (Crowley, 2017; Darling-Hammond et al., 2009) and that the geoscience PD model is useful for educators with various levels of previous pedagogical abilities.

The outcomes pertaining to participants' pedagogical gains for the full scope of Place-Based Stewardship Education principles (GLSI, 2016) were less definitive. Results from artifact analysis from NTW and VGI reveal that some elements of PBSE principles were commonly applied across all resulting student activities (i.e., situated learning in the places familiar to students; develop students' social-emotional and professional competencies). Whereas other elements of PBE were largely absent, including building in community action as a consequence of student learning, and creating opportunities for students to participate in public discourse. Upon analysis of the three case studies, it is observed that this pattern is mirrored by those PBSE principles emphasized during the PD programs' teacher learning experiences. These cross-case results indicate that, while the geoscience PD model is successful, there is a need for teachers to engage in further cycles to build on the initial learning experience in order to incorporate the vast aspects of PBSE.

1.6.3 Impact on teachers' inclusion of geoscience and interest-building activities in classrooms

The PD model seeks to increase student engagement in geosciences and build geoscience literacy. Measuring the effects on students was beyond the scope of this study, instead the evaluation relied on analysis of field notes, classroom artifacts, and teacher perceptions of the effects the program had on their curriculum.

Data from interviews, analysis of artifacts, and surveys from case studies showed that increased integration of geoscience and geosites in K-12 curricula was achieved by participating teachers in the programs. Interview data from EC and NTW teachers indicated an increased capacity to develop multi-disciplinary lessons through regional geosites. Analysis of artifacts and field observations corroborates this evidence in all cases and across all grade levels. Most commonly geosites and geoscience concepts were connected to science standards, however many of the classroom examples also addressed technology and English language arts standards. In the NTW case study, the Fayette State Park project showed that Geoheritage sites can provide rich settings that can connect to all subjects including Indigenous culture, mathematics, art, and construction.

Additionally, analysis of field observations and teacher-developed lessons in all three case studies reveal that, in some classrooms, the PD experiences enhanced in-school and school-community partnerships. Providing opportunities to develop these partnerships during the teacher geoscience field experience or follow-up sessions seems to support this process. However, further emphasis on partnership formation would need to be built into the lesson-design phase to create more universally applicable results.

Measuring impacts on student learning was beyond the scope of this project. However, it should be noted that interview data from NTW indicated that the teachers perceived deep learning gains when students engaged in inquiry-based field investigations. The interview data is confirmed by analysis of field observations and student products, particularly where lessons were student-centered, included system models, and connected to real-world topics. The evidence indicates that the model was successful with both novice and experienced teachers in the NTW case study, particularly in the U.P. Geoheritage Investigation project where extensive mentoring was provided during lesson design.

1.6.4 Effectiveness in different settings and scales

Similarities in the cross-case study analysis demonstrate that the PD model may be successfully incorporated into different settings with educators from various grade levels and subject area standards. However, results from interviews, classroom artifact analysis, and participant responses to reflection questions show that the method and extent to which geologic concepts were integrated into curricula varied between and within case studies. For instance, the effect on increasing teachers' classroom enactment of standards-based geoscience content was more modest in some classrooms than in others. Analysis of lesson plans from across the case studies and published teacher-developed ECs, demonstrates that Michigan's Earth & Space Science (ESS) standards were addressed most extensively where teachers were charged with teaching those grade-level standards. Whereas the majority of other teacher-developed curricula had more limited connections to ESS standards, either addressing a single indicator of Earth Science Literacy Principles (ESLP, 2009) or a lower grade level ESS standard. This in itself is not a challenge to the model, as long as the standards-based geoscience content is being addressed elsewhere in the students' K-12 educational pathway. However, if the PD model is being applied to integrate geoscience content into other content areas to address gaps in their ESS knowledge then this finding points to the need to be intentional in the 'Define' step of the Lesson Design phase (see section 1.3.2 above).

Another example of differences between and within case studies is the inclusion of field-based learning activities. Most EC and VGI participants connected students to geosites through Google Earth or virtual field investigations, not directly through outdoor field activities. EC interview and survey data indicated that participants had strong beliefs that having students visit geosites during the class day would be very beneficial. However, most perceived this to be impossible because of barriers in the school systems (such as insufficient time and money for travel and lack of equipment). Whereas the majority of teachers felt that virtually based experiences were immediately accessible to their students. Additionally, when such virtual experiences are accessible to the general public, they can provide ongoing learning opportunities for a wide range of stakeholders. This is especially evident in the EC case study where there have been more than 2,500 logged visits to teacher-developed ECs.

Despite the perception of barriers to leaving the classroom to visit a geosite, there are examples of field-based student learning experiences present in all three case studies. The cross-case analysis uncovered that two common supports were provided in each example. First, the teachers had both administrator and financial support for engaging in activities outside of the classroom. Second, in each case, participants had been provided extended mentorship during lesson design and implementation. Outdoor experiences were not a required component of lessons developed in the EC and VGI programs. However, one teacher in the EC case and two teachers in the VGI case incorporated visits to geosites into the student learning experiences. In addition to participating in the programs outlined in this study, all three classroom teachers were engaged with a regional hub of the Great Lakes Stewardship Initiative (https://greatlakesstewardship.org), which provides mini-grants and mentors for Place-Based Stewardship Projects. Whereas, in the case of NTW, field-based experiences were defined as an essential component of the teacher's developed lessons. The administration at NTW was very enthusiastic about engaging students in educational field trips and had federal financial support for travel costs. Additionally, the teachers had continuous mentorship from the GK12 Fellow similar to that provided by the regional GLSI hubs. While evidence of the student impact is limited, interview data collected in EC and NTW suggests that these experiences lead to high student engagement and deep learning gains (see section 4.6.2. and EC interview).

Interview data from NTW teachers indicated that student interest was widespread among all types of students including those normally unengaged, very active, and high achievers.

1.6.5 Limitations

The review of findings from multiple case studies and with a wide variety of educators provides in-depth understanding of the successes of the geoscience professional development model. However, sample sizes within studies were limited and not conducive to holistic quantitative measures or experimental study design. The agreement between qualitative and quantitative methods, including pre-post tests and surveys, supports the consistency of the findings. Still, the study may not necessarily be generalized to other environments due to the role of the principal investigator within the studies. The researcher-participant role as a program provider was unique, time intensive, and hard to replicate by others. Additionally, testing of each case study occurred over short durations that did not provide opportunities for longitudinal analysis of long-term effects on teachers or students.

1.7 Conclusions and Implications

The purpose of this dissertation was to design and systematically investigate a model for inservice teacher professional development that improves participant geoscience knowledge, pedagogical practices, and ultimately increases students' access to geoscience experiences throughout their K-12 educational pathway. Cross-case analysis demonstrated that the PD model is a promising method applicable to a wide range of K-12 settings. The three case studies presented in the following chapters, provide evidence that the PD model can be successfully implemented with teachers with a variety of educational and geoscience background experience. However, these findings also demonstrate that the extent of the success is based on the scale of financial and mentorship support provided. It is imperative to continue the PD experiences over multiple annual cycles to achieve the full extent of benefits that the PD model has to offer.

Based on the findings of this study, there are important implications for K-12 geoscience teacher professional development programs. Engaging teachers has the potential to impact many students, especially if sustained over time. Incorporating educators, as well as administrators and potential community partners, to collaboratively design the PD program is important for creating learning and support mechanisms that meet classroom and community needs. Including a lesson design phase for teachers to develop curricular materials helps to ensure the successful impacts of the teacher field-based workshops and to sustain classroom implementation. The case studies demonstrate that geologically-significant places are everywhere, including urban areas. Building teachers' awareness of familiar examples and how to connect them to their classroom content through this professional development model was fruitful. The mixed-methods approaches provide insights and stronger measurements of impact, which is especially important for working with underserved populations where researchers and PD providers are often from different cultural backgrounds. Ultimately, the model can provide a foundation for future efforts to increase geoscience literacy and career pathways

The fundamental aspects of the teacher PD Model and the resulting programs could be replicated. However, this approach is not without difficulties that include: (1) the intensive time required for facilitators and teacher participants; (2) the high financial costs of the intervention (3) disruptions caused by teachers leaving the district or being reassigned to new grade level or subject areas, which appears to be on the rise (Goldhaber & Theobald, 2022); and (4) the level of expertise and coordination required to implement such as a comprehensive program.

1.8 Future Work

Based on these research findings, additional studies are recommended to verify the generalizability of the proposed geoscience professional development model. Specifically, efforts should be focused on:

- Developing a more-holistic set of assessment tools that can be used by multiple stakeholders to measure the effectiveness of programs regularly and over time.
- Determining the long-term student outcomes and if there are other influences on the various aspects of student learning which are not addressed in the proposed model.
- Characterizing critical elements of success for fostering long-term transformative partnerships between stakeholders (e.g., universities, schools, out-of-school programs).

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2 Case Study 1. The Impact of EarthCache^{TM} Development as Part of a Geoscience Field Course for Inservice Teachers

2.1 Abstract

A case study has been conducted to understand the effects of integrating visiting and developing EarthCaches^{TM} into the Michigan Teaching Excellence program (MITEP), a three-year geoscience teacher professional development. The program's goal was to increase the content knowledge and pedagogical skills of educators, and, ultimately, increase student access to geoscience learning experience within the school day. Thirty-five K-12 educators from three urban Michigan school districts participated in the study. The majority taught standards-based geoscience or other science curriculum. During a two-week summer field institute, participants learned from experts about earth science concepts & current research developments. The focus was to connect Earth Science Literacy Principles' Big Ideas and common student misconceptions with standards-based education through inquiry- and field-based methods. Starting with the second cohort, educators used the EarthCache^{TM} website, GPSr units and Google Earth to locate and learn about several geosites. Later educators developed and published their own EarthCache^{TM} as a program deliverable. Longitudinal and mixed data collection methods were used to measure the effectiveness of the program. Results suggest that these activities increase teachers' geoscience knowledge, field skills and pedagogical ability to integrate geosites into classroom curriculum. In addition, EarthCaches^{TM} developed by MiTEP teachers provide an ongoing educational resource that builds awareness of geosites and geoscience knowledge in the general public.

2.2 Introduction

Understanding geoscience concepts and the interactions of Earth system processes in one's own community has the potential to foster sound decision making for environmental, economic and social well-being (American Geological Institute, 2008; Earth Science Literacy Initiative [ESLI], 2009). The integration of science and community within education can build enduring public science literacy (Roth and Lee, 2004).

This is especially important for communities with Underrepresented Groups (URG). The negative health and environmental impacts of geoscience industries, such as energy and mineral resource extraction, production, and disposal disproportionally fall on URG communities. There are a range of geoscience issues, including natural hazards, water quality and quantity, and climate change are all inextricably linked to topics of race, equity, justice, and marginalization of URG communities.

This challenge is exacerbated by the expected shortage of well-trained geoscientists for the coming decade (Wilson, 2019), and the fact that the geosciences are the least diverse discipline in science (U.S. Department of Education, 2019). There is a continued call to recruit a talented and diverse workforce (Cramer et al., 2021).

School-age children are an appropriate target audience for improving earth science literacy and interest in geoscience topics. Studies show that the transition of underrepresented minority students into a career in geosciences can begin while students are still K-12 students (Levine, 2007). However, earth science remains relatively de-emphasized in both teacher education and the K-12 science classrooms (Banilower et al., 2018). This is especially lacking in students' education prior to high school. This is despite the substantial appearance of earth science in the National Research Council's Framework for K-12 Science Education (NRC, 2012) and the subsequent Next Generation Science Standards (NGSS Lead States, 2013),

Educators have the potential to increase the number of geoscientists over time, but they also have the potential to increase the geoscience literacy of all young Americans. Research shows that, if properly trained and resourced, teachers have a profound effect on student learning and engagement and play a critical role in establishing and maintaining student involvement in math, science and technology (Darling-Hammond et al., 2020).

Research demonstrates that interdisciplinary, place-based, student-centered, field investigations can effectively increase knowledge and improve attitudes towards science in students from all cultural and ethnic groups (e.g., Geier et al., 2008; Marshall and Alston, 2014; Marshall et al., 2017; Riggs et al., 2007; Semken et al., 2017; Semken and Morgan, 1997; Unsworth et al., 2012). However, many educators charged with geoscience instruction have limited or no background in geoscience coursework (Wilson, 2014). To address talent recruitment needs, a special focus should be on ensuring the inclusion of geoscience education in schools which serve large populations of students who are traditionally underrepresented in geosciences. These issues highlight the need for effective geoscience teacher professional development programs. yet few examples exist in the literature that consider the needs of teachers serving students from URG.

In 2010-2014 the Michigan Teaching Excellence Project (MiTEP) was implemented to address this need. The program was designed to empower urban K-12 teachers to lead their schools and districts through the process of systematically improving science teaching and learning. Participants from three large urban Michigan school districts engaged in the program over a three-year period. MiTEP included both summer and academic-year components, and used a variety of on-site, residential, field, distance, and inservice delivery methods (Klawiter and Engelmann, 2011). The program components were modified each year based on participant and instructor feedback to ensure continuous improvement to achieve the course goals. Following the second year of the program, the instructors observed that many lesson plans developed by teachers did not demonstrate any connections to the field sites or Michigan centric content summer field courses. Additionally, GPS and other geospatial technology skills were not progressing. To address program goals, the MiTEP EarthCache^{TM} Program was developed to incorporate EarthCache^{TM} (EC) development to improve the learning experience and support further integration in their classrooms.

EarthCache^{TM} is a partnership of The Geological Society of America (GSA), Geocaching.com, and other partners around the world to provide and jury a platform for an outdoor "treasure" hunt for geologically significant places using hand-held Global Positioning Systems (GPSs) and smartphone GPS. EC sites are listed on geocaching.com, where members of the general public can locate a geologic feature and complete an educational task related to that place and how it was formed. Visitors can later log their visit by submitting their findings on the website. Members of the general public can develop an EC and submit them for publication consideration. The review process is managed through GSA (Lewis, 2007).

The purpose of this research was to determine the impacts of MiTEP EarthCache^{TM} Program on inservice teachers' geoscience pedagogical ability, content knowledge and teachers' classroom enactment of geoscience. The study used a mixed-methods methodology to identify the success of the professional development program to meet the unique needs of urban educators and complexities of school districts which serve populations with high percentages of underrepresented and economically disadvantaged students. To date, there are only a few articles that focus on the use of EC in education (Hagevik, 2011; Zecha and Hilger, 2015). None, to our knowledge, have studied the effects of including EC visits and development in teacher professional learning. Since this MiTEP EC Program is unique, and the first of its kind, the study employed a case study research design to achieve its purpose.

2.3 Setting

The activities described in this study were part of the larger MiTEP professional learning (http://www.mspnet.org/projects/mitep/library.html), facilitated by Michigan Technological University with funding from the National Science Foundation's Math & Science Partnership Program. More than forty teachers participated among four cohorts. Teachers received stipends and credit for participating in the project and for testing its approach to science-education reform. Although the specific course schedule and content details varied slightly for each of the four cohorts, the overall structure and scope of content coverage was essentially the same for each. Further information about MiTEP and an example of the course schedule is included in supplemental materials.

The components of the professional development (PD) program were modified each year based on participant and instructor feedback to ensure continuous improvement to achieve the course goals. Based on the results from cohort one and two, instructors decided to incorporate EC development and Google Earth tours into the field courses and Pedagogical Content Day (PCD) workshops, as ways to improve the learning experience and support further integration in their classrooms. Summer activities took place during the Earth Science Institute (ESI), a 2-week summer field-based program that was a requirement during the first and second year of the program for all four cohorts. These field courses were designed to introduce geoscience content to Michigan science teachers in an inquiry-based form that could be applied to their classroom teaching. The activities emphasized the development of participants' problem-solving skills and employed inquiry-based learning techniques. An important part of these courses was to utilize tools that research scientists use, and to have educators conduct scientific research. The style of the courses was observational, geographical, descriptive, analytical, and interpretive (Klawiter and Engelmann, 2011).

Table 2.1. Overview of the MiTEP EarthCache™ Program activities and mix-methods instruments. The table displays the placement of each activity within the larger MiTEP program schedule.

MiTEP Schedule	**MiTEP EarthCache™ Program**	**Activity**	**Evaluation Instruments**
Earth Science Institute I *[Note that Cohort 2 teachers experience the EC program during the National Park Internship instead of the ESI 1]*	Visiting EarthCache™ Sites	Introduction to EarthCache™	Pre/Post Visit EC Survey (2012)
		GPS Skills (Waypoint, Navigation)	Site Specific EC Visit Survey (2012)
		Visiting EarthCache™ Sites	
	Developing an EarthCache™	Geosite Selection	EarthCache™ Development Post Survey (2012)
		Visiting the Geosite to Collect Information	
		Developing the EarthCache™	
Pedagogical Content Workshops		Publishing the EarthCache™	
	Integration of Google Earth	Intro to Google Earth	Group Interviews (2011 & 2012) Initial Artifact Analysis of Geosite Lessons (2013)
		EarthCaching with Earth	
	Classroom Implementation	Reflection Activities	
After conclusion of MiTEP	Continuation of Activities Independently	Monitor EarthCache™ & Communicate with Visitors	Semi-structured interviews (2014) Artifact Analysis of Published Geosite Lessons (2018) Post Survey (2021)

Activities in this paper are focused on the addition of the MiTEP EC Program. The program was integrated into approximately nine days of activities for each cohort conducted over nine months of the broader MiTEP program with the second, third and fourth cohorts of teachers (see Table 2.1). The activities associated with the PCD workshops took place onsite within each school district during the school year. In the third and final year of the program, some MiTEP participants completed National Park internships for their capstone experience.

2.4 Participants

The thirty-five educators participating in the study were from Grand Rapids Public Schools, Jackson Public Schools, and Kalamazoo Public Schools. These three urban Michigan school districts serve large populations of students from economically disadvantaged backgrounds and URG in the fields of geoscience (see Table B.1). All of them participated in the second, third and fourth cohorts of MiTEP. Cohort 1 had already completed the ESI courses when this program was incorporated. To be selected for the multi-year MiTEP program, educators were first nominated by district representatives, then underwent an application process, and were selected based on qualifications such as leadership abilities, interest and subject area. The participants had a wide range of teaching experience, and previous experience in geosciences coursework (see Table B.2). At the time of the program implementation, the participants taught grades ranging from kindergarten through high school. Most taught middle or high school science classes. Some participants taught science in addition to other subject areas. Some did not include geoscience content in their required classroom standards. About half of the participants changed positions or schools within six years after the conclusion of the program (Table B.3), some moving to administrative positions, retiring or leaving the education field.

2.5 Program Implementation

The MiTEP EarthCache™ Program began in 2011. The main components of the program (Table 2.1) and their timeline are briefly described below. For further details and examples of the materials provided to ESI Participants see section 1.4 in the supplemental materials.

Phase 1. Introduction to EarthCache™: During the ESI summer course, participants engaged in a short session where instructors introduced EC and the geocaching website as well as GPS technology. The use of handheld GPS units was integrated throughout the two-week field course with teachers being asked to take waypoints at each of the Geosites that were visited. After a few days of basic GPS practice, teachers were split into small groups and asked to visit two ECs that were developed by the course instructors based on field sites and content that had been part of previous ESI courses. The intent was that the published ECs would create a guided inquiry experience to learn earth science concepts and GPS navigation skills, as well as provide an example of a high-quality EC with connections to the classroom. Two or three additional ECs were visited as part of the second week of the ESI. In addition to the course instructors, other content experts joined the teachers to explore the geo-sites and the Earth processes that shape the feature or phenomena. The application of field skills and content varied from site and topic. Common preconceptions were explored in relation to the geoscience content and the ‘Big Ideas’ of the Earth Science Literacy Principles (ESLP).

Phase 2. Selecting and Visiting Geosites during summer field experiences: After visiting the example ECs, each participant then identified one location that they visited during the summer field course to develop their own EarthCache™ publication. Cohort two (Summer 2011) participants developed the EC as part of their National Park internship, whereas cohort three and four teachers had the opportunity to develop ECs as part of ESI course activities. Some cohort three and four participants published a second EC later as part of their summer National Park internships. In all cases, teachers visited these geosites with geoscience experts to make scientific observations about the locations' geologic features, "reading the rocks" methodology to interpret the area's geologic history and to take photographs and GPS coordinates. A Geosite Field Collection Form was developed by course instructors to support the collection of necessary information while in the field.

Phase 3. Developing and Publishing an EarthCache™: Following the geosites visit, the participants were expected to develop their own EC to use as a pedagogical tool bridging the gap between standards-based classroom learning, contemporary research, and unique outdoor field experiences. The MiTEP ECs met all GSA and geocaching guidelines (Geological Society of America, 2013), but also included additional requirements to foster connections to K-12 standards-based classrooms including: scientifically oriented questions which guide the lesson; images and diagrams in addition to words to engage various types of learners; descriptions of complex topics were written using "student friendly language"; logging tasks that promote scientific inquiry to solve; description of the lesson connection to the ESLP; and focus on correcting common misconceptions in earth science (Engelmann and Huntoon, 2011). Teachers were provided with a guide for developing an EC, a general layout for the design and instructions on how to publish it online. Academic experts were available to aid participants throughout this process to ensure accuracy of content. Each EC was first submitted to the course instructors as part of the course grade. For EC developed as part of the National Park internship, park staff reviewed the participants' work. Submissions for review and publication were accomplished through the geocaching website. Once published, the ECs were available to the public at geocache.com and mitep.mtu.edu/earthcache.

Phase 4. Follow-Up Workshop: MiTEP facilitators met with participants for a PCD inservice Day early in the fall semester following the field course. The focus of the day was on exploring ECs and other geo-significant places through Google Earth. Participants worked in small groups to complete the interactive "Story of the Gay Stamp Sands" Google Tour and handout. The activity modeled how an inquiry-based geoscience lesson could be designed using a Google Earth tour and published EC sites located in the Keweenaw peninsula. Teachers gained experience using several Google Earth tools to communicate through video and informational text. Working in small groups, teachers were then afforded the opportunity to develop and record Google Earth tours with their own ECs and determine the best theme and manner to arrange the virtual field exploration.

Phase 5. Teacher-Project Reflections and Sharing: Teachers concluded their participation in focus-group discussions and individual interviews to reflect on the influence of the program on their teaching and ways to improve geoscience content and field activities. While also an important component of program evaluation, reflection activities are necessary components to ensure newly learned pedagogy and methods are successfully adopted into the classroom. Some teachers also presented their work at the Michigan Science Teacher Association Conference.

2.6 Study Design

The research was designed to measure the effectiveness of the program at meeting its intended outcomes (see Table B.4) and to explore key characteristics, meanings, and implications of the program in communities with high numbers of underrepresented and economically disadvantaged students. A case study research design using mixed and longitudinal methods similar to those described by (Fraenkel et al., 2012; Gast, 2010) was employed using a suite of instruments to measure each program goal. The instruments included surveys, semi-formal individual and group interviews, and archival content analysis (Table B.4). Combining distinct elements of quantitative and qualitative methodological strategies provides cross-data comparisons that are important to the validation of the results, especially for small-population and nonuniform group-size evaluations (Patton, 2002). Longitudinal methods allowed us to document gains related to continued personal engagement and barriers to integration during and after implementation. Additionally, the delayed survey enhanced reliability of the results by measuring long-term changes in pedagogical practices, content knowledge and classroom practice. All aspects of the project research were conducted in accordance with protocols approved by the Michigan Technological University Institutional Review Board (Project #M0314).

Formative evaluation was conducted throughout the entire MiTEP project to ensure that the program was responsive to the needs of the participants. The EC aspect described in this paper was an outgrowth of the cohort one evaluation, so only cohorts two, three and four participated in this part of the research. Emergent research themes, were established based on the initial review of the field notes, participant work and group interviews. Table B.4 shows which research objectives and emergent themes were measured by the various instruments. The instruments are briefly described below and additional details are provided in section 1.5 of the supplemental materials.

Surveys: During the 2012 summer, ESI I course all cohort four teachers completed a pre-activity survey before the EC visits, a site-specific survey for each of their EC experiences and a post-activity survey after all ECs have been visited. Both cohort three and cohort four participants completed a post-EC development survey at the conclusion of the 2012 summer. Finally, in spring 2021, cohorts two, three and four were invited to participate in a follow-up survey to assess the teachers' sense of self-efficacy after having adequate time to modify classroom practices.

Surveys included a demographic questionnaire to obtain background information about the participants' experiences and a mix between Likert-type item and open-ended questions. Likert-type item questions were a series of four or more questions measuring the same single variable (e.g., skill, knowledge). Each Likert-type question asked teacher participants to indicate their agreement with items on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The Likert-type items were combined into a single composite Likert-scale score for statistical analysis where appropriate (Field 2009).

Interviews: Focus-group interviews were conducted in fall of 2011 with cohort three to gather initial feedback on the program, and in spring 2012 with both cohorts three and four to gather more comprehensive results. The groups consisted of 6-8 participants from the same cohort. Interviews were conducted by MiTEP team members. These types of interviews are useful for getting high-quality data in a social context where people can consider their own views in the context of the views of others (Patton, 2002, p386). Group interviews have limitations, though, including the possibility that a participant with a minority viewpoint may not speak up against a dominant viewpoint or personality and therefore may not be useful for "the micro-analysis of subtle differences" (Krueger, 2009).

In 2014, individuals from each cohort were selected randomly and follow-up semi-structured interviews were conducted by the researcher to assess the long-term effects of the intervention, including whether EC-like activities had been incorporated into classroom practice. One limitation to this method is that not everyone was interviewed, so there is the possibility of skewed information that is not representative of the group; interviewer bias may be a factor as well.

In all cases, interview schedules were prepared as a result of the analysis of surveys, instructor feedback and field observations. All interviews were voluntary, lasting between twenty to forty-five minutes and were recorded then transcribed later for analysis. Analysis of interviews was conducted to better understand which teachers are more likely to benefit from this kind of program and any influence on teacher use of place-based pedagogy or geoscience integration.

2.7 Results

2.7.1 Archival Analysis

Archival Analysis of Published Geosite Lessons by MiTEP Participants– 2021: Between 2011-2014, participants successfully published a total of forty-seven geosite lessons on the MiTEP website. Forty-one of which were published as official ECs on the geocaching.org website (see Table B.5) The geosites were distributed throughout the state of Michigan, including: seven sites in three National Parks, sixteen within the communities of Houghton-Hancock area, twenty in the surrounding Keweenaw Peninsula, and four in the Lower Peninsula. Finding ECs in a place like Western U.P. was relatively simple, as they are abundant and a rich sense of place exists. However, the examples in the Lower Peninsula demonstrates that geosite lessons can be done in any area. A full list of published sites and a link to their website are located in section 1.7 of the supplemental materials.

As of June 2020, there were over 2,849 logged visits to the forty-one ECs published on the official geocaching website. Table B.5 in the appendices shows the resulting statistical breakdown of the visits per site. There was an average of sixty-nine visits to each site in the six to nine years following their publication. The range of visits annually varies from nineteen to two per site. ECs developed at the National Parks and near higher populated areas have more visitors than those in more remote, less populated areas. Analysis of published geosite lessons shows: use of scientifically oriented questions to guide investigations; ability to use images and models to conceptualize geologic concepts; ability explain complex ideas in everyday language; ability to follow professional standards of peer-review processes; conceptualize geologic concepts focused on connecting ESLPs to local place-based examples; and address common misconceptions in geoscience.

2.7.2 Surveys

Visiting an EarthCache™ Survey Site Specific Post Survey- C4 2012: Results displayed on Table 2.3 demonstrate that the majority of the participants perceived that visiting the three EC sites as part of the field course improved their ability to interpret geologic features (85% agreed), improved knowledge of geoscience processes and concepts (88% agreed) and enhanced their ability to connect classroom concepts to geosites (93% agreed). Questions related to navigation ability were only collected from two of the three ECs because participants did not have the opportunity to navigate on their own to the Woods Lake site for logistical reasons. The results show that the majority of the participants perceived that visiting the EC sites as part of the field course improved their ability to navigate with maps (90% agreed) and to navigate with GPSr units (97% agreed). There was less agreement for the activities' ability to improve their use of a compass (75% agreed).

Visiting an EarthCache™ Survey Pre/Post Survey- C4 2012: The results from the Visiting an EC Pre/Post Survey (n=15, 100% Completion rate) demonstrate that the majority of the participants perceived that visiting ECs during the summer field course increased their experience of identifying processes that shape a geologic feature (see Figure 2.1). These results are not statistically significant due to the low sample size but do provide some indication of how teachers perceived their change in ability due to visiting the ECs.

Additionally, results from an analysis of the five-item composite variable on the pre/post survey show that participants perceived that their geospatial navigational skills were improved through the EC visits (See Table B.6). The Cronbach's alpha values were above 0.73 for the composite variable for both pre- and post-survey results, suggesting that the items have acceptable internal consistency and allowing the mean to be used in statistical tests. The results from a t-test demonstrate a difference in pre/post mean 1.33 ± 0.88, $p < 0.05$ and indicate that there was a statistically significant improvement in geospatial navigational skills.

*Table 2.3. Results from the Visiting an EarthCache™ Site Specific Post Survey displaying the percent agree or disagree and, in parenthesis, the number of responses for each category on the five-point Likert-type survey. The survey included 43 responses from 3 sites with a 95% completion rate. *Only 28 responses from 2 sites collected.*

Item/Measure (# of questions)	Strongly Agree/ Agree	Neutral	Disagree/ Strongly Disagree
Improved Geologic Interpretation (3)	85% (110)	8% (10)	7% (9)
Improved knowledge of earth science processes and concepts (1)	88% (38)	12% (5)	0% (0)
Enhanced understanding of connecting classroom concepts to geosites (1)	93% (40)	5% (2)	2% (1)
Improved ability to navigate using a compass* (1)	75% (21)	11% (3)	14% (4)
Improved ability to navigate with a map* (1)	90% (26)	3% (1)	7% (2)
Improved ability to navigate with a GPSr unit* (1)	97% (28)	0% (0)	3% (1)

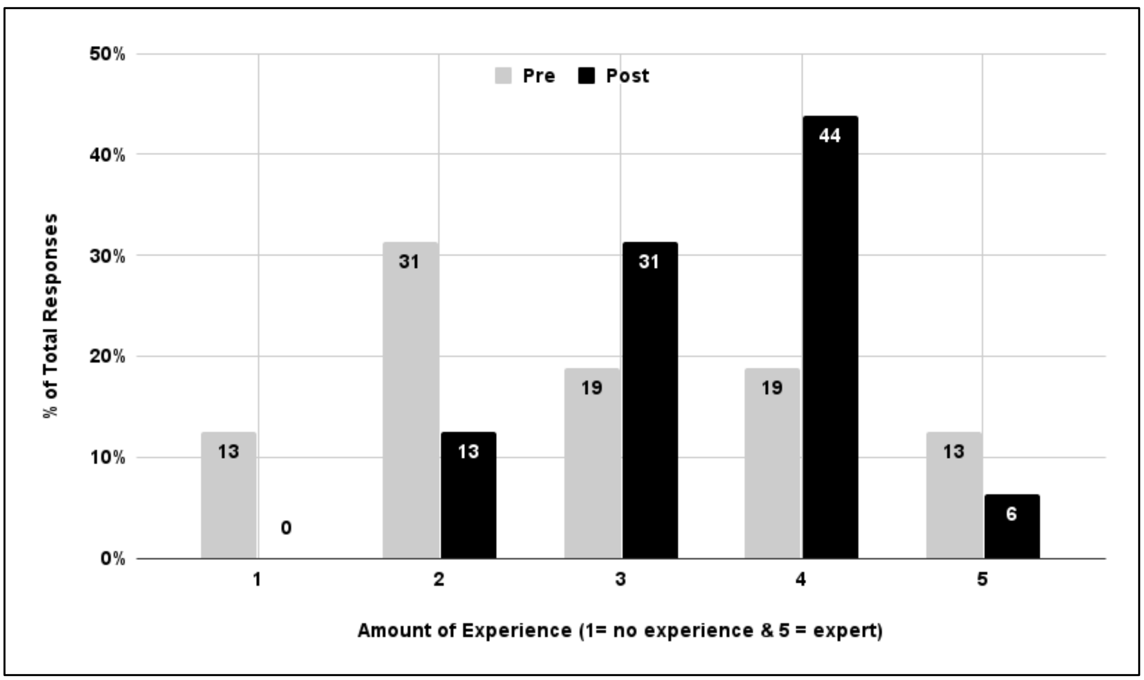

Figure 2.1. Results to the 2012 Pre/Post Visiting EarthCache™ Survey (n=15, cohort 4 only) item: Identifying Processes that Shape a Feature.

Responses to open-ended questions on the Visiting an EarthCache^{TM} Post Survey show that all participants perceived that they would consider visiting an EC again in the future (see Table B.6). The majority of those responses indicated that participants felt that visiting EC sites was an educational experience (73% of responses) that could contribute to their understanding of geoscience concepts and/or build awareness of regional geosites that could be used as examples for their standards-based classroom.

Developing an EarthCache^{TM} Post Survey- C3 and C4 2012: Table 2.4 displays the results of the Developing an EarthCache^{TM} Survey Post Survey which indicates that the majority of teachers (92%) perceived that by developing an EC as part of the summer course, they improved their geoscience content knowledge including increased understanding of geoscience concepts, awareness of Michigan geosites, and understanding of how geologic features provide evidence of geoscience processes. Additionally, the results also demonstrated that the majority of teachers (90%) felt that developing the EC helped them to develop field skills such as recognizing geologically significant features, and gaining confidence in collecting observations and data about geologic features. The survey results show that participants reported lower, yet strong, agreement, (84%) with the program's influence on improving pedagogical abilities such as the ability to communicate about geoscience concepts, and connecting science concepts to geosites. While the results are limited due to sample size, the item response frequencies show that middle school teachers tended to agree the activity had more effect on their pedagogy than high school teachers. See section 1.6 in the supplemental materials for selected response frequencies for more details on the collected data.

Table 2.4. Results from Post Developing an EarthCache^{TM} Survey displaying the percent agree or disagree and, in parenthesis, the number of responses for each category on the five-point Likert-type survey.

Item/Measure (# of questions)	Strongly Agree/ Agree	Neutral	Disagree/ Strongly Disagree
Improve content knowledge and geosite awareness (3)	92% (86)	4% (4)	3% (3)
Foster field and observational skills (2)	90% (56)	5% (3)	5% (3)
Improve pedagogical skills (2)	84% (52)	13% (8)	5% (3)
Visiting an EarthCache^{TM} would be beneficial to student learning (1)	84% (26)	13% (4)	3% (1)
The EarthCache^{TM} I developed is a valuable community resource (1)	97% (30)	3% (1)	0% (0)
Developing an EarthCache^{TM} is a valuable experience for teachers like me. (1)	90% (28)	10% (3)	0% (0)
The EarthCache™ I developed provides useful information for other teachers like me. (1)	77% (24)	23% (7)	0% (0)

Table 2.4 shows that the majority of the participants indicated that visiting the EC would be beneficial to students (84%), and that the EC they developed was of value as a community resource (97%). Results also demonstrated that participants perceived that developing the EC was a useful experience for themselves (90%). While the majority (77%) also agreed that the EC they developed was useful for other teachers like themselves, more (23%) responded 'neutral' than on other items in the grouping.

A breakdown of the item's response frequency shows a division in responses based on participant's background in geoscience coursework. All fourteen participants with more than five courses either agreed or strongly agreed with this item. Whereas seven of the sixteen participants (44%) with five or fewer previous geoscience courses responded as neutral to their perception that the geosite lesson they developed would be useful information for a teacher like themselves.

2.7.3 Interviews

2012 Group & 2014 Semi-Structured: Table 2.5 displays the frequency that themes and their corresponding sub-theme occurred in group or individual interviews. These were not the only co-occurring sub-themes but those occurring at the highest frequency and widest distribution throughout the interview. Table s1.11 in the supplemental materials provides more extensive results for the identified sub-themes including participant quotes which highlight specific narratives that provide further context. Evidence from interview data indicates that participants continued to interact with the EarthCache™ website after the program for two reasons: 1) visiting ECs with family or friends for recreational reasons, either on vacation or close to their home or 2) to learn more about geosites for use with students. Transcripts reveal that participants perceived that visiting the EarthCache™ website enabled their continued growth in awareness of geosites and related geoscience concepts (see Table 2.5. Cont.).

A goal of the course was to bolster teacher knowledge of geoscience content & practices. As shown in Table 2.5, results indicate that the majority of participants perceived that the inclusion of the program activities in the summer field course: built knowledge of regional geosites that they did not previously have; led to a greater understanding that geosites exist everywhere including in urban areas or sites within or close to their school community; positively impacted their earth science content knowledge; and increased their understanding of crosscutting connection to other content areas (e.g., social studies, math). Additionally, the majority of participants perceived more in depth and long-term learning gains were associated with their project geosite than in other aspects of the summer course. The results also show that many participants perceived that the program activities led to the ability to successfully interpret new geosites and use GPSr and Google Earth technologies to explore geologically significant places after the conclusion of the program (see Table 2.5). The interview data included participants who indicated they had little or no previous experience with these skills prior to the course. While more limited, some transcripts indicate that teachers perceived that participating in the program activities, including the EC publication process, expanded their ability to ask scientific questions, conduct research, and communicate science.

Another objective of the program was to strengthen pedagogical abilities including participant understanding of the social, political, cultural and physical environments in which students are asked to learn, one of the four components described by Cochran et al. (1993). Results demonstrate strong agreement of a perceived increase in ability to develop meaningful learning experiences using geosites and other places significant across all cohorts (see Table 2.5). The specific details of the perceived enhancements varied by individual or group throughout interview transcripts and included formal and informal settings. While not as widespread, some results also indicated that participants perceived the activities supported the development of other pedagogical skills such as effective question asking, inquiry-based instruction and facilitating learning experiences from a distance. Many interviews captured teacher perceptions that the program activities taught them how to use Google Earth and its features as a classroom method vehicle for virtual exploration of significant geosites (see Table 2.5).

Data from all interviews indicates that teachers perceived their students would benefit from learning experiences similar to those in the MiTEP EC Program for a variety of reasons including: increased student engagement; building student sense of place/community; opportunity for authentic assessment through project-based activities; and community-based learning (see Table 2.5). However, these same results also indicated that most teachers perceived that there were many obstacles that make traditional EC activities impractical to implement in most school settings. The most frequent perceived barriers included: lack of administrative support; time and monetary difficulties to visit ECs off-campus; lack of access to GPS or computers for students; limited number of published ECs in the school community; difficulty finding geosite that match their rigid curriculum requirements; and limited time in single-subject courses to develop ECs (see Table 2.5).

Despite barriers, transcripts reveal the extent and manner in which teachers perceived they intended to or did adjust their classroom curriculum to include modified, "EarthCache-like" activities. The 2012 group interviews provided the initial results of whether teachers were incorporating new strategies attributed to the MiTEP EC program, whereas the 2014 semi-structured interviews provided more concrete results. As shown in Table 2.5.Int., there were three types of student engagement with geosites that emerged during data analysis. First, the most commonly occurring type of classroom integration was engaging students in content through virtual visits to geosites through Google Earth and/or through photographs and collected samples. The second type of classroom integration included students visiting significant places to learn content as a class or on their own. The final and least common type of classroom engagement reported was having students research geosites and/or develop educational materials about significant places that they visited. See Table s1.11 in the supplemental materials for specific examples.

Table 2.5. Display of the most common research themes and their corresponding sub-theme appearing in group or individual interview transcripts These were not the only co-occurring themes, but the highest frequency. The following language was applied to describe the number of interviews in which the theme occurred: All = 3/3 or 6/6; Most= 2/3, 5/6 or 4/6; Half= 3/6, Some= 1/3, 2/6, or 1/6; None= 0/3 or 0/6. N/A was applied when the timing of the interview would not be relevant for the specific theme (e.g., teachers could not implement activities yet).

	High Frequency Co-Occurring Themes	**2012**		**2014**
		C3 (n=3)	**C4 (n=3)**	**C2, C3 & C4 (n=6)**
Cont	Engaged with EC resources beyond end of the program, leading to continued content growth	Some	Most	Half
CK	Increased awareness of significant geosites (e.g., urban building stone, eutrophic lake)	All	Most	Half
CK	Deeper understanding of the geoscience content specific to the geosite by developing EC	All	All	Most
Sk	Improved navigation skills in GPS and Maps	All	Most	Some
Sk	Ability to use Google Earth to explore geosites	Some	Some	Most
Sk	Ability to identify geosites, including in school community beyond those studied in the course	Some	Most	Half
Ped	Increased ability to teach geoscience through a particular place	All	Most	Most
Ped	Ability to use Google Earth as a classroom tool for virtual exploration of significant geosites	All	Some	Half
Bar	Perceived barriers to integrating official ECs in traditional K-12 classrooms (e.g., time, cost)	All	All	All
Ben	Perceived benefits to including geosite lessons in classrooms (e.g., engagement, authentic assessment)	All	All	All
Mod	Intent and/or suggestion on how to modify EC activities experienced for K-12 classroom	Most	All	N/A
Int	Classroom integration occurred where students experienced virtual exploration of geosites	Some	Most	All
Int	Classroom integration occurred where students visited geosites to explore content outside the school	N/A	N/A	Some
Int	Classroom integration where students researched geosites and/or developed educational materials	N/A	N/A	Some
Com	Teacher-developed ECs built community awareness of geosites and/or geoscience literacy	All	All	Half

Interview transcriptions revealed a common theme that emerged from many participants, centered on the benefits of their work for the larger community and general population. Most teachers perceived that the ECs they developed had positive benefits for the community where they were developed or for those that visited the locations in person or virtually (see Table 2.5. Com.).

2.7.4 **Follow-up Survey**

Responses from the 2021 survey were more limited than any other data collection methods (n=20, response rate 69%). This is in part due to execution of the survey overlapping with the 2020-21 schools year which created substantial added challenges to teachers during the Covid-19 pandemic. Figure B.1. shows that of the 20 respondents, most are regularly or sometimes interacting with visitors that logged their EC on the website and/or have visited the EC website. The majority have visited the EC website often, 55% visited an EC at least once in their own region (55%) and/or outside their region (45%). Only 1 respondent had developed and published an EC after the course. 25% of the respondents indicated that they have never personally conducted any of the aforementioned activities.

The results indicated that only half of the participants were in the same position they were when they started the program. Of the 10 respondents who changed positions 3 are still teaching K-12 in a new district or subject or grade, 5 are working in K-12 education as an administrator/support staff, one had retired and one had left the field of education (see Table s1.10 in the supplemental materials). When interpreting the results of the survey it should be noted that in the 8-10 years since participating with MiTEP 13 of the respondents had worked directly with students for more than 6 years, 4 for 1-6 years and 2 hadn't at all, meaning their answers are not reflective of the program itself, rather than the change in their circumstances.

The responses to the Likert-type items broadly suggested that there was strong agreement about the pedagogical abilities, content knowledge and skills gained from their EC experiences following the participation in the program. Figure 2.2. show that all respondents maintained that they gained knowledge from developing the ECs (100%), and that all participants agreed (80%) or were neutral (20%) that visiting or developing ECs expanded their ability to teach geosciences through a particular place. While there was less agreement overall, the majority of respondents agreed that: developing an EC increased confidence to use geo-significant (90%) and/or Michigan relevant examples in their classroom (90%); and the program expanded their ability to use Google Earth to explore geosites virtually (85% agree; 10% disagree) or as a classroom method vehicle for virtually exploring significant geosites (80% agree, 5% disagree). Results demonstrated that of all the items, respondents tended to agree least with the statement that they still think about the EC Site they developed (80% agree; 5% disagree; 5% strongly disagree). In general, these follow-up statistics were consistent with the teachers' responses to similar items in immediate post program surveys or follow-up interviews.

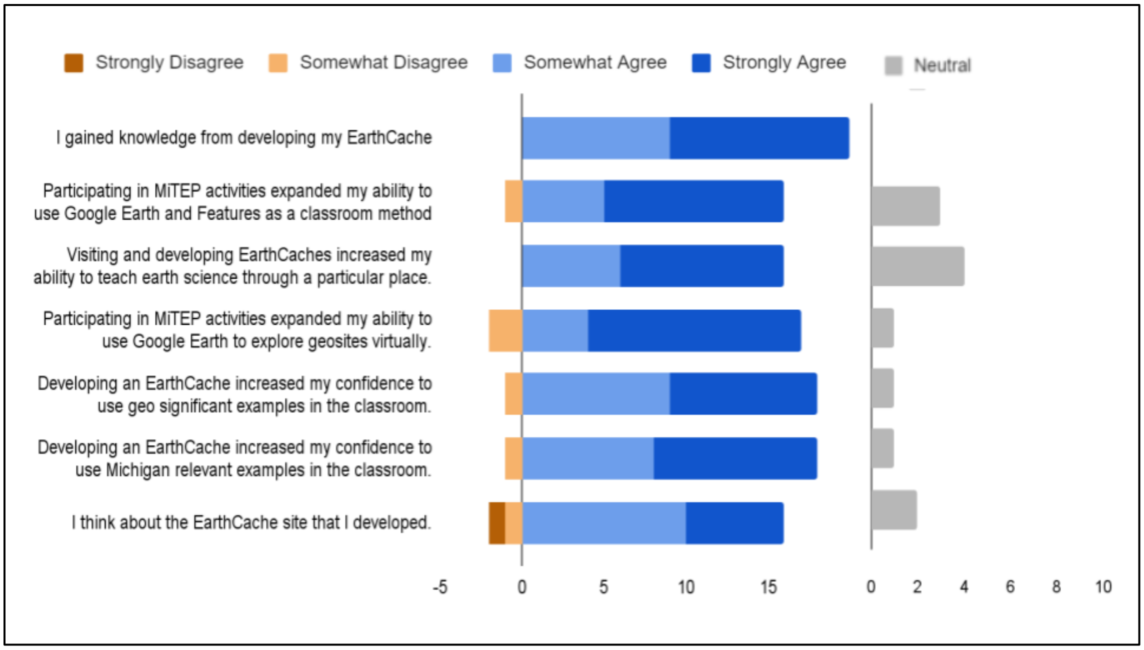

Figure 2. 2. Results from the 2021 Survey (n= 18) Likert-type question: Check all of the boxes that describes how each statement relates to your EarthCache™ experiences following your participation in our program. Note that the data set does not include the two respondents that have not taught since the end of the program.

Figure 2.3 show that the teachers' responses to the Likert-type items suggest that there was modest effect on their classroom practice. Of those that had taught since completing the MiTEP program (n=18) 2 teachers teaching earth science for more than 6 years, one high school and one middle school, perceived that they never connect geo-significant places to the concepts they teach. The remaining connect geosite to concepts often (39%) or sometimes (50%) including those teaching elementary or non-earth science content. The majority of the respondents group sometimes (61%) or often (11%) encouraged students to explore classroom content through an educationally significant place at or near the school yard and sometimes (72%) or (6%) often use Google Earth as a tool to explore significant places with students.

When asked about previously perceived barriers to integrating EarthCaching or similar activities into many classroom settings, participant responses were much more mixed than other topics, indicating that some of these challenges may have shifted over the course of time since the program (see Figure B.2). Lack of funding for classroom field trips and limited time due to strict curriculum requirements are challenges that the majority of teachers agree with. At least half of the respondents agreed that lack of information, limited local regional sites and lack of equipment are barriers to integrating EarthCaching or similar activities into many classroom settings.

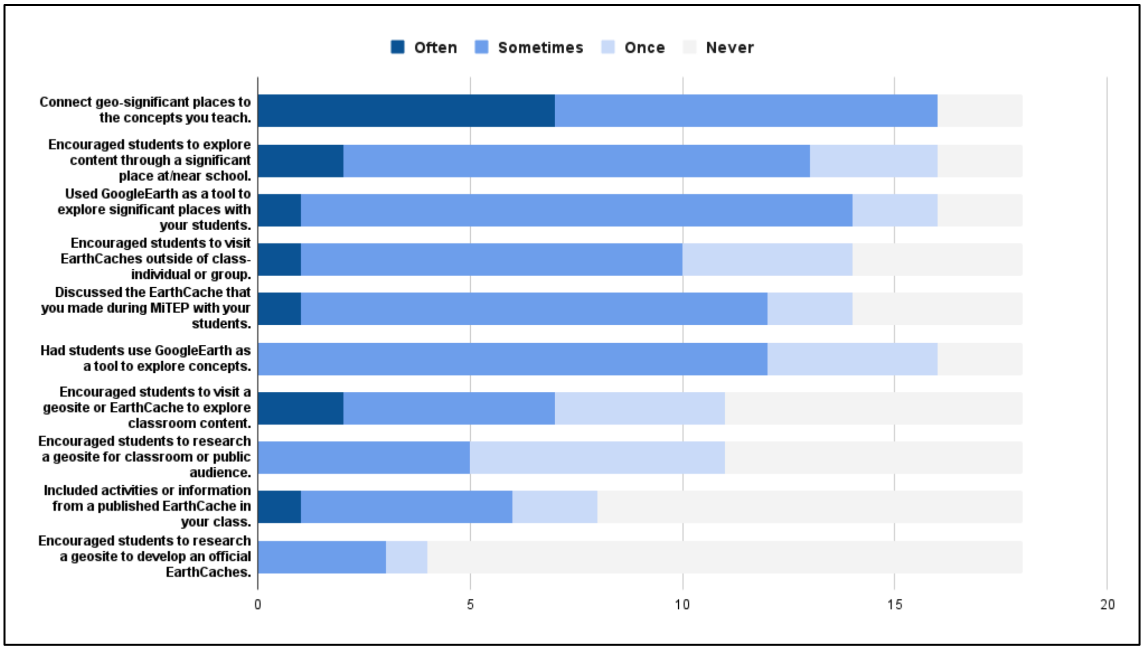

Figure 2. 3. Results from the 2021 Survey (n= 18) Likert-type question: Choose the response that best describes how often you included each of the following in your classroom practice since participating in MiTEP. Note that the data set does not include the two respondents that have not taught since the program.

2.8 Discussion

Both quantitative and qualitative results demonstrated participation in the program had long-lasting benefits on teachers' geoscience pedagogical abilities, content knowledge and, in many cases, increased the integration of geoscience and regional geosites in K-12 classrooms with high populations of underrepresented students. Additionally, the EarthCaches™ and geosites lessons created by institute participants provide ongoing learning opportunities for the general public, further strengthening Earth Science Literacy and awareness of regional geologic examples. Abundant literature exists on the positive effects of learning experiences that focus on field, place, inquiry and integration methods on students' geoscience literacy and practices (e.g., Mogk and Goodwin, 2012), fewer examples focus on summer geoscience institutes for K-12 teachers. This study provides evidence of the effectiveness of integrating EC visits and development of geosite lessons into summer field experience to promote geoscience literacy and place-based pedagogy. Evidence demonstrates that this promising intervention is applicable to a wide range of K-12 settings and can be successfully implemented with teachers with a variety of educational and geoscience background experience.

2.8.1 Effect on Geoscience Pedagogical and Content knowledge

By visiting and developing ECs during the summer course participants were exposed to student-centered geoscience field experiences that led to an increase in geoscience knowledge and abilities. Interview data revealed perceived gains across a wide variety of geologic principles and concepts, generally centered in the context of geosites visited during or after the program. Published ECs demonstrate participants mastery of site-specific content and ability to apply ESPL Big Ideas to geosite content. The results from the 2021 survey data shows that participants generally perceived long-lasting increases in knowledge. Both qualitative and quantitative evidence supports participants' perceived improved spatial navigation skills, abilities to recognize geologically significant features and, to a lesser degree, confidence in making observations and collecting data. Interview and survey data show strong evidence for improved technology skills with GPS and Google Earth. Some transcriptions suggest that the inquiry-based approach of the program was unique from other aspects of the summer course, leading to increased gains. These results demonstrate the benefit of the program in developing both skill and knowledge for teachers from a wide variety of grade levels, whether they have little or considerable content knowledge prior to the course. Observed gains during the program corroborate previous studies (Fuller et al., 2006; Mogk and Goodwin, 2012) showing the importance of field experiences with student-centered learning can increase knowledge and skill building.

Visiting a wide variety of geosites over the field course and MiTEP EC program provided teachers with an opportunity to explore the course concepts in the context of multiple locations and topics. Through that experience teachers were exposed to rural and urban geosites that helped them build understanding of the regional geologic history and the diversity of geosites. Mixed-method results show a perceived increase in awareness of geosites through visiting and developing EC sites. Interview data suggests that the variety of locations visited during the course was a key characteristic for building awareness of geosites in and around their own community, recognizing geosite may be quite small and not always picturesque. Interview data pointed to authentic interpretation experiences and continued access to publicly available ECs supported participants' ability to locate beyond those studied in the course. These results demonstrate the benefit of the program on supporting teachers to identify geosites that can be used in their classroom settings. This adds further evidence to field investigations being an important component to build expertise in geoscience (Luera & Murray, 2016; Schiappa and Smith, 2019) and corroborates with research that states that professional learning should be framed in the context relevant to the community in which educators teach (Birnbaum, 2004).

During the EC program and in other aspects of the summer field experiences, participants engaged in learning experiences grounded in field-, place-, and inquiry-based instruction which support achievement and retention of underrepresented students in the geosciences (DeFelice et al., 2014; Semken, 2005; Semken et al., 2017). The EC program successfully supported teachers to develop a geosite lesson as demonstrated by archival analysis of published lessons and participant comments addressing the value of the lessons for achieving intended learning gains. The 2021 survey demonstrated that most participants (80%) perceived that visiting or developing EC expanded their ability to teach geoscience, none disagreed. Results show that during the course, teachers agreed that the program improved their ability to connect classroom concepts to geosites and increased their ability to teach geoscience through a particular place. Additionally, qualitative results suggested some perceived increase in other pedagogical abilities including inquiry-based learning and use of driving questions. Some teachers described how developing a geosite lesson built their awareness of the number of learning opportunities that can be made at each site and that it supported: *"What question will allow the student to ponder the complete process we are hoping they understand? What question will require that one think critically about THIS place?* (cohort 4 teacher, 2021 survey). This demonstrates the benefits of adding the development of geosite lessons, such as an EC, into the teachers' summer field experience to support place-based and inquiry pedagogy in geosciences.

2.8.2 **Effect on Enactment of Geosciences**

The program sought to increase student engagement in geosciences and build earth science literacy. Measuring the effects on students is beyond the scope of this study. Instead we relied on teacher perceptions and descriptions of the effects the program had on classroom instruction.

The mixed-methods results indicated that the majority of teachers perceived participating in the program increased the integration of geoscience, raised their confidence and use of geosites in the classroom curriculum. It is important to note that this perception was not universally held among participants. Six teachers disagreed or remained neutral on the 2012 survey item- *developing* an EarthCache^{TM} *increased the frequency in which they connect geo-significant places to the science concepts they teach.* Five of those six taught non-earth science subjects including biology and chemistry at the time, perhaps indicating that the geoscience topics explored during the program did not overlap with their classroom standards. Additionally, the one Earth Science teacher that disagreed had extensive previous geoscience college level courses and self-reported that they were already using geologically significant places in most lessons. Despite this, participating in the EC program had a modest effect on increasing the enactment of teachers' classroom enactment of geoscience in their standards-based classrooms. Interview data indicated some, but not all, teachers had incorporated modified 'EarthCache-like activity' in which they visit significant places to learn content through an inquiry-based exploration. The 2021 survey confirms this pattern.

The majority of respondents to the 2021 survey have integrated Google Earth as a tool to explore significant places as a class or with individual students. Teachers' perceptions indicate that virtual field trips provide an important way to access and explore geosites more frequently because their students do not have access to the alternatives due to funding and time constraints. The data demonstrates the importance of including the Google Earth workshop as part of the program in underserved communities and data adds further evidence that virtual field explorations have applications in K-12 settings (Venturini and Mariotto, 2019).

While less frequent, more than half of the teachers reported having students research a geosite or develop educational materials as part of the class since the completion of the program. Authentic student experience supports urban students to identify as scientists (Chapman, 2017), and move towards action in their community (Gallay et al., 2016). Teachers indicate in interviews and surveys that authentic and outdoor experiences are less frequently integrated because of the large time required to prepare compared to other aspects of the program such as utilizing Google Earth or hands-on classroom activities. This demonstrates a limitation to the MiTEP EC program as it did not support teachers and districts to navigate these barriers. However, successes were achieved in one Grand Rapids school, where extra mentor and monetary support for student place-based stewardship projects was provided through the regional Great Lake Stewardship Initiative hub (https://greatlakesstewardship.org/). This example of success indicates that further coordination with community groups with mutual interests could be a beneficial way to amplify results.

2.8.3 Connecting to official EarthCache™

Interviews and the 2021 surveys showed that the teachers often discussed the ECs that they made with their students. Participants' interview dialogue demonstrated value for the being introduced to the official EarthCache™ program. The reasons provided included feelings of professional accomplishment from publishing an EC and value for being able to locate new geosite through the platform, in addition to the development of their own aforementioned content knowledge gains. Additionally, widespread qualitative data demonstrates that teachers perceived that students would benefit from participating in similar EC experiences. Survey and interview results show that teachers commonly encouraged students to visit ECs outside of class, some providing extra credit.

However, only a small portion (22%) had ever encouraged students to develop an official EarthCache™ and none visited official EarthCache™ as part of the school day. These facts indicating that most teachers had difficulties including traditional EC in their curriculum. The 2021 survey data indicates that the cost and time to visit traditional ECs regularly persist as a perceived challenge for those respondents still in the classroom. This is complicated by the fact that official ECs cannot be placed on school campuses due to understandable safety concerns.

2.8.4 Effect on Community

Data from the published EarthCache™ show that vast majority are still used regularly, years later, as educational resources which serve the broader community. There are a large number of people who continue to log visits to the published EC each year. A review of the comments left by visitors indicate that these people perceive value for the knowledge they gain for the geosite lessons that participants developed during the PD including increased awareness of regional assets. Research suggests that local businesses and communities have the potential to benefit from additional tourism connected to people visiting ECs in the region (Dowling, 2013; Zecha and Regelous, 2018). Therefore, the addition of developing an EC as part of teacher field experiences has the capability to provide a long-lasting resource for the local and regional community. Especially with partners such as national parks or non-profit organizations who have synergistic goals to improve geoscience literacy in families and communities. Additionally, the published ECs may serve as curricular materials for future PD programs. This has been the case with the ECs developed near Michigan Technological University, which have been the basis for field explorations of at least five other teacher PD programs.

2.8.5 Limitations

We have documented many successes of the professional development program in this case study and have made suggested improvements based on data analysis. The results of mixed-methods and longitudinal research were used to strengthen the study design; however, these results cannot be interpreted with absolute confidence due to small sample size, limited population and the non-experimental case-study design. While the instruments were carefully designed to measure the effect of adding these aspects on the larger course, the fluidity of the experience from the perspective of participants makes it impossible to separate the specific content, skill or pedagogical gains associated with the EC program from the full summer ESI course or the complete 3-year MiTEP experience.

Longitudinal data from 2021 was helpful. However, only a subset of the full population was able to be reached as many contacts were missing. Since contact information was based on the email from the original schools, those that are still teaching or in that district were more likely to participate than those that are no longer in the same position. This may impact the results.

2.9 Implications

The elements of this program are shared through the supplemental materials including links to EC, program descriptions, and teacher resources. The materials are intended to provide a framework in which other instructors can make the geoscience professional development more relevant to teachers and students. Each aspect of the program seemed to be important for getting to these overall results.

The program and research were designed specifically for inservice teachers in urban and suburban settings who were part of a much larger three-year MITEP experience. While this course is no longer being offered because of the end of the grant funding, aspects of the program have used in additional settings aside from the implementation and evaluation described here including: the 2013 NTW Fayette Historical State Park Field-based Workshop (see section 4.4), a 2013 Natural Hazards and the Human Impacts Field-based course at Michigan Technological University, and the 2019 VGI Field- Based Workshop on Integrating Geosites through Virtual Reality (see section 3.4.2). Evaluation data collected from participants after these programs provided more teacher perspectives supporting the conclusions above (see sections 3.7.1 and 4.6.1). The successes point to the ability of this program to successfully integrate into a variety of inservice professional development programs for educators teaching social studies as well as teachers from rural areas. The program has the potential to be adapted for undergraduate courses and pre-service educators. Other emergent technology applications, such as classroom virtual reality experiences, could be applied.

The fundamental aspects of the MiTEP EC Program and results could be replicated. However, this approach is not without difficulty. For example: (1) managing EC requirements create more logistic and technical difficulties than more traditional deliverables such as lesson plans; (2) identifying EC locations within a close proximity to the field experience with proper permission and other EC requirements; (3) the program requires many experienced experts and personnel in the field to keep everyone safe and comfortable so that significant learning can occur; (4) instructors should model inquiry-based pedagogical approach , yet many university instructors may not have this expertise; (5) complex geosites and phenomena can be difficult for teachers with little previous background in the geosciences; (6) participants must be provided with ample time while at the site, and after the field experience to develop a high quality EC; (7) developing ECs in locations close to participants' school could prove to be especially challenging if the school is located far from the geoscience experts and PD providers; (8) for maximum effectiveness this and other PD programs need to work with participants to overcome any systemic barriers that could inhibit enactment.

2.10 Conclusions

Abundant literature exists on the positive effects of learning experiences that focus on field-, place-, and inquiry-based methods on students' geoscience literacy and practices, fewer examples focus on K-12 teacher geoscience professional development. This study provides evidence of the effectiveness of integrating EarthCache™ and Google Earth applications through the MiTEP EC Program, including strengthening geoscience pedagogical abilities and content knowledge. The PD program supported changes in classroom enactment leading to students engaging in geoscience, including those from populations historically underrepresented in geosciences. Resulting student experiences included visiting significant places to learn classroom content, most often virtually or near school. In some limited cases, students conducted research or designed public educational materials related to community geosites. Mixed and longitudinal methods were applied as part of the case study research design. The data suggests that the integration of the EC program into the MiTEP summer field experiences and following teacher workshops had a measurable positive impact on its participants both in the short and long-term.

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3 Case Study 2. Integrating Michigan Geologically Significant Sites into K-12 learning experiences through Virtual Geosite Investigations: *Examples & Results from Western U.P. Initiatives*

3.1 Abstract

Heavy rains and subsequent flooding in June 2018 altered the visual landscape in the five-counties of the Western Upper Peninsula (Houghton, Keweenaw, Baraga, Ontonagon, and Gogebic Counties), exposing some interesting geological features and leaving a lasting impression upon our communities. This event was used to develop an example virtual reality field investigation that could connect geosciences to the classroom, and served as the starting point for the Virtual Geosite Investigation (VGI) professional development program. From 2019-2021, the program provided training and mentorship support for Western U.P. educators to design similar virtual learning experiences for standard-based K-12 classrooms. The program is based on a geoscience teacher professional development model, developed through a collaborative partnership between the local MiSTEM Network (Region 16), Regional Area Media Center (REMC1), Lake Superior Stewardship Initiative, and Michigan Technological University experts. This research documents the effects of the VGI program to enhance rural educators' pedagogical ability, content knowledge, and increase classroom enactment of geoscience and technology learning opportunities. It also considers the program's unique approach to support teacher-designed virtual reality field-based learning as a means to remedy the obstacles of integrating hard-to-reach geosites into traditional K-12 classrooms. Mixed methods of data collection, including a suite of surveys and artifact analysis, were used to measure the effectiveness of the program. The results demonstrate the success of program activities in supporting a wide-range of teachers from rural schools to design technology inclusive, place-centric learning experiences that address core classroom standards and the Michigan Integrated Technology Competencies for Students (MITECS). The findings point to the efficacy of well-designed PD that provides ample opportunity to employ technology that is available to K12classrooms, and the need for ongoing geoscience expertise that is tailored to the school community to ensure successful outcomes.

3.2 Introduction

A new field-based geoscience program designed for rural K-12 teachers and their classrooms was first implemented in the Western Upper Peninsula (U.P.) of Michigan in 2019. The program differed from other programs in four main ways. First, the program focuses on interdisciplinary connections between earth science and technology literacy by engaging participants in both outdoor and virtual field experiences. Second, the program recruited educators from all subject areas and grade levels, as well as community partners associated with Geoheritage locations within or near the school-community. Third, the program centered on building learning experiences situated in geologically significant places, or geosites, that are familiar to students and communities. Fourth, the program included comprehensive support and professional learning activities, executed through a collaboration of partner organizations. Although the program continues to be implemented, this paper focuses on the program development and the observations to date.

Development of the program was motivated by the well-documented lack of earth science learning experiences available to the majority of K-12 students (Banilower et al., 2018; Wilson, 2014). Yet, understanding geoscience concepts and the interactions of earth system processes in one's community has the potential to foster sound decision making for environmental, economic, and social well-being. While there likely exist many nuanced causes for the lack of inclusion of earth science content in standards-based classrooms, one obvious factor is the low percentage of educators with a background in geoscience (Wilson, 2014). Enhancing pre-service teacher programs is an important way to increase the percentage of qualified teachers entering the K-12 educational workforce. However, there is a declining number of students graduating from university-based teacher education programs and evidence of declining interest among youth in pursuing a teaching career (Aragaon, 2016; King & Hampel, 2018). The strain on the teacher labor market is exacerbated in rural areas such as the Western U.P. that are geographically far from teacher education systems (Goldhaber et al., 2018). School districts in the Western U.P. regions have reported an increase in hiring of non-traditional teachers with limited pre-service training (e.g., P. Witt, personal communication, August 18, 2020), underscoring the need for continued professional learning opportunities for in-service educators. This program focused on increasing the earth science learning opportunities by enhancing practicing educators associated pedagogical ability and content knowledge (Gulamhussein, 2012; Yoon, 2007) that are inclusive of the significant places and local phenomena that are familiar to students.

There are numerous places or events with both geological and cultural significance within or near most communities. These place-based examples can be valuable resources used to engage students in geoscience topics when integrated into existing curricula (Riggs, et al., 2007; Semken, et al., 2017). This approach allows for natural opportunities for interdisciplinary learning experiences for earth science to connect with other content areas through authentic, real-world investigations. In the geosciences, field-based education is valued for its broad development of knowledge, skills, and scientific and professional identities (Boyle et al., 2007; Kastens et al., 2009; Petcovic et al., 2014; Whitmeyer et al., 2009) and for building multidisciplinary and interdisciplinary connections (Anderson and Miskimins, 2006; Barrett et al., 2004). There are many examples of field-based experiences incorporated in inservice teacher training (Crawford, 2007; Luera and Murray, 2016; Wee et al., 2007).

Ideally, field-based geoscience courses for educators would be situated in the places or topics related to the teachers' home school-community and aligned with the policies and resources of the teachers' districts. If this does not occur, participants are less likely to successfully implement the same caliber of learning experiences modeled in the field-based institute, even if they feel they perceive that the course improved their geoscience pedagogical ability, content knowledge and built their awareness of geosites they could use in their classroom. While participants may be interested in including geosites in their classrooms, they are unable to make the necessary changes within the constraints of the school schedule, course content, and available resources (Luera & Murray, 2016). These statements are based in part on previous research conducted by our department on field-based summer institutes for urban educators (see section 2.8.2). In that study, interview data showed that educators perceived that including learning similar to what they experienced in the field-course would positively impact student learning. However, educators described a wide variety of barriers to implementing field-based lessons in their classrooms, including lack of resources and planning time, need to teach to the test, and distance to sites. Longitudinal data from the study showed rapid turnover in teaching assignments, with the majority of participants no longer in the same positions as when they took the course.

The program in this study was designed to remedy the obstacles of integrating geosites into standard-based K-12 classrooms, including creating professional learning sessions built around utilizing the supports and resources available to teachers when they return to the classroom. Additionally, the project will engage the use of virtual field trips. There is abundant literature on the use of the available technology to support the integration of significant locations into the classroom (e.g., Alizadeh, 2019; Cheng & Tsai, 2019; Kippel et al., 2019; Woerner, 1999; Yildirim et al., 2020), this program will explore how students and teachers can engage in the building of those virtual field experiences. Program development was further shaped by the specific needs and assets of rural educators and students. The design was also informed by the overlaps in science and technology education frameworks adopted widely by school districts, as well as with the research in place-based stewardship (Marckini-Polk et al., 2016).

The overarching goal of this research is to determine the impacts of integrating select strategies into regional based, in-service teacher training and system supports. The intended outcome was to enhance rural educators' pedagogical ability, content knowledge and increase classroom enactment of geoscience and technology learning opportunities. This paper details the program design which 1) modeled place-based, inquiry learning experiences that integrated technology and earth system concepts and applications, and 2) provided ongoing mentorship and resource support for classrooms. Findings are presented, including limitations and considerations for future efforts. Examples and classroom products are included in the paper or supplemental materials to provide context.

3.3 Setting

The program was open to all K-12 educators and informal educators serving students from the Baraga, Gogebic, Houghton, Keweenaw and Ontonagon counties in the rural region of the Western Upper Peninsula of Michigan. These five counties each have a high childhood poverty rate (children defined as under 18 years old). In 2018, the childhood poverty rate for each of the counties was Baraga (21.0%), Gogebic (26.8%), Houghton (15.5%), Keweenaw (18.6%), and Ontonagon (25.0%) (The Annie E. Casey Foundation, 2018). In addition, these five counties have a higher representation of Native American students (5.13%) than the state overall (0.6%) (Center for Educational Performance and Information [MCEPI], 2019; and MCEPI, 2020). There are two tribal entities in the region: the Keweenaw Bay Indian Community of the Lake Superior Band of Chippewa Indians, located on both sides of the Keweenaw Bay Peninsula in Baraga County and the Lac Vieux Desert Band of Chippewa Indian Community, located at Watersmeet in the western most region of the Upper Peninsula.

The region has many geosites and cultural connections crosscutting a wide variety of geologic processes and historical events. Many of the features have been incorporated into national, state and local parks or preserves; yet many features exist outside of these designated locations and are often unknown to the community. MiTEP EarthCaches provide some examples of these (see section 2.7). Most recently the landscape along the Portage Lake and surrounding areas were modified significantly during large scale flood events in the summer of 2018 (Roache et al., 2020). The 2019 workshop and exemplar resources used these significant locations and events for the context of the summer workshop learning experiences and geoscience topics.

At the time of the offering, the region included 19 different school districts with a total student population of 8,541 students (MCEPI, 2019; and MCEPI, 2020). The schools' curriculum and state assessments are framed by a set of academic and career readiness standards provided by the state of Michigan. Relevant academic standards include Michigan Science Standards (MSS), which is closely aligned to the Next Generation Science Standards, the Michigan Integrated Technology Educational Competencies for Students (MITECS) and Michigan English Language Arts (ELA) Standards.

The school districts in this region are provided a wide range of services through the Copper Country and Gogebic-Ontonagon Intermediate School Districts (ISDs). These ISDs work in close partnership with Regional Area Media Center #1 (REMC1), the Western U.P. MiSTEM Network region #16 of the MiSTEM Network and the Lake Superior Stewardship Initiative (LSSI), a hub of the Great Lake Stewardship Initiative (GLSI). All districts had access to regional resources including 360-degree cameras, virtual reality equipment, computer equipment, software, and technical support from REMC1 resource clearing house (remi.org) and access to LSSI Stewardship Project support including mini grant funding, mentorship and professional learning (http://lakesuperiorstewardship.org/).

The region is home to many community partners, including Michigan Technological University (MTU), a public research university, located in Houghton, Michigan across the Portage Lake from the city of Hancock location of the Copper Country ISD and other lead project partners. There are six colleges, over 20 departments and centers at MTU. Those relevant to this program include the Great Lake Research Center, the Center for Science and Environment Outreach (Civil and Environmental Engineering), and the Geological and Mining Engineering and Sciences Geology Department.

The project in part took place during the Covid-19 pandemic which has had a profound impact on the education system. In March of 2020, students across the region experienced school closures and shifted to remote learning. During the 2021-22 school year, districts were conducting modified, in-person instruction with many schools offering remote options for quarantined and distance learners. Other unprecedented changes, such as shifts to online instruction, limitation on field trips or interactions with community partners, upended typical methods of student learning and impacted students' academic preparations. Many students in the region lack reliable access to the internet or technological devices at their homes. The crisis also affected students' mental health (Leeb et al., 2020) and created unique homelife challenges. These shifts required rapid updates to professional learning and other systems to support the educators to meet their students' needs.

3.4 Program and Implementation

The specific goals for the Virtual Geo-Investigations (VGI) program was to generate interest and knowledge in students and teachers for geoscience topics by engaging them through virtual reality technology in scientific investigation of places that elicit cultural connections and bring real world context to Earth system processes. The project was centered on place-based, culturally centered professional development activities for teachers that demonstrate the authentic integration of technology as well as employ elements of effective professional development to facilitate teacher learning and instructional change. Table C.1 in the appendices provides a logic model displaying an overview of the project resources, activities and outcomes.

The program was led by a team of representatives from four agencies: The Center for Science and Environmental Outreach (place-based stewardship project mentor) and the Great Lake Research Center (research geoscientist) at Michigan Technological University, along with REMC1 (educational technologist) and the Western Upper Peninsula MiSTEM Network (program director) at the CCISD. While each partner's main role is noted in the previous sentence, each member was involved in planning and implementation of program activities described in more detail below. The workshop agendas and resource lists can be viewed in section 2.2 of the supplemental materials.

3.4.1 Program Initiation and Planning: May- June 2019

The program was conceptualized during the 2018-2019 school year when project partners identified overlapping objectives, potential for collaborative resource sharing and other support systems. Prior to the project initiation the team developed research-based, professional learning experiences and accompanying resources and secured a match in funding through Michigan Space Grant Consortium/NASA award program. The program website (see section 2.2 in the supplemental materials) was created to feature activity specific resources related to content, technology and pedagogical practices and program related evaluation and orientation materials.

Program leaders partnered with environmental engineers, geologists, and STEM educators from Michigan Technological University to develop an exemplary virtual field geosite investigation (see section 2.2 in the supplemental materials) for the summer workshop and subsequent support sessions. In October 2018, the group went on a field exploration of sites along the Huron Creek watershed located in the city of Houghton (see Figure 3.1). The purpose of the field work was to describe the resulting features from the June 18, 2018 extreme rain event and subsequent flooding and its impact on the watershed. High-resolution 360-degree and other camera images were collected at each site along with field notes and interpretations from experts.

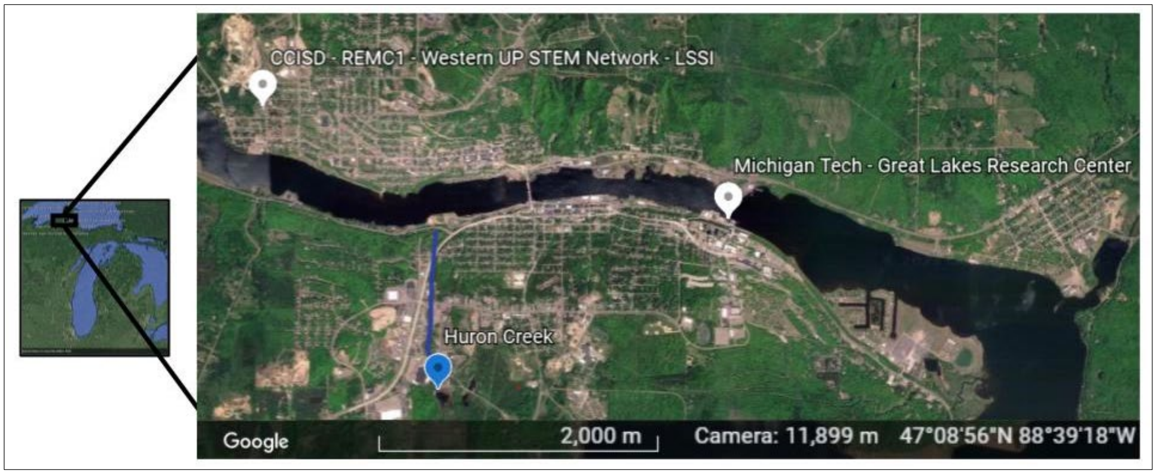

Figure 3.1.Map displays the locations of the coordinating institutions along the Portage Lake in Houghton and Hancock area. The example Virtual Geosite Investigation at Huron Creek is noted in blue.

Following the visit, the project team sketched out the virtual tour, by connecting the target content to the natural phenomena visible at the site with existing data and YouTube Videos from the event. Then using free software, the photos were developed into a virtual tour overlaying still images, sound, data and a map. A teacher narrative and google map with the virtual tour were developed to accompany the virtual experience. This product can be seen on the program website. Partners used established listservs and websites to recruit K-12 science educators from all content areas. Registration was through CCISD General Education department.

3.4.2 Geosite investigations workshop and sessions: Summer-Fall 2019

Summer Workshop: During the workshop participants developed earth system content knowledge through the Huron Creek virtual field experience and while investigating local EarthCaches to develop their own simple virtual field experience. Additionally, educators learned how to facilitate student experiences using technology (360-degree camera, Google Tour Creator program, virtual reality classroom kits) in a meaningful way, and identified geologically significant sites and phenomena in the community that could be connected to their classroom curriculum through virtual field explorations.

Follow-up professional learning sessions: Beginning in fall of 2019 presentations at statewide conferences and further regional sessions were planned and implemented. The regional sessions reached 45 regional educators, many of whom did not attend the summer workshop. For those that had participated in the initial workshop, the follow-up sessions served to further increase target pedagogical and technical skills.

3.4.3 Supports for VGI development and implementation: 2019 - 2021:

The development of VGIs with teachers began in fall of 2019 and continued throughout the project. Classrooms were supported through: mentoring sessions, field explorations with Geoheritage experts, further 'on-demand' technical sessions and other coordinated support mechanisms such as stipends and mini-grants. Details of each participating classroom activities during this time are outlined in Table C.3- C.7., located in appendix C. General activities included selecting and touring a relevant geosite with a community partner or expert related to their curriculum and field experience topic, and engaging with partners and project staff through virtual and face-to-face support sessions to develop and implement virtual field experiences. Classroom teachers were able to select from one of two approaches for incorporating the development of the VGIs into the classrooms either 1) build the field experiences for their students or 2) have the students develop the virtual field experience themselves. The program team met periodically to discuss the progress of the classroom VGIs as well as challenges and solutions, particularly after the onset of disruptions due to the Covid-19 pandemic

3.4.4 Virtual Geosite Investigations shared with the broader public: 2021

The VGIs and other products were shared with participants and interested stakeholders including: schools, families, and community partners via conferences; further professional learning opportunities sponsored by the program partners including LSSI and AGI; and student participation in the LSSI's Lake Superior Celebration virtual project gallery. Teachers and students that had developed VGIs were targeted to participate in or present at events as a way to promote student/teacher voice and leadership opportunities.

3.5 Participants

3.5.1 Summer Workshop

K-12 classroom in-service teachers and informal STEM educators throughout the region were invited to participate in the program. There were 15 participants that attended the 2019 Summer Workshop (see Table C.2) including 11 elementary, middle and high school teachers, three informal educators and one K-12 technology coordinator. Of the fourteen participants that were actively teaching students in the classroom, all but two were teaching some earth science and all but one reported using examples of geologically significant places when teaching at least during some lessons. While the majority taught at least some physical or life science, other subject areas included history/social science, mathematics, technology, and English literature arts.

The workshop participants possessed a broad spectrum of previous experiences with the program's target learning objectives (see Table 2.1 and 2.2 in the supplemental materials). The majority (73%) had no experience with 360-degree cameras and no experience (47%) or limited (26%) with Google Expedition. Ten participants had some personal virtual reality (VR) experience, four had implemented VR experiences in their classrooms at least once, and only two had previously developed VR experiences themselves. 20% of participants perceived themselves to have no experience identifying the processes that shape a geologic feature, whereas 60% considered themselves to have some experience and 13% were well experienced. Only 13% of participants perceived themselves to have no experience using geologically significant places when teaching students, whereas 73% considered themselves to have some experience and only one person (7%) felt they were well experienced.

3.5.2 VGI Development

Five of the fifteen workshop participants went on to develop VGIs as part of their classroom curriculum during the 2019-2020 and/or 2020-2021 school years. An additional two teachers were recruited after the summer workshop by partner teachers or staff. The specific demographics of the participants are outlined in Table C.3-C.7 in the appendices. Prior to their experience, participants were asked what they hoped to achieve by participating in the program. Common answers included: the desire to integrate VR technology into their classroom, build their technological and related pedagogical abilities, increase student awareness of significant places and improve integration of science/earth science into their curriculum.

3.6 Study Design

The research was designed to measure the effectiveness of the program at meeting its intended outcomes (see Table C.1) and to explore key characteristics, meanings, and implications of the program in rural communities. A case study design was applied using a mixed-method approach similar to those described by (Fraenkel, Wallen et al. 2012). A suite of instruments was employed to measure each program goal. The instruments included surveys and archival content analysis. Combining distinct elements of quantitative and qualitative methodological strategies provides cross-data comparisons that are important to the validation of the results, especially for small-population and nonuniform group-size evaluations (Patton 2002). The data collection and sources are briefly described below, further details and copies of the instruments can be found in section 2.3 of the supplementary materials.

Surveys: In 2019 all participants were asked to complete a pre-activity survey before and a post-survey after the completion of the workshop. In 2021, all educators that participated in the development of VGI with their classrooms, completed a post-program survey. The surveys included a demographic questionnaire, and a mix between Likert-item and open-ended questions. Likert-item questions were a series of four or more questions measuring the same single variable (i.e. skill, knowledge, etc.). Each Likert-scale question asked teacher participants to indicate their agreement with items on a scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Analysis of the Virtual Geosite Investigations and field notes: Table C.3 – C.7 were developed to display information about each individual project including: the classroom situation, resources, student activities, strategies, the outputs and impacts. These were developed from teacher responses and facilitator notes that included details of participant interactions, communications and support activities. Artifact analysis of the published VGIs was conducted in 2021 to evaluate the intended learning outcomes and to systematically generate insights on the full implications of the program design. A coding scheme was created and implemented to capture desired information (see section 2.4.1 in the supplemental materials).

3.7 Results

3.7.1 Workshop and Program Surveys

The post-workshop survey results are displayed in section 2.4.2 of the supplemental materials. Participation in the survey was limited (n=4, 27% response rate), the responses represent a sample of the attendees' perceptions of the day-long workshop. Results show that all respondents agreed (2 strongly, 2 agree) that the workshop: was useful, included relevant information, developed their ability to develop VGI that could be used in the classroom, increased their ability to deliver quality instruction to students, and that they would be more likely to teach earth science concepts after their workshop. The post-workshop survey results also demonstrate a strong agreement (1 strongly agree/3 agree) among respondents that the workshop: developed their confidence to connect geosites to the lessons, improved their knowledge of earth science processes, developed their ability to use VR field experiences in the classroom and provided them a useful tool that could be used immediately. All post-workshop survey respondents agreed (4) that the workshop helped develop the ability to recognize geologically significant features of geologic processes that shape the landscape. One participant perceived less agreement with others' strong support (2 strongly, 1 agree, 1 somewhat agree) that the workshop developed abilities to deliver and confidence to develop learning experiences that integrate technology into science and other content areas.

Table s2.3, in the supplemental materials, includes coded responses from the open-ended questions on the post-workshop survey. The results demonstrate that the time to practice was an important component of the workshop for one participant.

> "*Thanks for giving us time to practice with the material. So often lots of information is thrown at us and then we go home, remembering little of what we learned. Thanks for letting us use the materials and for giving us time to process its use (Post Workshop Survey, open response)*."

Other participants indicated that they gained new pedagogical perspectives on how to use Virtual Reality and EarthCaches^{TM} to create engaging earth science student learning experiences. It should be noted that the post-workshop survey responses indicated participants felt they would need further learning and support to successfully develop their own VGI, including: further time to discuss how to implement their own classrooms; support connecting to community partners; ongoing access to technology, content experts, and equipment.

The results for the post-program survey (n=6, 75% response rate) is displayed in section 2.4.3 in the supplemental materials. Results show that respondents agreed (1) or strongly agreed (5) that the experience helped to develop their confidence to design learning opportunities that integrate technology across content areas, and that they were more likely to integrate Earth Science concepts into their classroom because of their participation in the program. All post-workshop survey respondents agreed (3 strongly agreed, 3 agreed) that the experience was useful and had provided educators relevant information. The post-workshop survey results also demonstrate a strong agreement among respondents (4 strongly agreed, 1 agreed, 1 somewhat agreed) that participation in the program improved their knowledge of Earth Science processes and concepts, and helped to develop their use of Virtual Reality Field Experiences in the classroom. Similar to the post-workshop survey, the results were more varied in the respondents' perceptions that the experience helped to develop their confidence to connect geosites to the lessons they teach (3 strongly agreed, 2 agreed, 1 somewhat agreed). Those participants that did not participate in the entire program and were instead recruited by a partner teacher after the summer workshop had taken place indicated lower levels of agreement to the post-program survey statements.

Included in the supplemental materials is Table s2.4 which displays the coded responses from the open-ended questions on the post-program survey. Those results demonstrate that using strategies such as integrating familiar places and providing ongoing support were important components of the program design.

> "*Our project was grounded in outdoor local spaces, encouraging students to visit and experience sites with their families. Our expert partner was also essential support. She was able to connect with students with both knowledge and passion. Her collaboration also motivated and informed me as a teacher (Post Project Survey Q2 open response)*."

Other participants' responses indicated that they gained opportunities to apply target pedagogies by participating in the program, including integrating student voice, learning technology, and other aspects of place-based learning. Additionally, the participants stipulated that to be successful in implementing similar learning experiences beyond the end of the program they would need: continued access to equipment; content and technical experts: further practice with the software; and support incorporating the experience into the classroom.

Improving associated technological knowledge and skills was a goal of the program. Figure 3.2 shows that participants with limited previous experience using associated virtual tour software perceived their experience level increased by participating in the program (a2, a4, a5, b2, b3). Whereas those who reported having prior experience perceived limited or no gains from their participation in the program (a1, a3, b1). The results demonstrate an increase in self-reported experience using 360-degree cameras in all participants except for those that reported having prior experience. Moreover, partner teachers that did not attend the workshop reported having less experience with 360-degree cameras, except where the participant (c1) was partnered with teachers that reported high levels of experience prior to the program. Those attending only the workshop (group b) reported less gains in ability to use the 360-degree cameras than those that participated in the full program (group a).

Other intended outcomes of the program were to increase educators' ability to interpret regional landscapes and to integrate geosites into instruction. The results shown in Figure 3.2 demonstrate that most participants (a1, a2, a4, a5, b1, b2) reported an increase in their ability to identify earth science processes that shape a feature, however two participants with moderate levels of self-reported experience reported no change in their experiences levels (a3, b3).

Additionally, Figure 3.2 shows that survey results demonstrate that all of the participants who participated in the full program reported gains and increase in ability to use geosites when teaching (group a). Of those participating in only the workshop, one reported (b1) a strong perceived increase in their ability, while the others (b2, b3) indicated no perceived change in their overall abilities.

3.7.2 Archival Analysis of Classroom Products and Field Notes

Analysis of the program artifacts shows that over the period of 2020-2021, eight educators and one hundred sixty students participated in the development of 5 Virtual Geosite Investigations The five rural schools that participated were from a variety of classroom settings including: an alternative high school literature and science course, a high school history course, a 6th grade geography and writing class, upper elementary classroom with large populations of Native American students, and a middle school science and technology classroom in a small city.

The VGIs were associated with eleven geosites in Houghton, Baraga, and Ontonagon Counties of the Western Upper Peninsula region of Michigan (see Figure 3.3). All of the VGI locations were situated in an outdoor setting in the same county as the school. Sites included: public lands, private business, historical sites, recreational areas, coastal areas, wetlands, waterfalls/cascades, beaches, and a roadside area. Some examples highlighted multiple locations within a significant geographic area (e.g., Bond Falls) whereas other examples highlighted multiple regional geosite locations with no specific geologic or heritage ties between them (e.g., L'Anse area). Three of the five sites that were connected to community partners were engaged as part of a LSSI Place-Based Stewardship Project

Products from the program were further incorporated into a regional showcase and professional learning experiences. All projects were successfully integrated into a regional event, designed to showcase place-based projects. An estimated 500 students and 25 teachers from 15 school districts were engaged in the activity. Participating students were asked to reflect on their school year accomplishments and consider the similarities to other classrooms. Teachers from two of the projects presented their projects during virtual professional learning sessions, engaging another 25+ formal and informal educators.

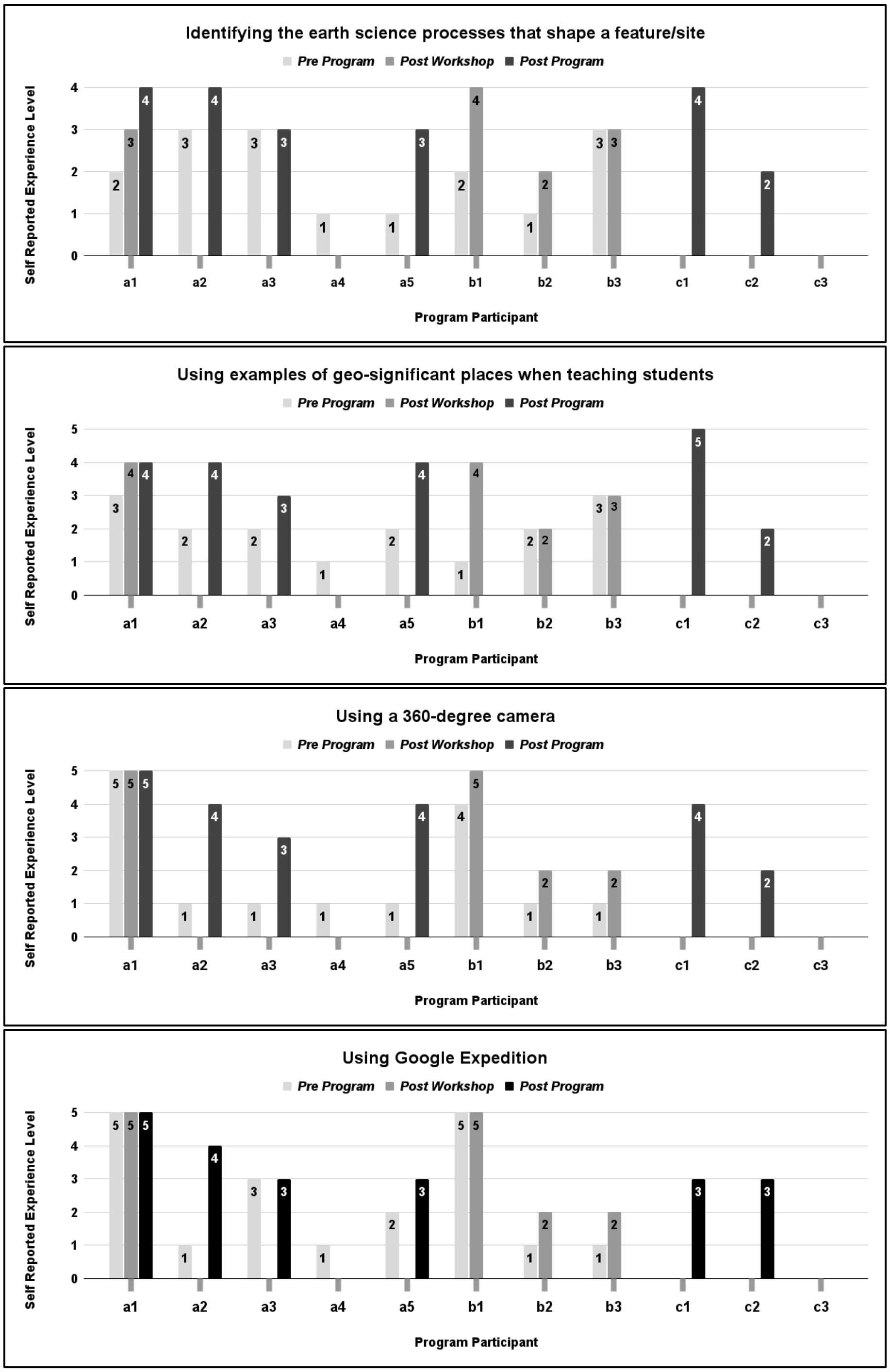

Figure 3.2. Displays the longitudinal results related to the change in experience level. The respondents were separated into three groups depending on their overall level of participation in the program. Group A participated in the full program including workshop and classroom experience. Group B only participated in the workshop. Participants in group C did not participate in the summer workshop, however were involved in aspects of developing and implementing the classroom learning experience.

Figure 3.3. Map of Western U.P. geosites that were developed into VGIs during the program.

Figure 3.4 shows each of the five projects had mixed results in their ability to meet the targeted outcomes. Project A and D achieved some level of success in all of the measured outcomes. Whereas, projects B, C and F displayed more modest results, with at least two target learning outcomes missing from the analyzed materials.

One of the goals of the project was to increase student engagement with regional-centric geology. Figure 3.4 shows that all of the projects were able to integrate opportunities to build awareness of regional geosites into the learning experience. Four of the five projects engaged students in either the historical or present-day cultural significance of the locations. However, only two of five projects engaged students in studying the geologic significance or the Earth System phenomena that makes the site unique. Additionally, three of the projects included learning objectives targeting geoscience content either at grade level (projects A & D) or below grade level (project B). The most common connection was to NGSS ESS2 Earth's systems, including topics related to earth materials, earth systems, and the role of water in Earth's surface process. Some projects also connect to NGSS ESS3, Earth and Human Activity. While other examples were developed within a geoscience location, students were engaged in disciplines such as geography or writing, not necessarily geosciences. No direct connection to crosscutting concepts was identified as an explicit learning outcome based on the final VGIs.

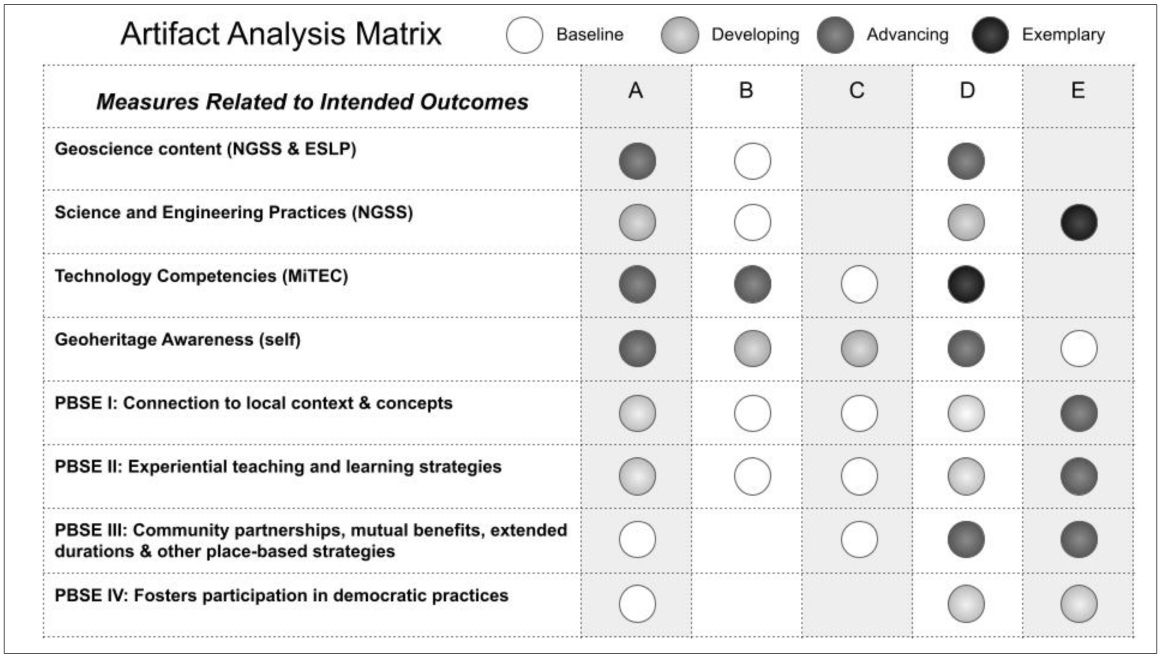

Figure 3.4. The matrix displays the results from the artifact analysis. A four-point scale was developed for each criterion: Exemplary, Advancing, Developing, or Baseline. if no evidence for that element was identified in the analysis. Note that it is possible that the intended outcomes were met by the projects, however were not observable from artifacts available to researchers.

The project sought to improve technology and science skills. Four of the five projects provided evidence that students had opportunities to develop technology competencies related to MITECS (see Figure 3.4). These project artifacts provided evidence that the student learning was mainly center in 2 of the 7 technology competencies: creative communicator, where students communicate for a variety of purposes using appropriate platforms, tools, and digital media; and knowledge constructor, where students curate resources using digital tools, produce artifacts and make meaningful learning experiences for themselves and others. For example, integrating a VGI enhanced with several digital posters displaying geologic information and images into a park website designed to educate visitors. Additionally, four of the five projects engaged students in the use of Science and Engineering Practices (SEPs), most commonly displayed was NGSS SEP 8: obtaining, evaluating, and communicating information. Of those projects, two included student performances with at least one SEP at grade level and multiple indicators below grade level. One project, which tied the virtual exploration to a ten-year Stewardship Project at a public coastal site, included evidence of students applying three SEPs at or above grade level.

Another project goal was to foster strategies such as place-based and experiential learning. The guiding principles for exemplary place-based stewardship education (Great Lakes Stewardship Initiative, 2016) informed the PBSE criteria. Overall, the projects rated highest on PBSE I (set the focus on local context and concepts) and PBSE II (establish foundations for place-based and experiential learning). Figure 3.4 shows that one project achieved exemplary results, two projects achieved developing (B & C) and two projects achieved baseline results (A & D) in these categories. The projects were more split in their overall ratings for PBSE III, deepening the impact, where two projects achieved advancing (D & E), two projects achieved baseline (A & C), and one project included too few elements related to the principles in this section to achieve any rating. The projects achieved lower ratings on PBSE IV, developing skills for participation in democratic practices, where two projects achieved developing results (D & E), one project achieved baseline results (1), and two projects (B & C) demonstrated too few PBSE IV elements to achieve any rating. Analysis of the results shows that, as a whole, the project had the most success of achieving at least a baseline level of the following PBSE elements:

- Experiences are about the environment in the context of the community
- Builds knowledge of how humans affect and are affected by the environment
- Draws on multiple disciplines and ways of knowing
- Includes assessments that produce evidence of learning and skill development
- Has clear but flexible learning goals
- Benefits the local environment and the community
- Involves diverse partnerships, including robust partnerships
- Cultivates student voice
- Develops socio-emotional and professional competencies

3.8 Discussion

Collectively, the results demonstrated participation in the program had benefits on teachers' geoscience pedagogical ability and content knowledge. In some cases, participation in the program increased the integration of geoscience and regional geosites in rural K-12 classrooms, including in classrooms with underrepresented students. Additionally, the virtual geosite investigations created by participants may provide ongoing learning opportunities for the general public. This could lead to gains in Earth Science Literacy and awareness of regional geologic examples beyond the classroom. Abundant literature exists on the positive effects of learning experiences that focus on place, inquiry and technology integration methods on students' and practices (e.g. Smith & Sobel, 2014). Fewer examples exist which focus on integrating virtual and outdoor field based professional learning programs for inservice K-12 teachers. This study provides evidence of the effectiveness of integrating outdoor and virtual geosite lessons into on-going professional development experiences to promote Earth Science Literacy and place-based pedagogy. While limited, evidence demonstrates that this method is applicable to a wide range of K-12 settings, and educators from varying geoscience background experience. This builds on previous work pointing to the benefits of inservice teacher professional development that model important pedagogies through field- based investigations can effectively increase knowledge and improve attitudes towards geoscience (Luera and Murray, 2016; Semken et al., 2017).

3.8.1 Effect on Geoscience Pedagogical Ability and Content Knowledge

Participating educators gained knowledge of Earth Science processes and developed the ability to recognize geologic processes and features in regional landscapes. Results from surveys suggest that delivering learning experiences situated in geosites improves knowledge. Both outdoor and virtual explorations appear to be effective according to both educator and student feedback. Additionally, survey results demonstrated that activities improved targeted technological abilities. Evidence suggests that greatest gains were achieved by those who participated in the full scope of the program, as well as those with limited levels of previous geologic or technological experience.

Results suggested the summer workshop was successful for increasing participants' interest in the significant place and phenomena studied. Additionally, the majority of workshop participants perceived modest gains in content knowledge and skill, albeit limited in scope to the context explored in the workshop. This suggests that the model is effective for meeting the diverse set of needs of rural educators from diverse K-12 subjects and levels of prior knowledge. However, ongoing and long-term participation would be needed to meet regional needs. Annual field and virtual based workshops would be required to have deep impacts on learning.

The program activities aimed to increase teacher related pedagogical abilities. Survey results show that teachers agreed that the program improved their ability and confidence to use geosites in instruction. Additionally, teachers perceived their participation supported them to integrate virtual field experiences into their classrooms. This was true for respondents that self-selected "novices" and "experienced" on the pre-program survey, demonstrating the program's ability to support the diverse range of educators from the region to integrate geoscience into their classrooms. Post-program participant survey responses agreed they were more confident in designing learning opportunities that integrate technology across content areas. These gains were more limited for those that participated in only part of the full program.

The program's ability to support participants to integrate place-based strategies into student learning experiences are demonstrated in the analysis of program artifacts. Classroom products demonstrated the experience provided an avenue for the majority of participants to develop experiential learning activities, which authentically blend multiple disciplines, and connect student learning to local places. In some cases, the experience enhanced partnerships (in-school or school-community). Projects that were part of established Place-Based Stewardship projects were successful in additional PBSE categories, such as fostering democratic practices. The success of projects in schools without these previously established projects indicates that the program may be a useful entry point for those wanting to modify their curriculum to a more place- and project-based approach.

3.8.2 Effect on Integration of Geosciences and Technology into Instruction

The program sought to increase student engagement in geosciences and authentic use of technology. Measuring the effects on students was beyond the scope of this study, instead we relied on teacher perceptions and artifact analysis. Post surveys showed that educators felt they would be more likely to teach Earth Science concepts after their experience. Similarly, they felt more confident to implement a curriculum that integrates science and technology.

Analysis of the classroom products provided evidence of all five projects reaching some success in integrating geosites into their classroom curriculum. Additionally, technology competencies are apparent in most classroom VGIs, as well as students engaging in SEPs. The MITECS and SEPs are limited in scope, indicating that VGIs should be blended with other STEM opportunities. The effect on increasing teachers' classroom enactment of standards-based geoscience content was more modest. Only 60% (three of five) of the classroom lessons engaged students in NGSS related content standards. This may point to the need to be more intentional with supporting teachers that are unfamiliar with geoscience related standards and who may not normally be charged with including Earth Science in their classrooms.

Overall, analysis of survey results and collected artifacts show the program's ability to increase the enactment of geosciences and technology integration. This is despite the wide-ranging disruption created by the Covid-19 pandemic. The program appears appropriate for a wide range of age groups, content areas, and for students from a wide range of backgrounds, including Indigenous populations and lower socioeconomic levels.

It is important to note that the survey data showed that teachers perceived they would need continued access to equipment and experts to continue to offer these opportunities to future students or in new geosites. This is supported by research describing educators' need for ongoing professional development that is tailored to their classroom situation (Darling-Hammond et al., 2020).

3.8.3 Broader Effects on Community

Results from analysis of the collected artifacts demonstrates that the program generated additional benefits to the educational and broader community. The VGIs and accompanying presentations produced by the program created further awareness of regional geosites in school and community members not directly involved with the program. By utilizing free and easily accessible platforms such as Google sites, Google Expeditions, and RoundMe, the final projects were shared beyond the school community. One limitation with utilizing these free programs is that the companies that host the software may decide to discontinue their products, as was the case with Google Expeditions experienced by the program team and participants in this case study. The number of visitors to the virtual tours was not measured as part of this program, however this could be integrated into future iterations of the program and research measures. Providing teachers with opportunities to present at professional learning events allowed for additional learning and professional gains for the teachers involved.

A further benefit of this program to the community was its success at fostering partnerships to advance school and community connections. In most cases these partnerships were one sided, mostly focused on benefiting the student learning (e.g., partners presenting to students). However, in two of the projects (4 & 5), artifacts demonstrate that these partnerships were more mutually beneficial, focused on positive outcomes for the community and the classrooms. For example, in project 4, the final products were displayed on a public website, created by high school students, designed to raise public awareness about the local geology at a local park and acted as an authentic assessment of the student learning. These two projects were part of a longer-term partnership. Further evidence would need to be collected to determine the magnitude and sustainability of these community connections.

3.8.4 **Limitations:**

We have documented successes of the program and suggested improvements based on data. The results are not definitive due to small sample size, limited population and the non-experimental case-study design. However, since this is an ongoing effort, further data is expected which would build depth to the findings presented in this paper. The longevity of the impact on students and teachers is unknown. Additionally, the program took place during the Covid-19 pandemic, which may have influenced the results, so that they would not be replicated during a year with fewer disruptions. Future studies on the impact of the innovations should consider longitudinal analysis and use an experiential approach to measure teacher and student learning gains.

3.9 Implications

Section 2.2 of the supplemental materials includes links the project website, examples, program descriptions, and teacher resources. Our goal in developing these materials is to demonstrate how geologically significant places, and the related concepts and systems, may be used as a curricular element in a wide-variety of classrooms, age groups and socio-economic levels. The materials are intended to provide a framework for others who are seeking to increase the relevance of learning experiences and foster a technologically capable and earth-science literate population.

All activities of the program appear to be important to achieve the results presented in this case study. The development of the virtual geosite investigations provided opportunities to build technological, scientific, and/or communication skills while building geoscience content knowledge. The summer workshop provided an important opportunity to model geoscience, place-based learning through virtual and outdoor settings that could be replicated in the classroom. Introducing educators to available resources, partners and significant locations provided confidence and tools necessary to apply learning to the classroom. The multi-organization team offered ongoing support during the school year to meet the needs of rural educators from a wide range of grades and subjects. Opportunities for students and teachers to showcase their projects and learning with the wider community provided leadership and reflection opportunities for students and broader impacts to their work.

Sustained access to a wide variety of mentors provided tailored support for each project, ensuring success no matter the background of the educator, the students or their school-community setting. Regional Geoheritage and place-based experts support teachers to make geoscience connections to curriculum meaningful. On-demand access to equipment and technical support was important for combating time-consuming and frustrating hurdles. This type of mentorship can be expensive, making it infeasible for many programs. Combining efforts and utilizing existing systems of support made facilitation of activities reasonable. Overlapping service areas between organizations and goals was key to efficient collaborations.

Integrating both virtual and outdoor aspects provided depth in learning, and flexibility for dynamic classroom settings. Outdoor settings lent themselves to gains in interpretation of landscape or natural phenomena, geospatial/navigation skills, and use of 360-degree cameras. The inclusion of classroom-based activities provided further exploration of Geoheritage connections and content learning. The dynamic of engaging in both outdoor and virtual settings allowed the project to maintain relevance before and after the shifts in learning, experienced during the pandemic.

The fundamental aspects of the VGI program and results could be replicated. However, this approach is not without difficulty. The following should be considered: (1) Locating geosites may be daunting in unfamiliar locations; building on existing resources, such as published EarthCaches and field guides, is helpful. (2) Continued access to equipment and technology support seems unavoidable as the available technology rapidly evolves. (3) The necessary time and funding for mentorship can be extensive. (4) Educators and partners stipends and travel reimbursement is needed in rural, under-resourced settings challenged with large travel distances. (5) Coordinated support for facilities, equipment, activities, and fiscal elements of the program was possible because of well-developed partnerships between institutions.

In future iterations of the program, the team will identify new focal topic(s) to meet the learning needs of new and previous participants. Consideration will be given to including an asynchronous portion on the project website for participants to explore introductory concepts and see examples of examples from the first cohort. Scrutiny over data organization and methods to ease sharing of images and built content will be conducted. Future work could be conducted to measure the impact of these activities and efforts on pre-college students pursuing earth-science related studies in college and subsequently practicing professionals.

3.10 Conclusions

This study provides evidence of the effectiveness of the Virtual Geosite Investigations program on strengthening geoscience and technological pedagogy and content knowledge, including integrating virtual and place-based investigations into course curriculum. The program supported changes in classroom enactment leading to students, including those underrepresented in geoscience, engaging in geoscience content and grade-appropriate skill building activities situated in familiar and geologically significant places. A case-study approach was utilized to uncover key characteristics of the program and its potential for being an effective program in rural settings, where resources and staff are limited.

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4 Case Study 3. Integrating Michigan Geosites into K-12 learning through Professional Development & Mentorship Program: *Examples & Results from Nah Tah Wahsh / Hannahville Indian School*

4.1 Abstract

This research is a case study documenting the effects of a program designed to increase access to geosciences learning experiences at a small, rural school district located within a tribal community in Michigan's Upper Peninsula. During 2012-2015, a researcher from MTU GK12 Watersheds Fellows program worked with educators and community members to integrate geoscience and place-based learning experiences into K-12th grade student activities. A teacher professional development (PD) program was designed to meet the local needs and utilizing regional assets. The program engaged educators in field-based sessions, lesson development sessions, supportive implementation, and reflection activities. This study combines the results collected during the program (including survey, content test, and focus groups) with newly conducted artifact analysis of field notes and products developed by the participants and students. The work seeks to answer the question "what effect did the program have on participants' pedagogical abilities, content knowledge, and the enactment of geoscience learning in the various classrooms?" Mixed methods of data collection were used to measure the effectiveness of the program. The results demonstrate program activities were successful for supporting a wide-range of teachers from the school to integrate engaging learning into their K-12 standards-based curriculum through regional geologically and culturally significant sites. Outcomes such as increased teacher collaboration and students' professional competencies were also achieved. The findings point to the necessity to design PD that is tailored to the school community and ensure sustained support, including geoscience and educational mentoring, to promote the instructional changes.

4.2 Introduction

Indigenous people, like many other ethnic and cultural groups, are underrepresented in the geosciences. Out of the 610 geoscience doctoral degrees awarded to U.S. citizens and residents in 2016, Native Americans received 5 or less than .1% (National Science Foundation [NSF], 2019). Despite deep traditional cultural connections between environmental stewardship and Earth systems, there is a lack of degreed scientific expertise from tribal communities. The need for building earth and environmental science expertise in reservation-based communities has been well-documented (Grenier, 1998; Marcus, 2002; Riggs and Semken, 2001; Semken and Morgan, 1997). There is a continued call to recruit a talented and diverse geoscience workforce (e.g., Cramer et al., 2021; Huntoon and Lane, 2007). The progress through the educational systems and into the geoscience profession has been described as a "pipeline", where barriers to attracting or maintaining individuals are characterized as "leaks' ' in the pipeline. Others prefer the term "pathway" to indicate that the movement into the career field isn't a "one size fits all" approach that must account for differences among students and their learning situations (Altman et al., 2008). There are a wide range of reasons for the underrepresentation of certain populations in geoscience majors and careers, including barriers to participation, and lack of awareness of, and interest in, the geosciences (Levine et al., 2007).

Community schools are an ideal place to engage K-12 students in geoscience pathway programs as the vast majority of youth have access to public education. National science standards give equal weight to Earth & space science (ESS) from kindergarten through graduation (National Research Council, 2012; Next Generation Science Standards Lead States [NGSS], 2013). Much is known about the types of educational experiences that can contribute to student engagement. For example, Schultz et al. (2011) noted the importance of authentic learning experiences to "sustain student interest in the sciences". Aikenhead (1996) observed the importance of highlighting the relevance of science within Indigenous cultural communities. Previous research points to a number of strategies, such as place- (Riggs and Semken, 2001), field- (Unsworth et al., 2012), and inquiry- (Marshall and Alston, 2014) based instruction, that have been shown to positively affect underrepresented students' knowledge or motivation.

Yet, geoscience learning continues to be limited in K-12 student experiences (Banilower et al., 2018; Wilson, 2014). There is a low percentage of educators with a background in geoscience (Wilson, 2014). Even knowledge about geoscience careers is limited among science teachers (Sherman-Morris et al., 2013). Additionally, some inservice educators have limited pedagogical experience with instructional strategies that engage diverse populations of students.

Inservice teacher professional development can be used to improve disciplinary content and pedagogical practices. However, most inservice teachers engage in limited amounts of PD. One recent report found that less than 60% of high school teachers, 75% of middle and more than 95% of elementary teachers surveyed spent 36+ hours in PD during a three-year period (Banilower et al., 2018). The numbers were worse for teachers of high percentages of students historically underrepresented in STEM and of those in the smallest schools (Banilower et al., 2018). Only about a quarter to a third of teachers, depending on grade range, had substantial opportunities to rehearse instructional practices during these PD experiences and even fewer worked closely with other teachers from their school (Banilower et al., 2018). Additionally, there are systematic barriers in many school settings that make it difficult to engage students in community based and authentic experiences, including funding, scheduling, and limited opportunities for teacher collaboration during the school day.

Universities and other institutions that are dedicated to education can play a key role in outreach and partnership with community schools to provide geoscience pathway activities (Huntoon and Lane, 2007). In 2012, Michigan Technical University (MTU) partnered with Nah Tah Wahsh PSA through the NSF GK12 Global Watershed Program (award #0841073). As part of that work the author and supporting faculty initiated a multi-level partnership between various school-community stakeholders including administrators, teachers and community members. We sought to establish a collaborative partnership to increase student geoscience experiences at multiple grade levels through geoscience PD situated in regional geosites and provided mentorship over extended periods of time. During the first school year, substantial effort was given to understand the school-community culture, the operational systems, the needs of the students and teachers, as well as the potential avenues to engage students in geoscience learning. In the following years three main PD projects, which are the basis of this study, were collaboratively designed and implemented. Collectively these will be referred to as the Nah Tah Wahsh Geosciences Pathway Program.

A case-study research design was selected to understand the benefits and limitations of the approach to engage various student groups in effective geoscience pathway experiences. The following research questions were explored: what effect does the program have on participating educators' pedagogical skills, content knowledge, and their enactment of geoscience learning with their students? This paper details the following program design element: 1) engagement of a wide variety of educators within a single educational setting 2) model field- and inquiry-based learning experiences focused on geoscience content and practices, 3) facilitate educators to develop learning experiences that connect earth science or geosites to their classroom standards, and 4) provide ongoing mentorship and resource support for classrooms through implementation. The intellectual merit of this work lies in its flexible approach to integrate geoscience education into core school curricula at multiple grade levels. The broader impacts of this study will be the gains in geoscience literacy and understanding of scientific processes exhibited by Nah Tah Wahsh students and the Hannahville community, as well as the recruitment of Indigenous and other marginalized groups to enter the career field.

4.3 Study Population and Setting

Setting: The Hannahville Potawatomi Indian Community is located in a rural area of Michigan's central Upper Peninsula. The region has many geosites with connections to a wide variety of geologic processes with historical and cultural significance. Many of the features have been incorporated into parks or preserves such as Books State Park, Fayette State Historical Park, and Rapid River County Park. Also, many features exist outside of these designated locations and are often unknown to the community.

The tribal government provides a number of programs for its community including an Environmental Protection Program, water/wastewater treatment plants and a youth center. The youth center has many services including a Summer Youth Employment Program and summer academic program called Kids Zone serving ~75 students annually. In addition, the community established the Hannahville Indian School in 1976 to address the special academic needs of Potawatomi students. Then in 1995, the Nah Tah Wahsh Public School Academy (PSA) was established as part of the State of Michigan Charter Public School Academy, allowing the school to provide education to children from outside the tribal community (A. Soucy, personal communication, January 4, 2001). Although the Hannahville Indian School and Nah Tah Wahsh PSA have separate distinction, for all intents and purposes of students' daily learning, they function as a single unit and often are referred to as Hannahville Indian School/Nah Tah Wahsh PSA (hereafter Nah Tah Wahsh PSA will be used).

During the study period, 2012-2015, the average annual total school population was 168 students, with ~61% of students identified as American Indian and ~90% of students classified as economically disadvantaged (Michigan's Center for Educational Performance and Information, 2015). The school curriculum includes Potawatomi cultural courses in addition to courses aimed at fulfilling the required State of Michigan subject area content expectations. The school's curriculum and state assessments are framed by a set of academic and career readiness standards provided by the state of Michigan (Michigan Department of Education, 2015). Relevant academic standards include Michigan Science Standards (MSS), which is closely aligned to the Next Generation Science Standards (NGSS). Students take earth science in eighth grade, Physical Science as freshmen, Biology as sophomores and Chemistry as juniors. During the study period, the school has not reached adequate yearly progress goals set by the No Child Left Behind Act. Consequently, there was motivation by administration and staff to increase student achievement in all STEM content areas.

While staff working at the school, youth services or natural resource department were well qualified, many did not live within the Hannahville Tribal areas and often were not affiliated with the tribe. Staff turnover could be an issue as well. For example, during the three-year study period, there was a new high school science teacher each year. Many educators expressed interest in learning more about the locations within the community and the work occurring at the schools or surrounding areas. It should be noted that other PD was occurring at the same time as this study, however none focused on geology, science, inquiry-based instruction, or place-based pedagogies. The school had access to federal funding which covered all transportation costs and were open to educational field trips.

Study Participants: The sample for this study included seventeen Nah Tah Wahsh educators, representing all fourth, sixth-twelfth grade teachers, and six summer youth employees, representing all KidZone Youth assistants. All of the participants were employees of the Youth Services Department or Nah Tah Wahsh PSA. There was a total of 173 students that participated in the resulting learning experiences. The participating educators were only involved in one of the three projects. Further participant details are included in Table D.1a-c Participant Information Table and within the program description below.

Program Partners: The program was overseen by a cross-agency team including: the MTU GK12 Fellow, select geoscience & educational researchers from MTU, and school and summer youth administrators. The program was designed and implemented with the permission of the Hannahville Tribal Council and with input from select tribal departments and the participating educators. The principal investigator has a location as a researcher-participant (Feig, 2011).

4.4 Geoscience Pathway Program Description

The goals for the program under study were to generate knowledge and motivate students and teachers in geosciences. The activities were centered on place-based PD activities for educators (teachers and youth educators) that demonstrate the authentic integration of geoscience phenomena and examples, and employ elements of effective PD to facilitate teacher learning and instructional change (Darling-Hammond et al., 2020). Table D.2 Program Logic Model, provides an overview of the outputs and outcomes of the program. The workshop agendas, resources and resulting lesson plans can be viewed in the supplemental materials in section 3.3. The activities are further described in the section below.

Program Initiation and Planning, 2012 - 2013: The Nah Tah Wahsh geoscience pathway program was conceptualized during the 2012-2013 school year. Throughout the year, the GK12 Fellow visited Nah Tah Wahsh, Youth Services and other community programs multiple times each month. The purpose of these visits was to become familiar with the school learning environment and to build relationships with staff and students. Much of the time was spent observing classroom instruction, mostly in the high school science course. Informal interviews with middle and high school teachers, school administrators, youth service administrators and other staff were conducted to understand perceived student learning needs, potential barriers, interests, and the current level of engagement in geoscience at each grade. In the second half of the year, the GK12 Fellow partnered with the high school science teacher to develop and deliver inquiry-based experiences through watershed investigations that included laboratory and field activities rooted in Earth system and chemistry topics. This and other similar, smaller scale concurrent activities are not included in the study.

Project 1 (P1): Summer Youth KidZone, May - August 2013: During the summer of 2013 the MTU GK12 fellow worked closely with the staff from the Hannahville Youth Services to design a geoscience pathway project for students within their Summer Youth Employment and KidZone Program. The Hannahville KidZone program serves first to sixth grade students at Nah Tah Wahsh schools, five days a week, from late June to Early August. Typically, KidZone assistants work with at least one adult employee to deliver educational programming. These KidZone Assistants are tribal members and descendants, aged fourteen to eighteen, employed through the Summer Youth Employment program. The project was intended to improve community members' understanding of how water moves through the tribal lands and to build understanding of how changes in one Earth system affect others. Additionally, the project sought to develop scientific skills and to raise awareness of regional geoscience related careers in the KidZone Youth Assistants.

In May of 2013 interested students participated in a speed interview at the summer job fair. All six KidZone Youth Assistants self-selected to participate in the intervention. Throughout the summer the teenaged youth engaged in the project activities for one or two days a week, while performing normal duties the remaining three or four days a week. The first phase of activities included a field-based investigation focused on local water resources and hydrological processes within tribal watersheds. The second phase supported the Youth Assistants to develop and implement STEM lessons to KidZone first to sixth grader students, and the creation of water awareness videos for community members. Table D.3 in the appendices section, provides an overview of the input, activities and products of the project. Further detailed information is located in supplemental materials.

Project 2 (P2): Fayette Historical State Park Interdisciplinary Lessons, October 2013 - May 2014: The GK12 Fellow collaborated with ninth to twelfth grade educators and school administrators to design and implement a second project during the 2013-14 school year. The project focused on engaging youth in inquiry-based, interdisciplinary lessons at Fayette Historical State Park (henceforth referred to as Fayette). The park is situated on the Garden Peninsula in Michigan's south-central Upper Peninsula approximately seventy miles from Hannahville, Mi. The park includes unique coastal and ecological landscapes connected to the limestone features part of the Niagara Escarpment (Dellapenna, 1987). The area has rich historical and cultural connections to Indigenous people and 19th century iron smelting operations (Jacques, 1976). The park features a historic townsite with more than 20 buildings and five miles of trails with views from the limestone cliffs that surround the harbor. The project centered on connecting geoscience content and skills to the landscapes and history displayed at the geosite.

Project planning occurred during the first half of 2013. In October 2013, the kick-off professional development activity occurred during a scheduled inservice day. Educators engaged in a six hour 'field-day' at Fayette. These activities were designed to improve earth science literacy and increase knowledge of the geosite to spark connections to classroom curriculum. Additionally, the PD aimed to model effective pedagogical practices and foster a collaborative culture. During the first half of the day, small groups of educators explored six historical and geologic sites within the park using maps and GPS coordinates to navigate to the locations on their own (see supplemental materials). Participants completed inquiry-based educational tasks related to a guiding question and provided at each of the designated locations. Topics included: Michigan geologic history, Niagara Escarpment and the Michigan Basin, fossils, cuesta, formation of coastal bays and headlands, Cedars/Microclimate, Indigenous history, iron smelting resources and processes. In the concluding activity teachers explored the area on their own, brainstorming lesson ideas for their own students based on the geosite & their classroom standards.

The field-day was followed by a series of after-school, mini-sessions which included collaborative interdisciplinary lesson development, field trip planning and reflection activities. The sessions were split into whole and small group work. Together participants engaged in professional development focused on building inquiry and field-based lessons utilizing the BSCS 5E Instructional Model (Bybee, 2014). Additionally, much of the logistical planning for field day (e.g., agenda, transportation, permission slips, student maps) was done as a whole group. Whereas, lesson development took place in self-selected pairs. Teachers collaborated to develop multi-day learning activities which matched both classrooms' content standards and Fayette's geologic history.

On May 14th-16th 2014, forty-two high school students engaged in the teacher-driven learning experiences. The first and third day took place in the school with students rotating in five mixed grade level groups during first through fifth hours. The field trip to Fayette took place on the second day. Guiding themselves, students visited five different sites throughout the park for thirty-minute activities (see section 3.21 in supplemental materials for more information). Interdisciplinary topics included Language/Culture, Social Studies/Music, Health/Science, Art/ELA, and Math/Building Trades. A Northern Michigan University professor of Native American Studies joined the Cultural/Language group for the field day.

Following the students' experiences, teachers engaged in a lesson debrief, revision and reflection activity. The facilitated group discussions centered on successes and challenges experienced by teachers while engaging students in field-based classroom practices and culturally relevant themes. Table D.4, in the appendices, provides an overview of the input, activities and products of the project.

Project 3 (P3): U.P. Geoheritage Field Investigations, Summer 2014 - Spring 2015: Beginning in summer 2014, the GK12 Fellow worked with fourth, sixth to twelfth grade teachers to enhance youth engagement in geosciences & application of geosite within their individual, grade-level science curriculum. During the first phase of the project, eight educators and support staff engaged in a MTU summer graduate level field course titled Geoheritage of the U.P. Three teachers engaged in all five days of the course, whereas the other seven participated in one or two days. Participants spent time in the field investigating several Geoheritage sites within one hundred miles of their school (see supplemental materials section 3.3 for further details). These sites included: Kitch-iti-kipi Spring at Palms Brook State Park, the Niagara Escarpment at Fayette State Park, the Cedar River Watershed, glacial features within the Menominee Drumlin Field, Precambrian geology and historical mining activities in Marquette and Iron Mountain. Activities at each site targeted specific Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009) as well as NGSS crosscutting concepts and scientific and engineering practices (NGSS Lead States, 2013). Place-based learning highlighted past and present Earth system interactions, and related socio-cultural contexts. Teachers engaged in data collection processes with two concurring studies with MTU researchers: Kitch-iti-kipi Spring hydrology and Depas Tributary water budget. Lessons were organized by the GK12 Fellow and co-facilitated by geoscience experts and Hannahville Indian Tribal Departments.

The second phase of the project took place in the fall semester of 2014. Five teachers selected one geosite to connect to their classroom standards. The fourth to eighth grade classrooms are self-contained, where a single teacher is charged with all core instruction. There is one individual teacher who delivers all ninth to twelfth grade science instruction. Teachers participated in follow-up mini-sessions and mentorship activities. Resources and just-in-time support the development of an extended BSCS 5E lesson plan (Bybee, 2014). Fifty-six students engaged in one of five lessons. Each student's learning experience included classroom activities and field-based explorations in one or more of the eight regional Geoheritage sites (see supplemental materials section 3.3 for more details). The GK12 Fellow supported each individual teacher during preparation and the field investigation portion of the lesson. Reflection and professional leadership opportunities were interwoven into the project. In December, the teachers engaged in facilitated group discussions. Three out of six teachers selected to earn university course credit for their participation in the project. Two teachers presented at the annual Michigan Science Teacher Association Conference in Lansing in March 2015. Table D.5 provides an overview of the input, activities and products of the project.

4.5 Study Design

The research was designed to measure the effectiveness of the program at meeting its intended outcomes and to explore implications of the program design for engaging classes with high numbers of Indigenous students in geosciences. A case study approach was applied using a mixed-method approach similar to those described by Fraenkel et al. (2012). Each research goal was measured by multiple measures (see Table 4.1) to support the validity of the findings through the convergence of information and ensure different perspectives were not overlooked (Morse, 2009; Patton, 1999). All data collection was conducted as part of the regularly scheduled activities with youth services employees and school educators. Further details on data collected and copies of the instruments can be found in section 3 of the supplemental materials. All aspects of the project research were conducted in accordance with protocols approved by the Michigan Technological University Institutional Review Board (Project M1078 [474488-1]).

Table 4.1. The table indicate which instruments are used to measure each project goal. Note the following abbreviations: P1= Summer Youth Kids Zone, P2= Fayette Park Interdisciplinary Lessons, P3= U.P. Geoheritage Field Investigations

	Teacher Geoscience Pedagogical & Content Knowledge			**Teacher Motivation or Interest**			**Enactment of Geoscience/ Geosites use in Class**			**Effects on Student Learning**		
Project	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Pre/Post Content Test	■		■									
Pre/Post Survey	■	■		■	■			■				
Post workshop Survey				■	■	■						
Interviews	■	■	■	■	■	■	■	■	■		■	■
Archival Analysis	■			■			■		■		▒	▒

Pre/Post Content Test. Pre/post content tests were conducted to measure gains in geoscience content knowledge for the P1 and P3 educators who participated in multiple days of field PD activities. The design and content of the two tests differed, each being aligned to the specific learning objectives of the projects. A quasi-experimental design was applied in P1 by utilizing other Summer Youth Employees (n=8) as a control group. The P1 test and scoring rubric were modified from the 2011-12 Environmental Literacy Water Assessment (Caplan et al., 2012; Gunckel et al., 2012). All questions were free responses. The tests were independently graded by two researchers and entered into Excel. Basic descriptive statistical tests and the effect size (Coe, 2002) were calculated to compare differences in performance between the two groups. Additionally, scores were separated by content groupings including: Water Pathways; Watersheds; Substances and Water; Engineered Systems; and Water Movement within Trees. Tables and figures were developed to display the results.

Surveys. All participants were asked to complete a pre-activity survey before and a post-survey after a field-based workshop and/or at the completion of the project. Surveys were designed to measure geoscience pedagogical abilities, content knowledge, and in some projects, participants' interests. The surveys included a demographic questionnaire and a mix between Likert-type and open-ended questions. Each Likert-type scale question asked teacher participants to indicate their agreement with items on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Likert-type scale responses were converted into numerical codes (-2, -1,0,1,2) and displayed as frequency distributions. Open-ended questions were coded & grouped.

In addition, a Post-project Motivation Survey was used in P1 & P3. The survey was adapted from the ARCS Model of Motivational Design (Keller, 2010) which included groups of Likert-type scale questions for attitude, confidence, relevance, and interest. Likert-type scale responses were converted into numerical codes and were reported as mean scores with standard deviations by grouping. All survey data were recorded in Excel. Tables and figures were developed to display the results of all survey results and are located in the supplemental materials.

Interviews. Group interviews were conducted at the conclusion of each project to assess participants' perceptions on the projects' effect on student learning and other research goals. These types of interviews are useful for getting high-quality data in a social context where people can consider their own views in the context of the views of others (Patton, 2002, p. 386). Following Krueger's (2009) focus group guidelines for questioning techniques and structures, these sessions lasted thirty to fifty minutes and followed predetermined questions.

Select individual semi-formal interviews were also conducted with randomly selected participants at the conclusion of the third project to better understand individual viewpoints and any subtle differences between participants. All interviews were voluntary, lasting between thirty to fifty minutes and were recorded then transcribed later for analysis. Codes were derived from each interview transcript separately, using an initial set of code related to the research questions and allowing additional codes to emerge through analysis. Themes or patterns were developed based on the grouping of codes. The number of occurrences of each theme was recorded into Excel and linked in the supplemental materials. The interviews were then cross-referenced for frequent and co-occurring themes and a table created to support analysis across projects. All interviews were conducted and analyzed by the principal investigator.

Analysis of Documents, Artifacts and Field Notes. Documents developed by the participants, such as instructional plans, field-based learning artifacts and their students' work, were collected and analyzed (see supplemental materials section 3.4). Additionally, field notes from classroom observations and open-ended unstructured interviews with students, staff and community partners were collected throughout the project. Content analysis was conducted on the collected materials and field notes (Savenye and Robinson, 2005). The Geosites Integration Matrix was designed to systematically identify, analyze and rate the strength of the project at meeting its goals, as observed within the collected materials. The NGSS Disciplinary Core Ideas (DCIs) for Earth and Space Science (NGSS Lead States, 2013) and the Earth Science Literacy Principles (ELSP, 2009) were consulted to inform elements relevant to the geoscience content. Additionally, the NGSS (NGSS Lead States, 2013) were consulted for evaluating the depth at which science and engineering practices (SEP), scientific crosscutting concepts (CCC), and including nature of science (NOS) elements were observed into learning experiences. Geoheritage research informed the elements of the similarly named category, to consider the mode in which the geosites were connected to educational and cultural aspects of learning that lead to increased knowledge and sense of place (Casey, 2001; Groat, 1995; Semken, 2008). The guiding principles for exemplary place-based stewardship education (Great Lakes Stewardship Initiative [GLSI], 2016) informed elements of the pedagogies of place-based education. Each project was scored separately, and a table was developed to display the results for further cross-project analysis. A four-point scale was developed for each criterion: exemplary, advancing, developing, or baseline. A rating was not given if no evidence for that element was identified in the analysis.

4.6 Results

Between 2013-2015, seventeen educators and six youth assistants participated in the programs. As a result, there were eleven multi-day learning experiences created. More than one hundred seventy kindergarten to twelfth grade Nah Tah Wahsh PSA students participated. The lessons created were associated with more than ten geologically significant locations in Delta, Schoolcraft and Marquette Counties of the south-central region of Michigan's Upper Peninsula (see Figure 4.1). These locations were based on places that the educators had visited during a field-based learning experience.

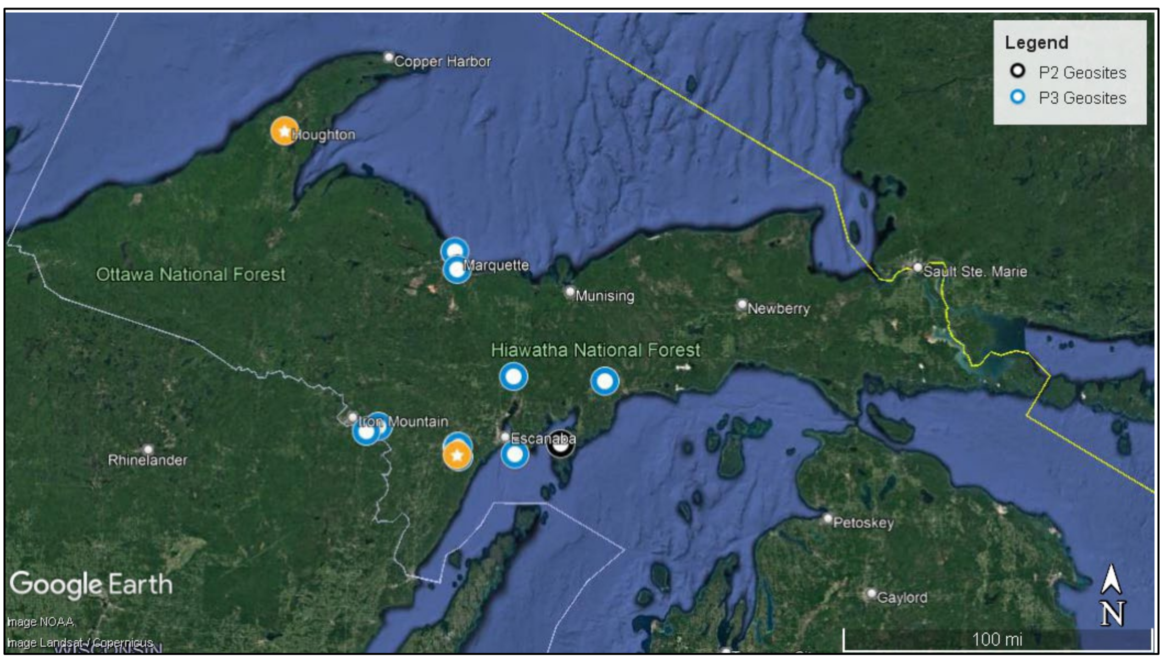

Figure 4.1. A map displaying project locations. The orange dots represent locations of the main collaborating partners, with Michigan Technological University in the northwest and Hannahville Indian Community in the southcentral. The geosite visited included tribal lands, state & regional parks, roadside areas, igneous, sedimentary and metamorphic outcrops, watersheds, drumlin field, a karst spring, and a water treatment plant.

4.6.1 **Survey and Content Tests**

Content tests and several surveys were implemented to measure the effect on participants' pedagogical abilities, content knowledge, motivation and interests. Participation in the tests and surveys was high across all three projects (85%-100% completion rates). The delivery of the test & surveys varied for each project, but generally occurred before and after the workshop, and immediately after the program. Highlights from the series of each projects' surveys are summarized by each research topic below. The complete project results can be found in the supplemental materials.

4.6.1.1 Pedagogical Abilities and Content Knowledge

Pre/Post Content Tests (P1 and P3): In 2013, a pre/post content test was administered to all P1 participants (test n= 6, 100% completion) and compared to the control groups' (n=8, 89% completion). The results displayed in Table 4.2 shows that the participants' mean scores increased from 23.3 (StdDev. +/- 5.66) to 30.5 (StdDev. +/- 5.05). The only participant who did not show growth was absent for several sessions. The effect size for the experiential group to control group was calculated with a pooled StdDev. The resulting effect size was equal to 0.60, indicating the intervention had a medium to small effect (Coe, 2002). Differences between participants' pre-and post-test results were analyzed by question and content grouping. Pre/post test results show that the program had a medium to large effect on more than half of the measures, with the highest effect on questions related to watersheds and engineered systems. The results demonstrate that the program had no effect on 22% of the individual questions, predominantly connected to the Water Movement Through Tree grouping.

Table 4.2. Displays the results for the pre- and post- project content test for both the P1 control group and test group. The participant group had positive growth in mean scores following the intervention. The effect size for the experiential group to control group was calculated with a pooled Standard Deviation.

	Test Group		**Control Group**	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Mean	23.3	29.3	22.5	21.8
Std. Dev	5.7	5.1	5.37	6.6
n	6	6	8	8

A multiple-choice pre/post content test (n=3, 100% completion) was administered to P3 educators in 2014. Results of the pre/post content test show that all teachers who participated in the full 5-day workshop scored 10%-20% higher on the post-course test than on the pre-course test (see Table 4.2). The participants included teachers with limited or medium levels of previous geoscience coursework.

Pre/Post Skill Survey (P1 and P2): A pre/post project survey (n=6, 100% completion) was administered to all P1 participants to measure perceived changes in technology skills. Comparison of each item's pre and post results show mixed results, with positive and negative impact on participants' confidence in their technology abilities. The item with the most positive change was 'use of GIS'. The most extreme changes in confidence ratings, both in the positive and negative direction, was the use of GPS, and use of computers to conduct research. The largest overall decrease was on participants' confidence in using environmental measuring equipment.

A pre/post project survey (n=9, 100% completion) measured the perceived effect of the P2 PD on participants' pedagogical and content knowledge. Survey results demonstrate that the majority of P2 participants felt the field workshop activities: improved their knowledge of Earth systems concepts (89% agreed/strongly agreed, 11% neutral); and enhanced their understanding of how to connect the concepts they teach to places of significance (77% agreed/strongly agreed, 22% neutral). Additionally, the survey results show P2 participants shared relatively strong agreement that the field workshop activities: develop their ability to recognize geologically significant features (89% agreed/strongly agreed, 11% neutral) ; that they would be able to recognize the geologic significance of other places with similar features on their own (77% agreed/strongly agreed, 22% neutral); and that their ability to navigate with a GPS unit was improved (77% agreed/strongly agreed, 22% neutral).

4.6.1.2 Motivation and Interest

Post-workshop motivation survey (P3): Results from the P3 post-workshop motivation survey (n=6, 100% completion) demonstrated that the majority of participants perceived that the field course sustained their attention (u=1.6, Std Dev= +/-0.7), was a satisfying experience (u=1.4, Std Dev= +/-0.9) and relevant to their situation (u=1.5, Std Dev= +/-0.9). Measures related to confidence in geoscience topics were more modest (u=0.6, Std Dev= +/-1.4). The post-workshop motivation survey results (see Table 4.3) were split into groups based on the number of workshop days they attended, two versus five days. The confidence ratings, and in part the satisfaction ratings, were much more limited in responses from educators who only participated in 2 days of the course. On the open-ended portion of the post workshop survey all agreed they would like to repeat the course. Reasoning participants provided included "do field work", to "learn new ways to teach students outdoors" and to "gain knowledge".

Table 4.3. Results to the U.P. Geoheritage Workshop (P3) post-motivation survey separated into two groups based on the number of days that the participant engaged with the summer course. The survey included groups of Likert-type scale questions for attitude, confidence, relevance, and interest (see Section 4.5).

	Participants in Full Workshop				**Participants in Part of Workshop**			
Group	**Attention**	**Relevant**	**Confidence**	**Satisfying**	**Attention**	**Relevant**	**Confidence**	**Satisfying**
Mean Score	2.79	2.67	3.47	2.78	1.71	2.31	1.75	1.50
Std Dev	1.08	1.25	0.91	1.27	0.59	1.25	0.45	0.71
Not True	9%	17%	0%	17%	0%	0%	0%	0%
Slightly True	38%	37%	14%	33%	0%	0%	0%	0%
Mod. True	21%	15%	39%	14%	6%	0%	25%	11%
Mostly True	28%	22%	33%	28%	17%	27%	17%	28%
Very True	4%	9%	14%	8%	78%	73%	58%	61%

Post-workshop survey (P2): The results from the P2 post-workshop survey (n=9, 100% completion) demonstrated that all P2 participants (100% agreed/strongly agreed) that they: were interested in developing an interdisciplinary lesson based on the geosite; the geosite provided useful earth science information for a teacher like themselves; and believed that visiting the same sites would support student learning. Additionally, there was strong agreement (89% agreed/strongly agreed, 11% neutral) that the field workshop activities: supported them getting to know the other teachers they work with. The responses to open-ended questions collected from the Fayette Post Survey provided further insight. According to the participants' responses, the best aspects of the field workshop were: being outdoors or in the place (5), working with others (4), learning to use the GPS (2), and being active (2). Additionally, open-ended responses show that teachers would repeat the learning activity again for several reasons including: to learn about the places around me (3), to gain knowledge (3), it is fun/enjoyable (3) and they would like to do it with students (2).

participants' responses to the open-ended post-project questions on the survey indicated that they would repeat the program experience because they valued the whole school, interdisciplinary and out-of-box approach, and because they gained new understanding of students' capabilities.

Post-project motivation and interest surveys (P1): The P1 post-project survey (n=8, 100% completion) Likert-type scale responses were converted into numerical codes (1, 2, 3, 4, 5). The P1 post-project survey results showed that the Youth Assistants perceived that the project had the most positive effect on their confidence about undertaking geosciences (u= 3.47, Std Dev= +/-0.91). With more mixed results in students' responses regarding: attention (u= 2.8, Std Dev= +/-1.1), relevance (u= 2.7, Std Dev= +/-1.2) and satisfaction (u= 2.8, Std Dev= +/-1.3).

The changes in pre/post response frequency related to science & career measures on the P1 Interest Survey demonstrated that there were mixed results, with both positive and negative directional changes for all measures. The most extreme differences in response, in both positive and negative direction, was to the measure "if I had a choice I would study science at school". The greatest net positive changes were for the following items: I would consider a career in education; I enjoy being outside; there are science related career opportunities in my community; I am good at science and I feel that I am able to contribute to the wellbeing of my community. There was a net negative response to the statements: I would consider a career in geosciences; I like working with younger children; and I am curious about nature.

4.6.1.3 Student learning and interest

Only the P2 post-program survey (n=10, 100%) included items to measure participants' perceived effects of the program on their students. Likert-type question results demonstrated that all participants perceived (100% agreed/strongly agreed) that they believed their students benefited from the interdisciplinary field trip, and that they believed that visiting other significant places with my students would support their learning (see Figure 4.2). Responses were more neutral (60% agree, 40% neutral) to whether the students were more engaged in the field-based portion than the classroom-based activities of the lesson. When asked on the open-ended questions why they would want to repeat the experiences, six responded it was because the experience was: beneficial, effective, fun, greater learning and improved teamwork.

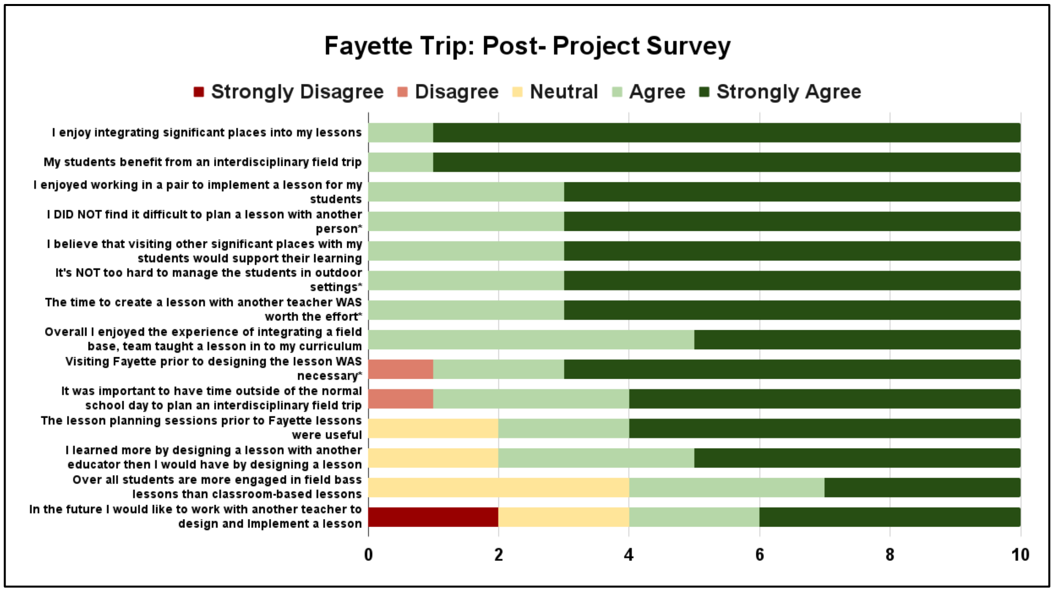

Figure 4.2. The results to the P2 Fayette Post-Project Survey displayed. The survey included both Likert-type scale questions and open-ended questions. Questions ending in '' were reversed for consistency in the display.*

4.6.2 Interviews

There were seven interviews conducted throughout the program, four group interviews (n=21) and three semi-structured individual interviews. Participation in the interviews was high across the projects (85%-100% completion rates). Table 4.4 displays the most common themes identified in group or individual survey transcription data and the corresponding codes. These were not the only co-occurring sub-themes but those occurring at the highest frequency and widest distribution throughout the transcribed interviews.

Participants from all three projects perceived having a greater awareness of regionally significant places and increased content knowledge than they had prior to the intervention. These gains appear specific to the geosite they engaged with during the field course or lesson plan design. P1 and P3 educators indicated learning gains specific to: the geoscience content, new awareness of community careers & programs, and enhanced abilities to use GPS and Google Earth. Additionally, transcripts from all three projects demonstrated participants perceived gains in their pedagogical abilities. P2 and P3 transcripts show participants perceived an increased capacity to develop multi-disciplinary lessons. Dialogue from the P3 group interview suggested widespread agreement that ESS was easily included into other subject areas and scientific disciplines. Other specific pedagogical gains appeared unique to each individual and included: inquiry, outdoors learning, integration of authentic scientific research, using computer based or physical models in science and integration of geologically significant locations.

Table 4.4. Displays the frequency that themes and their corresponding sub-theme occurred in group or individual surveys. These were not the only co-occurring sub-themes.

Code	Co-occurring Theme	Frequency by Interview						
		P1		P2	P3			
		G	G	G	G	I	I	I
		Adult Adm. (n=3)	Youth Asst. (n=5)	All HS teachers (n=9)	All teachers (n=5)	6th (n=1)	7th (n=1)	8th (n=1)
CK	Increase awareness or deeper understanding of local/regional geo-sites	None	Established	Established	Established	Established	Established	Established
CK	Participants gained earth science content through field course and/or lesson design	Established	Established	None	Established	Established	Established	Established
CK	Participants developed knowledge of community careers and programs	Established	Established	None	Established	Established	None	None
Sk	New ability to use GPS or Google Earth to explore geosites	None	Established	None	Established	Established	Established	(black)
Ped	Increase capacity to develop multi-disciplinary lessons (through place)	None	None	Extended	Extended	Established	Established	None
Ped	Increased confidence to teach earth science and/or with geosites	Established	Established	None	Established	None	Established	None
Ped	Perceived gain in pedagogical abilities; gains unique to individual	None	Established	Established	Established	Established	Established	Established
Enact	Successful enactment of Earth systems learning objectives	None	Established	Limited	Extended	Established	Established	Established
Enact	Experiences integrated into other STEM fields or crosscutting concepts	None	Established	Established	Extended	Established	Established	Established
Enact	Successful integration of geosites and field-based learning	None	None	Established	Extended	None	Established	Established
Enact	Inquiry-based and/or student-centered learning	None	None	Established	Extended	None	Extended	Established
Std	Perceived increase in youth engagement in learning through project	Established	None	Extended	Extended	Extended	Extended	Established
Std	Perceived increase in students' content gains related to geosite lesson	None	None	Established	Established	Extended	Established	None
Std	All types of students' learning (e.g., 'know-it-all', 'unengaged', 'very active')	None	None	Established	Established	Established	Established	Established
Std	Experiences supported youth to increase ability to work with other students	Established	Established	Limited	Established	Established	Established	None

Frequency Key	None	Limited	Established	Extended
	(white)	(light grey)	(grey)	(dark grey)

The perceived effect of the PD activities on participant motivation were also apparent in the interview data. Transcripts from P2 and P3 show that participants with varied experience levels indicate that the field and follow-up sessions: increased their comfort to teach earth science and/or with geo-sites; were highly valuable and highly relevant to their professional growth needs; and would be something in which they would participate again in the future. For example, a P2 participant with more than twenty years in art education described being originally jaded due to past experiences in 'outside' PD initiatives, but that the "experiences exceeded my expectations".

There was also evidence in the interview data of high value for engaging in the PD activities with their fellow teachers. A P2 educator, with more than 10 years of teaching experience, described high levels of perceived collaborations within the high school group. Teachers in P2 and P3 with less than one year of teaching within the districts felt the opportunity "especially useful for a new teacher to connect with other teachers." An experienced P3 teacher found that being in the field with fellow teachers created a more comfortable learning environment.

Interview data with youth assistants from P1, demonstrated a different perspective of the experience on their interest and attitudes. Dialogue indicated P1 participants had to work harder than their peers involved in other Summer Youth Employee programs. Interview data indicates participants perceived increased confidence in classroom teaching, and mixed interest levels for engaging in future teaching opportunities. However, data shows minimal to no interest in participating in similar field-based investigations in hydrological topics or during the summer. Moderately higher interest was demonstrated for participating in similar outdoor and hands-on activities within the school-year science course, particularly for topics related to biology or astronomy.

The P2 and P3 interview protocols contained measures eliciting participant perceptions for the effect on student learning. Interview data indicated widespread agreement that the inclusion of the newly developed experiences improved the relevance of the curriculum and increased the number of geosites, outdoor/field-based learning, or student-centered activities in their classes. Within both P2 and P3 there was strong belief that the experiences created resulted in a high level of student engagement and interest in learning. Example dialogue from transcripts included descriptions of behaviors such as increased reliability, more personal responsibility and ownership of lesson products. Interview data showed that P2 and P3 participants perceived that students' gained content knowledge and demonstrated improved professional competencies including collaboration and scientific practices. Teachers indicated that these gains were within all types of students including those normally unengaged, very active, and high-achievers. The results to the interview questions were different for P1, with no effects on youth engagement apparent in the K-6th KidZone adult or student transcripts.

4.6.3 Archival Analysis of Project Products and Field Notes

Results from the content analysis of collected program artifacts are displayed in Figure 4.3. Each project was scored separately and a table was developed to display the results for further cross-project analysis. Note that the analysis does not reveal the elements based on what is observable from artifacts available to researchers and therefore the ratings may be lower than what was actually produced.

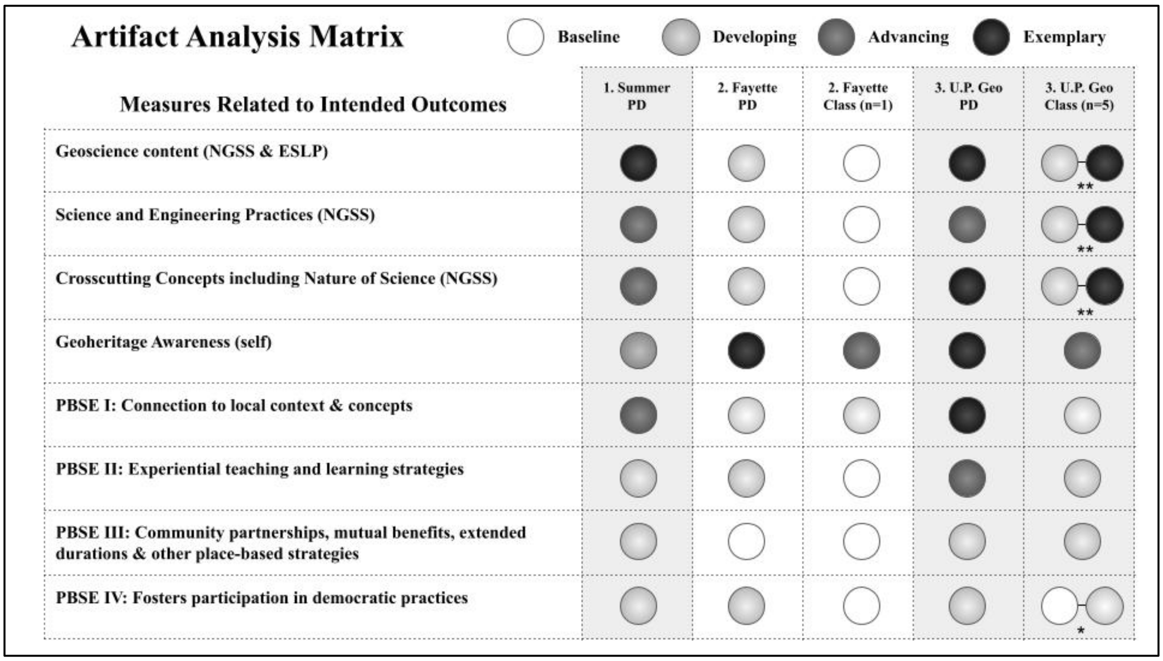

*Figure 4.3. The matrix displays the results from the artifact analysis. A four-point scale was developed for each criterion: Exemplary, Advancing, Developing, or Baseline. if no evidence for that element was identified in the analysis. Note that '**' indicates differences between projects, and '*' indicates differences between indicators that are consistent between projects.*

Geoheritage Awareness: Results from the content analysis revealed details about how P2 and P3 educators connected geosites to their lesson (see Figure 4.3). Results of the analysis show that all teacher-development lessons included outdoor learning situated within geosites, and that the focus of the learning objectives was either on geologic or cultural significance of the location, not necessarily both. Records also showed that all program participants were able to connect geosites to their subject specific standards, including other science disciplines, math, building trades, social studies, and ELA.

Geoscience Content: The analysis of the documentation demonstrated that the curricula were more varied in its inclusion of geoscience content, including NGSS and ESLPs (see Figure 4.3). The NGSS ESS was addressed most extensively in the 4th and 8th grade lesson part of P3, where ES is part of the classroom standards. Whereas the majority of other teacher-developed curricula had more limited connections, either addressing a single indicator of ESLPs or was below the classroom grade level of the NGSS ESS DCI.

This was in addition to their classroom standards. For example, ESS concepts were integrated into middle school life and physical science by focusing on modeling the unique ecological community and water movement present at Kitch-iti-kipi spring, and how these were resultant of the unique geohydrological features present at the site.

Science and Engineering Practice, and Crosscutting Concepts: The analysis indicated that all teacher-developed P2 andP3 lessons provided students the opportunity to engage in SEPs and CCCs, either at or below their current grade level (see Figure 4.3). The most common CCCs observed were patterns, energy & matter, systems, and aspects of NOS. These concepts were also present within documentation from the PL field experiences. SEPs such as asking questions, constructing explanations and using models were frequently observed in lesson plans and field observations. Whereas the SEPs of engaging in argument using evidence & obtaining and communicating information grade-level learning experiences were largely absent. Analysis of the collected documentation revealed differences between the inclusion of CCCs & SEPs in the P2 & P3 teacher-developed lesson. For example, records demonstrate that most P3 lessons were designed to engage students in multiple SEPs engaged throughout the multi-day experiences. Whereas P2 students' learning objectives included NOS or SEPs in a few select classes, however, such 3D learning was absent from other subject areas.

Place-Based Stewardship Education: Generally, the guiding principles for Place-Based Stewardship Education (PBSE) were more prevalent in the analysis results of P3 student experiences than P2 experiences (see Figure 4.3). Additionally, artifact analysis demonstrated that some PBSE elements within the criteria were more common across all student experiences. Those elements commonly addressed included student experiences that: were situated in the places familiar to students; included outdoor and field experiences; drew on multiple disciplines and ways of knowing; occurred in multiple grade levels and subjects within the school; and included opportunities to develop social-emotional and professional competencies. Whereas other elements were largely absent within the analyzed documentation. Those elements not addressed included opportunities for students to: build awareness of how a geosite is embedded in broader social systems; take some action as a consequence of their learning; have voice and choice in activity selection; foster reciprocal partnerships beyond classroom needs; participate in public discourse; define their personal values related to topics.

Records show that within each of these generalizations, each project had its own unique strengths. For example, KidZone Youth Assistants in P1 participated in community-based presentations and students involved in P2 had opportunities to explore broader social systems & define personal values during the Indigenous cultural and health science lessons. Additionally, all P3 teacher-developed learning experiences, had opportunities for students to engage in some inquiry based and hands-on learning activities over several weeks.

4.7 Discussion

What effect does a program targeting a wide breadth of K-12 educators from the same school have on participating educators' geoscience pedagogical abilities, content knowledge, and their enactment of geoscience learning with their students? This study attempts to answer this question by applying qualitative and quantitative measures in a site-specific sample of educators of fourth to twelfth students and youth assistants of first to sixth grade summer school students. We found that participation in the program widely increased participants' geoscience pedagogical abilities, content knowledge and enhanced their ability to connect geosites to their unique classroom settings. Additionally, interviews and artifact analysis demonstrated increased inclusion of geosites or geoscience content within the school curriculum. In most cases, lessons developed by the participants engaged students in field-based and experiential activities that were situated in the context of regional or community-based learning. Teachers shared a strong belief that the resulting experiences increased student engagement in learning and strengthened their pedagogical practices. The specific learning gains were unique to each participant based on their background and classroom setting.

Interviews and survey results demonstrated that by participating in the field-based PD sessions, the majority of educators perceived they developed target geoscience concepts, skills and awareness of geosites. This is consistent with other studies (Luera and Murray, 2016; Teed and Franco, 2014; Wee et al., 2007). Additionally, results from interviews suggest that engagement in the authentic, inquiry-based geoscience research as part of the field course and follow-up of the PD increased NOS and understanding of geoscience careers. The gains were seen in educators with limited or modest previous coursework in geology.

Interview data also demonstrates that participants in all projects perceived improvements in pedagogical skills. Both novice and experienced educators perceived benefits, although specific gains generally varied by project or participant's previous capabilities (i.e., system models, inquiry- and field-based). Similar to other research (e.g., Crowley, 2017; Darling-Hammond et al., 2009) ongoing support and mentorship components through implementation were indicated as important aspects for instructional change. The improvement in pedagogical abilities and content knowledge observed in the results implies that the program's design was successful for meeting the diverse needs of a wide-range of educators including those without extensive previous experience in geoscience and teaching.

Results from the P1 and P2 post motivation surveys showed that teachers engaging in multiple days of the workshop felt more confident with geoscience after the field sessions, although field notes revealed persistent misconceptions that needed to be addressed during follow-up sessions or during student field trips. This demonstrated the need for continued support to ensure that concepts are correctly transferred (Crowley, 2017; Yoon et al., 2007), and that teacher-research collaborations may improve practice (Impedovo, 2021).

Interviews and surveys from P2 and P3 show an increase in participants' motivation and interest in geoscience generally increased from participation in the PD activities. Generally, these participants found the program relevant (Semken and Williams, 2008), expressed enjoyment of the time in the field with colleagues, and had appreciation for the follow-up and planning sessions (Bruce et al., 2010). It is notable that both new and self-described 'jaded' teachers held these beliefs. Considerable time was spent with collaborating partners to understand and meet the needs of the school community. The program was specifically designed with input from P2 and P3 teachers to fit their individual and collective preferences while simultaneously targeting the research goals. This supports other literature that calls to move away from "one size fits all" to make the earth sciences relevant to specific cultural groups (Riggs and Alexander, 2007). Additionally, the use of small group work may further support teacher engagement and connection with the geology by building peer relationships in the field (e.g., Stokes and Boyle, 2009; Tedesco and Salazar, 2006).

The interview and survey results collected from P1 participants show drastically different perceptions of motivation and interest, particularly for the activities associated with the community-based investigation. While further research would need to be done to better understand the reasoning behind this perception, research on student engagement suggest that the following are a few aspects of the project design that may have contributed to this perception: limited student voice & choice (e.g., Dolan, 2003, Seiler, 2013), the geosites were close to school with limited scenic beauty (Tessema, 2021), and insufficient psychological preparation for field-work conditions (Orion, 1993).

Interviews, analysis of artifacts, and surveys showed increased integration of geoscience and geosites in K-12 curricula was widely achieved. The P2 & P3 teachers indicated an increased capacity to develop multi-disciplinary lessons through the regional geosites. Analysis of artifacts and field observations corroborates this evidence, showing success integrating geosites into different educational settings, grade-levels, and standards. This aligns with past efforts that have used field work to build multidisciplinary and interdisciplinary connections (e.g., Anderson and Miskimins, 2006; Barrett et al., 2004). Additionally, results from the content analysis indicated wide use of SEPs, CCCs and PBSE guiding principles, however these were limited in breadth and scope depending on the classroom. Similarly, for lessons developed for classrooms with curriculum exclusive of ESS standards, the geoscience content observed was often weak or below grade level. Time to plan lessons and ongoing availability of mentors were common themes in interviews and surveys that participants perceived as important to their success. Interview data demonstrated that collaboration between participants lowered barriers to implementation (e.g., limiting scheduling conflicts in the Fayette field experience, and increasing summer youth assistants' confidence to deliver lessons).

Interview data shows strong perceptions from P2 & P3 that students showed increased engagement with the inclusion of geosites, out-of-classroom, and student-centered experiences (Edwards, 2015; van Der Hoeven Kaft et al., 2011). While measure increases in student learning were beyond the scope of this study, teachers perceived strong student learning gains in content knowledge, including deeper understandings (Mogk and

Goodwin, 2012), nature of science (Shultz et al., 2011), and awareness that science happens within their community (Unsworth et al., 2012).

4.8 Limitations

The review of findings from multiple projects and with a wide variety of educators provides depth in understanding the various opportunities for increasing engagement in geosciences within the pre-college population. The drastic differences between the projects (e.g., school educators vs. summer youth employees) or between individuals within each project (e.g., novice vs. experienced teachers) demonstrates the importance of representing many voices for the reproducibility between different populations. Findings of the qualitative data were not verified with other researchers due to lack of funding and limited involvement of those familiar with the research. However, the agreement between methods, including pre-post tests and surveys, supports the consistency of the findings. Still the study may not necessarily be generalized to other environments due to the role of the principal investigators within the study and small sample size. Rich descriptions of the system and access to instructional materials are provided to support deep insights into the research context and promote transferability of the approach to other school settings.

The extended time spent with participants and the community allowed the researcher to have an extensive understanding of the context and culture within the school. This is particularly helpful for the validity of the finding arising from the qualitative methods employed (Savenye and Robinson, 2005). However, due to the time lag, participants were not able to be consulted during the culminating analysis and reporting phases of the research to verify the researcher's interpretations. Triangulation of data through multiple methods including both qualitative and quantitative measures enhances the credibility of the findings, including accounting for researcher bias, and particularly for understanding effects on participant geoscience pedagogical abilities, content knowledge and motivation. Measures were more limited for student learning and motivations. While the participants felt students increased their knowledge of the topics covered in the units, there was no control group data and triangulation of data was not feasible with the scope of the project and resources available. The longevity of the impact on students and teachers is unknown.

4.9 Conclusions and Implications

In this study we sought to engage students from across K-12 grade-levels in geoscience pathway experiences through in-service teacher professional development and follow-up mentorship. Building on previous geoscience and educational research the Nah Tah Wahsh Geoscience Pathway Programs, which include three distinct projects amongst other activities, was designed and implemented in a tribal community school. A cross-project analysis was conducted to understand the nuances and impacts of the approach on educators from different school settings, and with varying educational and geoscience background experiences. We found the approach effective for increasing the number of geoscience pathway activities students engaged in during their regular scheduled days. This is important for equitable access to the program especially in communities with a large population of URG students. This study sheds light on specific opportunities and obstacles of engaging the different groups within the school setting.

Conducting field observations and informal interviews over the course of the planning year allowed for the program activities to be grounded in the systems of the school setting. This ensured equitable access to all students at the school and removed barriers of implementation (e.g., burden on educators when out-of-school time is required to be involved in PD). Additionally, we found that when educators' interests and needs were included in the design of the field-based PD activities, as was the case with P2 & P3, the program was perceived as highly relevant to the educator. Whereas, when these were not taken into consideration, as with P1 youth assistants, the resulting experiences can lead to negative interest and attitudes towards geosciences. These cross-project differences demonstrate the importance of relationship building activities with all stakeholders within the systems.

This study showed that both teacher and student learning activities benefit from being organized around geosites. Geosites that provide an applicable setting for a range of disciplines and age groups were easily identified. Coordination around one geosite or multiple geosites successfully provided the premise for many content areas learning goals, leading to interdisciplinary and collaborative experiences. The experiences caused deeper understanding of concepts, practices, and career awareness essential for students to successfully move into the geoscience career pathway (Levine et al., 2009).

This study showed that most of the content for the learning experiences in P1 & P3 that targeted ESS learning goals came from the field experiences. This was different for P2 as the field course did not lead to ESS related objectives. However, the field experiences were still valued and exposed students to geosites with cultural and historical relevance. As with other studies, the results show that learning in the field about familiar places elicited high levels of engagement from multiple grade levels of students as well as in novice and experienced educators. This study shows that an ongoing and holistic approach can engage all of these populations in a single university-community partnership. This approach broke down barriers (e.g., transportation, need for substitute teachers) and supported a collaborative professional environment.

The follow-up mentorship activities were key to the program's ability to meet the diverse needs of the wide range of classroom settings available to be engaged. Rural schools, such as those in this study are isolated and often lack human support (Zinger, 2020). In this study the ongoing partnership between the researcher and educators allowed for responsiveness to the unique needs of the teachers and classroom topics. The relationships also built geoscience career knowledge and understanding of the nature of science. Additionally, the structure of the relationship honored the professional capabilities of the teachers as well as their location as a learner. Allowing them to ask for well-timed support or to brainstorm solutions when they needed it. Additionally, the close trust and familiarity with the researcher allowed for impromptu 'coaching' or direct teaching support and offered another avenue to engaging students in the geoscience pathways. The mentorship activities are especially important for schools with rapid teacher turn-over where extra support is needed for classroom logistics and to model pedagogies essential to science. This has implications for the expected demand for new teachers in upcoming years.

Many programs have been offered for K–12 teachers with the ultimate goal of increasing participation in the geosciences by underrepresented students (e.g., Pecore et al., 2007; Sedlock and Metzger, 2007). Other programs have infused field- or place-based methods through in-service teacher geoscience PD programs (e.g., Luera and Murray, 2016; Williams and Semken, 2011). However, this is the first study to our knowledge that characterizes the outcomes of a PD program that attempts to promote geoscience pathway activities throughout students' K-12 experiences through a prolonged and whole school approach. The ease of integration through geosites, the strengthening of relationships of school-community members and the resulting student learning suggests its broad applicability. Additional studies of the approach are still needed to replicate these findings with other situations, at the lower elementary level and with other assessments (Semken et al., 2017). Finally, further research is needed to investigate ways other partners (e.g., regional parks, educational technologist, workforce development agencies) could be leveraged to further remove barriers, promote sustainability of efforts and influence policy making.

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A Appendix: Unifying Chapter

*Table A.1. Information about the educators participating in each of the three case studies. *Note that under subjects taught the number of subjects may be higher than the total number of participants because educators teach multiple content areas*

Case Study (years)	**District & Community Information**	**Educators**	**Grade Level**	**Subjects***
MiTEP EarthCache ™ Program (2011- 2014)	Large, Urban Public-School Districts in Southern Michigan: Grand Rapids (n=3) Kalamazoo (n=20) Jackson (n=12)	n= 35 Cohort 2 (n= 3) Cohort 3 (n= 17) Cohort 4 (n=15)	K-5 (n=4) 6-8 (n=12) 9-12 (n=12)	Earth science (n=10) General science including Some geoscience (n=15) STEM standards but no geoscience (n=10)
Western U.P. Virtual Geosite Investigations (2019-2021)	Small, Rural Public-School Districts in Baraga, Gogebic, Houghton, & Keweenaw Counties; Western Upper Peninsula of Michigan	n=17 Full Program (n=5) Workshop Only (n=10) Lesson Only (n=2)	K-5 (n=3) 6-8 (n=5) 9-12 (n=6) K-12 (n=4)	Science (n=10) History/Social Studies (n=3) Title 1 (n = 1) Mathematics (n=6) Technology (n=2) ELA (n=3)
Nah Tah Wahsh Geoscience Pathways Program (2012-2015)	Small, Rural Public Service Academy & Youth Service in Hannahville Indian Community; Central Upper Peninsula of Michigan	n= 23 summer youth assistants (n=6) educators (n=17)	Summer 1st-6th (n=6) K-5 (n=4) 6-8 (n=3) 9-12(n=7) K-12(n=3)	Summer Classes (n=6) All subject at grade level including geoscience (n=6) Science only (n=2) Social Studies (n=1) Title 1/ Gifted (n = 1) Mathematics (n=1) ELA (n=1) Art (n=1) Vocational - Construction (n=1) Native Language & Culture (n=2)

Table A.2.This table displays the major elements of each phase of the proposed professional development model by case study.

Phases of PD Model	Engage Schools & Community			Teacher Designed Lessons			
	Partnership Formation	**Collaborative Program Design**	**Teacher Geoscience Experiences**	**Define**	**Develop**	**Deliver**	**Reflect**
MiTEP Earth-Cache	University faculty & graduate students from MTU, WMU & GVSU; Large urban districts; community partners chosen based on geosites NSF MSP funding	Faculty & graduate students designed PD; districts administration selected teachers & provided input on program; limited input from participants	2-week summer ES field course; sites & experts from many sites generally not near schools	Teachers selected sites from list; Defined topics based on ESLP Big Ideas & Curriculum Connections; Refined based on EC parameters	Teacher developed EC for publication online; Template provided; asynchronous; university support provided	EC published online; most teachers adapted the materials to be used virtually or provided 'EC-like' experience based on sites in or near the school community.	Provided time over multiple years; focus group sessions and individual written feedback
Virtual Geosite Investi-gations	Rural Public-School Districts of Michigan's' Western Upper Peninsula; Intermediate School Districts; regional STEM education network; regional place-based education hub; university staff;	Leadership team designed the PD including: ISD, REMC, STEM network and university staff. District needs and school improvement plans were consulted with no direct input from participants	1-day workshop, designed to run each summer in a new location; sites and experts are within the regional area; virtual and outdoor learning	Teachers selected the site and lesson objectives based on connection to schools and curriculum. There were no expectations that geoscience standards be addressed	Educators developed lessons and took 360-degree images asynchronously; templates provided; optional work sessions; support provided on request	Through teachers' lessons, students developed content for virtual experiences utilizing camera images provided by teachers or taking their own; some students engaged with VR software	1-Due to Covid-19 restrictions, teachers completed individual reflections asynchronousl y after the student activity was completed.
Nah Tah Wahsh	A rural district located on a Potawatomi Tribal Community in the Upper Peninsula; MTU faculty & GK12 Fellow; Community members; Teachers; Administration	Leadership team from educators, GK12 Fellow, school admin. with input from youth services and environmental services; with permission from tribal council	Three projects: all field based with 1 to 6 days in the field; local or regional sites; some participation in authentic research in addition to inquiry-based explorations of landscapes	Educators selected their own geosites and standards based on curricular and student needs; There were no expectations that geoscience standards be addressed	Educators were provided time, support and templates provided; in most cases this was done in collaboration with another educator of their choosing	1-day Youth Assistant delivered a single lesson in a classroom setting; all teachers deliver multi-day lessons which included a field visit to a local or regional geosite	Participants in all three projects had time to reflect collaboratively ; some also had individual reflections built into the PD experiences

Table A.3.This table displays the frequency of co-occurring themes apparent in transcript interviews from the MiTEP EarthCache and Nah Tah Wahsh Pathways Case Studies. Note that no interview data was collected in the Virtual Geosite Investigation Programs.

	MiTEP EarthCache™ Case Study					**Nah Tah Wahsh Case Study**				
	C3 Groups (n=3)	**C4 Groups (n=3)**	**C2, C3 & C4 (n=6)**	**Adult Adm (n=3)**	**Youth Asst (n=5)**	**HS (n=9)**	**ES-HS (n=5)**	**6th (n=1)**	**7th (n=1)**	**8th (n=1)**
Increase capacity to develop multi-disciplinary lessons through place										
Increased confidence to teach earth science and/or with geosites										
Perceived gain in pedagogical abilities; gains unique to individual										
Increased ability to teach earth science through a particular place										
Ability to use Google Earth as a vehicle for virtual exploration of geosites										

B Appendix: MiTEP EarthCache™ Program Case Study

Table B.1. Table displays information about the student population of the three public school districts participating in the MiTEP EarthCache™ Program during the years of implementation. Data Set: Michigan's Center for Educational Performance and Information, Student Count for Jackson Public Schools, Kalamazoo Public Schools, Grand Rapids Public Schools, All Grades and All Students (2011-14). https://www.mischooldata.org/ (accessed December 22, 2020).

District	Year	Total number of Students	%Economically Disadvantaged	% African American	% Hispanic /Latino
Jackson Public Schools (JPS)	2011-12	6063	74.00%	38.46%	5.86%
	2012-13	5982	70%	36.99%	6.35%
	2013-14	5823	69%	36.13%	6.41%
Grand Rapids Public Schools (GRPS)	2011-12	18,093	83.73%	36.16%	33.16%
	2012-13	17,444	81.56%	34.71%	34.81%
	2013-14	16,821	81.23%	33.42%	36.29%
Kalamazoo Public Schools (KPS)	2011-12	12,600	69.73%	44.59%	10.91%
	2012-13	12,627	72.36%	43.89%	11.56%
	2013-14	12,567	71.34%	42.51%	11.87%

Table B.2. Information about the MiTEP EarthCache™ Program participants. Information was self-reported by participants in the initial pre-program survey.

Districts	Grand Rapids Public Schools (n= 3) Kalamazoo Public Schools (n= 20) Jackson Public Schools (n= 12)
# of Teachers	N= 35
Subject Taught	Earth science (n=10) General science (includes some earth science standards) (n= 15) STEM but no earth science standards in curriculum (n= 10)
Grade Levels Taught	Elementary (n=4) Middle School (n=19) High School (n=12)
# of Previous College Level Earth Science Courses	>11 courses (n=5) 6-10 courses (n=9) 1-5 courses(n=15) No prior courses (n=2)

Table B.3. Information collected from MiTEP EarthCache^{TM} participants through the 2021 longitudinal follow-up survey (n= 20, 69% completion). The information provides an understanding of long-term position changes following the completion of the program.

Survey Response Rate Information					
	Total original MiTEP participants including cohort 2, 3 and 4	43			
	Email contact information	29	No email contact info	14	
Which MiTEP cohort did you participate in?			**% of responses**		
	C2	1	5%		
	C3	14	70%		
	C4	5	25%		
When you participated in MiTEP, which district did you work for?			**% of responses**		
	Kalamazoo Public Schools	12	60%		
	Jackson Public Schools	6	30%		
	Grand Rapids	1	5%		
	Jackson Intermediate School District	1	5%		
In the years since participating with MiTEP, how many years have you:		**None**	**1 -3 years**	**4-6 years**	**6+ years**
	worked directly with students?	2	3	1	13
	taught courses that included earth science concepts?	3	6	3	8
	taught courses that included other sciences?	3	7	2	8
	taught elementary students?	14	5	1	0
	taught middle school students?	10	3	3	4
	taught high school students?	12	1	1	6
	taught post-secondary students or adults?	19	0	0	1

Table B.4. Information about each data collection methods including the year, number of participants and the research objective or emergent theme.

Instrument	Geo-science Content	Geo-science Skills	Tech-nology Skills	Ped-agogical Ability	Class-room Practice	Comm-unity Benefits
2011 Group Interviews (n=19)	**x**	**x**	**x**	**x**		**x**
2012 Pre/Post Visit EC Survey (n=15)	**x**	**x**				
2012 Site Specific EC Survey (n=14)	**x**	**x**	**x**	**x**		
2012 Post- EC Development Survey (n=35)	**x**	**x**		**x**	**x**	**x**
2012 Group Interviews (n=35)	**x**			**x**		**x**
2014 Semi-Structured Interviews (n=7)	**x**	**x**	**x**	**x**	**x**	**x**
2021 Delayed Post Survey (n=21)				**x**	**x**	
2020 Analysis of published Geosite Lessons	**x**			**x**		**x**
Total Instruments	**8**	**5**	**3**	**8**	**2**	**6**

*Table B.5. Information about the geosite lessons published to the internet through the MiTEP EarthCache™ Program. *Note that the statistics displayed were based on the total number of visitors as of June 17, 2020.*

Number of MiTEP-Developed Geosite Lessons Published		
	on geocaching.com	on mitep.mtu.edu
	41	6
Year the of Geosite Lessons Publication		
2011	2012	2013-14
23	19	5
Number of Visits to the EarthCaches™ Published on the Geocaching Website*		
Total visits = 2,849	Visits Per Site	Annually Per Site
Mean	69	9
Median	60	8
Max	164	19
Min	16	2

Table B.6. Results from the 2012 Pre/Post Visit EC Survey (n=15, 100% completion) five item composite for geospatial navigation skills.

	Pre-survey	**Post-survey**
Mean	2.52	3.85
Standard Deviation	0.78	0.60
Cronbach's Alpha	0.754	0.734

Table B.7. Coded results from the Post- EarthCache^{TM} Visit Survey (n=15, 100% completion) the open-ended question: Would you consider visiting an EarthCache^{TM} site again? Why or Why not? Post-Test questions

Grouping	Example Answers
All 15 participants said they would consider visiting an EC Site again.	*"Yes, if I was going on a road trip I think it would make the drive much more interesting."* *"Yes, in my classroom to help teach concepts or devise an inquiry-based lesson."*
10 of 15 responses expressed explicit enjoyment of finding EC.	*"Yes, it is a fun, interesting way to sightsee and learn something new about where I am and the Earth around me."*
11 of 15 participant responses mentioned that they would visit an EarthCache again because it provided a learning experience.	
Three (of 15) C4 participants indicated that visiting EC was a good way to learn earth science concepts.	"*Yes, these EarthCaches that we visited were very valuable for understanding earth science concepts. Great programs."*
8 of 15 participants indicated that they would visit ECs again because they are a way to learn about the geology of an area. Many of these people indicated that they might not have known about a particular geosite if it had not have been for the EC.	Participant 8: "*Yes. Sites are educational and are good examples of geologic structures, features, landforms and related history of Michigan"* Participant 5: *"Yes, I think these were a cool way to find geo-significant places often you've driven by or overlooked."* Participant 2: "*Yes, I have seen some amazing places that I wouldn't have known about if it wasn't for EarthCache*." Participant 5 "*There's a lot more geo-significant places than I originally knew."*

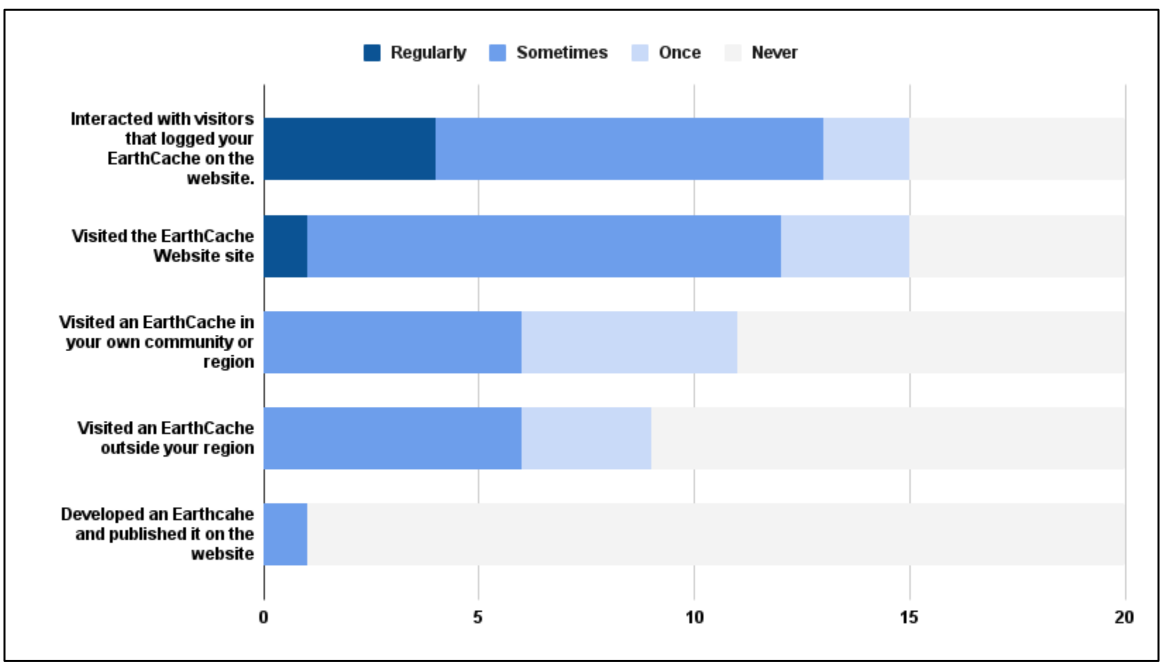

Figure B.1. Results from the 2021 survey (n= 20) Likert-type item: Choose the response that best describes how often you personally conducted each of the following activities since participating in MiTEP.

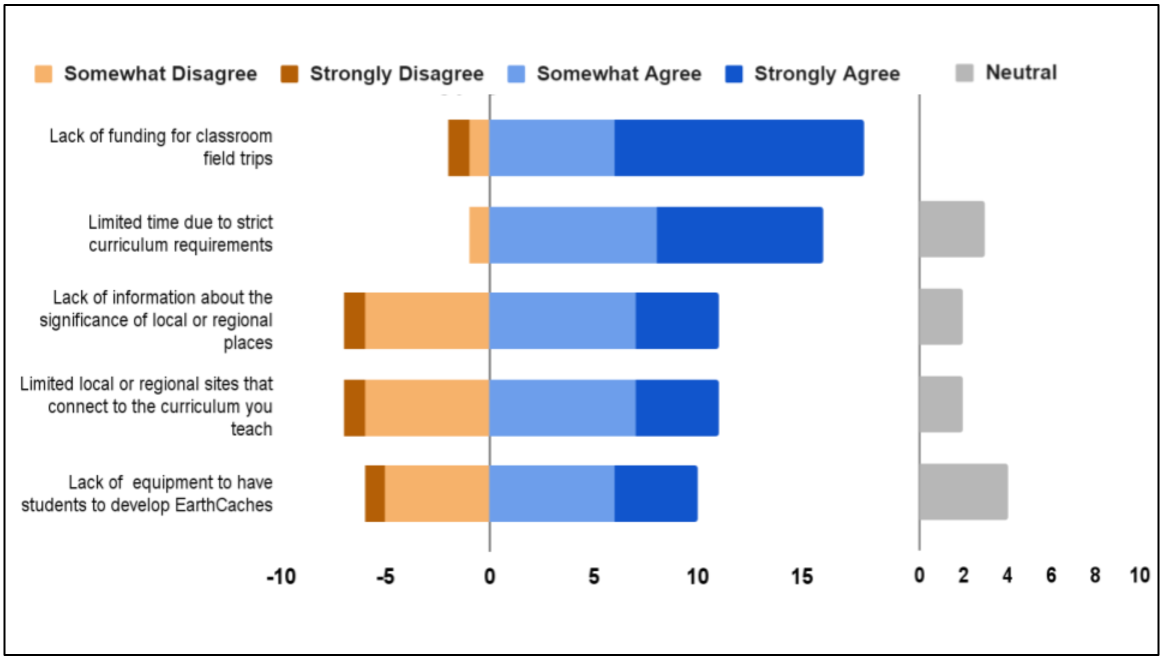

Figure B.2.Results from the 2021 survey (n= 20) Likert-type item: Responses to previous group interviews and surveys indicated that there were many barriers to integrating EarthCaching or similar activities into many classroom settings. To which extent do you agree that the following are current barriers to implementation.

C Appendix: Virtual Geosite Investigation Case Study

Table C.1. The logic model for the Virtual Geosite Investigations Program.

Resources & Assets	Goals.	Activities	Outputs	Intended Outcomes
Overlapping Missions between partners: LSSI, REMC1, Western U.P. MiSTEM Network, MTU (CSEO, GLRC, & GMES), and schools- ISD, local districts Geologically significant locations and events MiTEP EarthCaches Overlap in standards: NGSS, MiTEP, Common Core, MITECS, etc. Federal funding MSGC/NASA with state & local agency match	1) Increase teacher pedagogical and content knowledge in place-based, geoscience & technology integration 2) Increase number of geoscience and technology learning experiences 3) Raise awareness of regional geosites and phenomena 4) Foster stronger community partnerships	**Project Initiation** • Educator recruitment • Development of professional learning experience including exemplar VGIs and other resources **Summer Workshop** • Geosite Investigations through Virtual Field Experiences Workshop modeling place-based, culturally centered, and the integration of technology skills and geoscience concepts **Follow Up Sessions** • Mini-sessions incorporated into 3 other Western U.P. Technology Workshops **Development of VGIs in Classrooms** • Ongoing resource and technical support from REMC1; teacher leadership opportunities; further PD sessions and mentorship provide by LSSI and the Western U.P. MiSTEM Network	• Example Virtual Field Experience: Huron Creek Watershed • Program Website • 15 K-12 and informal educators engaged in the summer workshop • 46+ teachers engage in a virtual geosite exploration during mini-sessions • 6 VGIs created by teachers and partners • ~160 students engaged in experiences situated in WUP geosites • 4 professional leadership opportunities for teachers	Partnership forming and capacity building Student achieve-ment Increase earth science literacy and technology literacy Improved awareness of geosites and other significant places Teacher leadership opport-unities

Table C.2. Virtual Geosite Investigation summer workshop participants' demographic and background information collected through the Pre-Workshop Survey.

Survey Metric	n
Total Pre-Survey Respondents	15
Total Districts	7
Total Schools	9
Position	
K-12 Teachers	11
Program Coordinator	3
Community Partner	1
Grade Levels (participants may be counted more than once)	
Elementary	3
Middle School	5
High School	6
K-12	4
Subject Areas (participants may be counted more than once)	
Science (at least some)	10
History/Social Studies	3
Title 1	1
Mathematics	6
Technology	2
ELA	3
How often do you teach students Earth Science concepts currently?	
never	2
some lessons	11
most lessons	1
How often do you use examples of geo-significant places when teaching students standards-based concepts?	
never	1
some lessons	11
most lessons	2

Table C.3. Details of the Virtual Geosite Investigation development at C.J. Sullivan Elementary School, L'Anse Area Schools

Situation/ Inputs	Activities	Outputs/ Impacts
Lead Teacher: 2019 was at the elementary school as a 5th grade teacher, moved to middle school to be the science teacher in the 2020-21 school year No partner teachers were engaged; strong connection to project leadership team and Geoheritage mentor Students: 5th grade science & writing 2019-2020, then same student in 6th grade science during 2020-2021, L'Anse School District Teacher participation in program activities: Participated in 2019 summer workshop, kickoff (virtually), mentorship support from 2019-2021 including content expert and technical support Utilized resources from resource clearing house in 2019-2020 and 2020- 2021 school year Geosites: L'Anse Township Park, Mouth of Huron, Pointe Abbaye, Eric's Bridge, Black Creek, Silver River	Teacher researched important local geosites that would likely engage students and could be inclusive to curriculum. Students engaged in a VR Google Expedition of rain forest; then promoted to develop their own VGI using 360-degree photos of local geosites. Students worked in groups to research and write about the interacting earth systems in one of the selected geosites. Students interacted with VGI mentors in Spring of 2020 to complete their projects. Student engagement and interest has prompted educators to revisit the sites at different times of year to add further to the existing VGI. Mentorship meetings with program leadership team	VGI developed: Earth system explorations in multiple L'Anse geosites VGI published in Google Poly Document with written content including links to 360-degree photos Completed regional VGI for popular geosites near Baraga, Pt Abbaye and Mouth of Huron. 36 students engaged in development of the VGI experience 1 teacher leadership opportunity: presentation at virtual PD session for national audience Educator plans to continue with a similar project connected to exploring how seasons change. The team participation in the 2021 Lake Superior Celebration

Table C.4. Details of the Virtual Geosite Investigation development at the elementary school in the Ewen-Trout Creek School District

Situation/ Inputs	Activities	Outputs/ Impacts
School: Ewen Trout Creek School District Lead teacher: 7th grade world history teacher and K-6th grade Title I interventionist Partner teacher: 4th, 5th and 6th grade teacher, English language arts and social studies Classroom: 6th grade students during the 2019-2020 school year, part of geography and writing lessons. Team participation in program activities: • Leader teacher participated in the 2019 summer workshop and follow-up sessions, • mentorship support from 2019-2021 including content expert & technical support Utilized resources from resource clearing house in 2019-2020 and 2020- 2021 school year Ontonagon County geosite: Bond Falls	Lead teacher visited geosite with a community partner and took photos. Teacher recruited a partner teacher at school who did not attend a workshop to support work with students. Gogebic Ontonagon ISD staff and REMC1 provided technical support Students selected an image taken at the falls, then researched and wrote 3 points of interest to be included in the VR geo investigation. Mentorship meetings with program leadership team	VGI Developed: • Multiple sites at Bond Falls in winter • VGI published in Google Poly • 281+ views from December 2020 to June 2021 • Document with captions including links to 360-degree photos 2 teachers and 2 additional community partners engaged in the outdoor and/or virtual field experience 8 students engaged in development of the VGI experience 1 teacher leadership opportunity The team participation in the 2021 Lake Superior Celebration Educator plans to continue with another student developed VGI connected to the Porcupine Mountain State Park.

Table C.5. Details of the Virtual Geosite Investigation development at Dollar Bay High School, Dollar Bay Tamarack School District

Situation/ Inputs	Activities	Outputs/ Impacts
Lead Teacher: 8th-12th grade social studies and history No partner teachers were engaged Class: 10th and 11th grade students participated during their high school history class (2020) and/or economics class (2021). The shift in subject areas was due to disruptions caused by the pandemic Team participation in program activities • Participated in 2019 summer Workshop and Kickoff (face-to-face), • Mentorship support from 2019-2021 including field experience, content expert & technical support Geosite: Osceola Township Historic Sites within Houghton County. Osceola township has in their management plan to update the recreation areas including the historical significance. Lake Superior Stewardship Initiative (LSSI) Team: The project was included as one aspect of the school's 2019-2021 LSSI Stewardship Project Mini-grant proposal. The district had created several opportunities for students to engage in place-based projects throughout their K-12 careers. This project was a pilot to more formally connect high school history and other social sciences courses.	Teachers visited sites with Geoheritage expert Teacher built partnership with the township to create VGIs that would benefit the recreation plan All students in class conducted research on each of the Osceola Township sites; there was intent for the tour to be put on Osceola Twp. Webpage. Some students participated in transferring the research onto the RoundMe VR platform Teacher is engaged with other teachers in the building and district as well as other districts to discuss how to deepen impacts and systematize place-based education.	VGI Developed: • 1 geosite at Electric Park was loaded into Round Me (https://roundme.com/tour/718542/view/2263313/) • Several other photos and research compiled into a document Further geosites were not made into VGIs due to the disruptions of Covid-19 pandemic and teacher subsequent retirement 2 students engaged in development of the VGI experience; 10+ students conducted research on geosites The team participation in the 2021 Lake Superior Celebration

Table C.6. Details of the Virtual Geosite Investigation design at Horizons High School, Calumet Laurium Keweenaw Public Schools

Situation/ Inputs	Activities	Outputs/ Impacts
Co-lead Teacher: 9^{th}-12^{th} grade language arts Co-lead Teacher: 9^{th}-12^{th} grade math & science Horizons High School is an alternative high school within the Calumet Laurium Keweenaw Public Schools Team participation in program activities: • One co-lead participated in 2019 summer Workshop • Visited the geosite with a Geoheritage Expert • Both teachers participated in mentorship support from 2019-2021 including content & technical support sessions Classroom: 9^{th}-12^{th} grade high school students in language arts class engaged in the development of the VGI and Google Site Geosite: Gratiot River Park is located in Keweenaw County, on the shores of Lake Superior and at the mouth of the Gratiot River. It is the only county-owned park. Lake Superior Stewardship Initiative (LSSI) Team: A partnership was developed prior to this project between the school and the county to support clean-up and Geoheritage awareness at the park. The teachers were part of a LSSI team that had done place-based stewardship projects at the selected geosite in the past. The project was included as one aspect of the 2019-2021 LSSI Stewardship Project Mini-grant proposals.	Gratiot River Park. Teachers and students visited the park together with a Geoheritage expert to take 360-degree photo and discuss the VGI inclusion in the website they were designing for the park The VGI is a part of a larger Google Site that is linked to the Keweenaw County website Students developed geology infographics focused on the different beach stone present. These are embedded into one VGI shared by the whole class Horizons developed an infographic template for their students to use as they drafted their website	Development of VGI as part of a larger website built to support their community partner: see https://sites.google.com/clkschools.org/gratiotriverparkrocks/home 2 teachers and 1 additional community partner engaged in the outdoor and/or virtual field experience 4 students participated in the development of the VGI and park website A Rock Infographic Guide template for students was developed The team participation in the 2021 Lake Superior Celebration

Table C.7. Details of the Virtual Geosite Investigation development at Washington Middle School, part of Calumet Laurium Keweenaw Public Schools

Situation/ Inputs	**Activities**	**Outputs/ Impacts**
Co-Lead Teacher: middle school technology teacher in 2019-2020; transitioned to middle school science teacher then to district technology coordinator in 2020-21 Co-Lead Teacher: middle school science teacher in 2019-2020, retired and supported project in 2020-21 SY Class: 7th grade students participated during core science & technology classes Team participation in program activities: • One Co-lead participated in 2019 summer Workshop • Both teachers participated in mentorship support from 2019-2021 including content and technical support sessions. School has own 360-degree camera and technology support Geosite: Calumet Waterworks Park on Lake Superior & adjacent school forest located in Houghton County Lake Superior Stewardship Initiative (LSSI) Team: The teachers had done place-based projects at the geosite in the past. The project was included as one aspect of the 2019-2021 LSSI Stewardship Project Mini-grant proposals.	The lead teacher recruited a partner teacher from their school to connect the VGI to ongoing projects, and serve as content expert. Teachers and students visited the site to take images during an annual field experience at the adjacent sites to establish/collect data at native planting and forest health plots. Covid-19 pandemic created disruptions before the second planned trip. Retirement and job changes stalled the development of the VGI to date, plan is in place to complete Teacher is engaged with other teachers in the building and district as well as other districts to discuss how to deepen impacts and systematize place-based education	A collection of 360-degree images and videos of the field experience with students at Washington Middle School 2 teachers and 1 partner engaged in the outdoor and/or virtual field experience 110, 7th grade students engaged in development of the VGI experience Educators plan to continue building this VGI to support annual field experience and related Community based Stewardship Projects. Participation in the program led to coordination between teachers to integrate technology projects into existing interdisciplinary stewardship projects

D Appendix: Nah Tah Wahsh Pathways Case Study

Table D.1a. Participant information for the Summer Youth KidZone Project.

Grade Levels	# of Youth Assistant	Gender	# of Youth Assistant
10th	5	Female	4
12th	1	Male	2

Table D.1b. Participant information for the Nah Tah Wahsh Project 2, Fayette State Park Interdisciplinary Lessons. Table key: Y= yes, N= no, X= indicates that criterion is true.

Grade Level				Current Courses		Participation Level		Experience Level		Geoscience Background	
K - 3	4 - 5	6 - 8	9 - 12	Subject	Is earth science included ?	Teacher Field Day	Designed Field-Based Lesson	# of years teaching	Year of Current Position	# college level science courses	# college level geoscience courses
			X	Science	Y	X	X	7	1st	11-15	1-5
			X	Social Studies	Y	X	X	9	5th	6-10	1-5
X	X	X	X	Art	N	X	X	25+	13th	1-5	1-5
	X	X	X	Native Language & Culture	N	X	X	3.5	3rd	1-5	0
	X	X	X	Native Language & Culture Aide	N		X	unknown	unknown	unknown	unknown
			X	English Literature Arts	N	X	X	7	1st	1-5	0
			X	Vocational - Construction	N		X	unknown	unknown	unknown	unknown
			X	Mathematics	N	X	X	20+	1st	>15	0
X			X	Health/PE	N	X	X	2.5	1st	1-5	1-5
	X			5th grade	Y	X		6	6th	1-5	0
X				2nd grade	Y	X		7	5th	1-5	1-5

Table D.1c. Participant information for the Nah Tah Wahsh Project 3, U.P. Geoheritage Field Investigations. Table key: Y= yes, N= no, F= full course, P= part of the course, X= indicates that criterion is true.

Grade Level				Current Courses		Participation Level		Experience Level
K - 3	4 - 5	6 - 8	9 - 12	Subject	Is earth science included in classroom-based standards?	Field Institute	Lesson Implementation	# of years teaching
	X			K-8th, Gifted/Title 1	N	F	Y	20+
	X			4th grade	Y	P	Y	15+
		X		6th grade	Y (mostly biology with some earth science)	P	Y	20+
		X		7th grade	Y (mostly physical with some earth science)	P	Y	>2
		X		8th grade	Y (mostly earth science with some physical science)	F	Y	5+
			X	11th grade Chemistry	Y (all high school science: earth science, biology, chemistry, physical)	F	Y	15+

Table D.2.Nah Tah Wahsh Pathways Program Logic Model.

Resources & Assets	Activities	Outputs	Outcomes		
			Short-term	Mid-term	Long-term
▪Research-based guidance on geoscience-based strategies ▪Hannahville Community: Administrators from Nah Tah Wahsh PSA /Hannahville Indian School, Youth Services, Natural Resource Department ▪University Partners: MTU GK12 Watersheds Program Graduate Fellow, and other Geoscience & Educational Researchers ▪Regional and community based Geologically Significant Locations ▪Funding: MSGC, NSF, in-kind match from MTU GMES Depart. & Hannahville	<u>2012- 2013 School Year</u> ▪Observations & co-teaching activities HS Science Course ▪Collaborative Program Planning 2013 Summer ▪P1: Summer Youth Kids Zone, Water Budget Analysis & Student led Water Lessons <u>2013 - 2014 School Year</u> ▪P2: Fayette Interdisciplinary Lessons: Teacher Field Workshop, Lesson Design, Highs School student Fayette lessons ▪Observations & co-teaching activities in MS classrooms ▪Research: Depas Watershed & Kitch-iti-kipi Spring <u>2014-2015 School Year</u> ▪P3: U.P. Geoheritage Field Course: UP Geology Field Course, Lesson Design, Student lessons ▪Continued Research Projects	▪17 educators & 6 summer youth assistants engaged in field-based geoscience PD ▪15 educators & 6 summer youth assistants engaged in geoscience pathway curriculum development & implementation ▪173 K-12 students engaged in learning experience during classroom ▪8 Summer Youth Student engaged in summer learning experience & lesson planning for x? 2nd - 6th grade students. ▪2 teacher presentations at State Conferences & 2 presentations at regional or national geoscience conferences	▪Increased teacher geoscience content knowledge, including & geosite awareness ▪Increased teacher knowledge of instructional strategies to engage students in geoscience content and/or geosites	▪Increased inclusion of geoscience, geosite & use of instructional strategies ▪Increased positive student attitudes towards learning ▪Increased student understanding of geoscience content or geosites ▪Enhanced Partnerships.	▪Increased Earth Science Literacy within the Community ▪Increased enrollment in geoscience or related degree programs

Table D.3. Provides a description of Project 1: Summer Youth KidZone. See supplemental materials for further details.

Situation/ Inputs	Activities	Outputs /Products	Intended Outcomes
Hannahville Youth Services: KidZone & Summer Youth Employment Programs 6 KidZone Youth Assistant- four 10th grade & one 12th grade students 8 Day Care Youth Assistant (Control Group) 3 KidZone Teachers 75 1st-6th grade students, separated by grade level Hannahville Tribal Employees with geoscience related careers Community Members & GK12 Fellow from MTU	Watershed Investigations: • Outdoor Field Skills: GPS Navigation & Observing Watershed components • Watershed Models & Simulations • Google Earth Virtual Tours: Connecting Watersheds Community Talent Tours • Water & Wastewater Treatment: Supervisor & Operator • Department of Planning and Evaluation: Environmental Program Director, Water Quality Specialist, & GIS Specialist Water Budget Investigation • What volume of precipitation is recharged into groundwater aquifer? Is Hannahville's water use sustainable? • Calculation of Total Input: Precipitation - Regional Data & School Weather Station • Depas Tributary Watershed Land Cover Investigations (GIS) • Measurement & Hands-on activities for Discharge, Evaporation, Infiltrations and Transpirations CA • Water Budget Analysis & Conclusions Public Communication & Lesson Design • Six youth-developed & implemented earth science lessons with KidZone 1st-6th grade students • Three Youth-developed informational videos for community members: Watershed, Water Cycle, and Water/Wastewater	Partnership building through Youth Services and Waste Data and conclusions from a Community-based Water Budget Investigation Three youth-developed informational videos for community members (Watershed, Water Cycle, and Water/Wastewater) Six youth-led earth science lesson plans Community Based Maps applying GIS and open resource data A series of student center, field-based investigation activities	Increase awareness of geoscience related tribal careers & departments Build/Improve mutually beneficial relationships between school and community groups Incorporate student-centered investigations into existing youth programs Content knowledge & attitudes towards topics Long term Increase earth systems science literacy among Nah Tah Wahsh /Hannahville school community

Table D.4. Provides a description of project 2: Fayette Historical State Park- Interdisciplinary Lessons.

Situation/ Inputs	Activities	Outputs /Products	Intended Outcomes

Nah Tah Wahsh PSA/Hannahville Indian School: All 9-12th grade students & teachers
 	
Fayette State Park: Coastal and Limestone Features, Niagara Escarpment, Cultural Iron Smelting, Indigenous History
 	
Additional school and community members
 	
School Supports: Dedicated time for fall field day and follow-up after-school sessions; bus transportation; administrator support
 	
GK12 Fellow from MTU, other experts
	Fayette State Park Field-based Workshop
	• 1-day workshop during fall scheduled inservice day
	• Teachers participate in an "EarthCache- like" exploration of Fayette Historical State Park
	• Objectives focused on:
	  ○ geo-navigational skills (GPS or Mapping) to locate geologic important areas
	  ○ Interpretation of regional geologically significant landscapes and other inquiry based educational tasks
	  ○ Modeling effective pedagogical practices
	Teacher Lesson Design
	• 11 High School educators developed interdisciplinary standards-based, field investigations through a series of afterschool professional development and work sessions
	• Team-taught interdisciplinary lesson over 3 days
	• Reflected and Revise lessons to promote more student-centered learning environments
	Student Experiences
	• All students participated in five interdisciplinary standards-based lessons that spanned multiple class periods.
	• Each lesson included a portion that took place during a field day within the Geoheritage site.
		PD Agenda & accompanying resources
		
		Student Field Day agenda & accompanying resources
		
		5, multi-day, interdisciplinary lessons
		• Fayette, an Indigenous Perspective (Culture & Language)
		• Photography and Descriptive Writing & Rubric (ELA & Art)
		• What is the importance of a slope on a roof system? (Building Trades & Mathematics)
		• How are scientific practices and procedures determined to be either approved or unapproved? (Science & Health)
		• The importance of music within present & past cultures (Social Studies & Music)
		Strengthened partnerships between teachers within the school
		
		Increased pedagogical capacity to deliver outdoor, place-based and interdisciplinary lessons.
			Increase educator's geoscience pedagogical and content knowledge including outdoor and place-centric learning; inquiry-based investigations
			
			Build/Improve mutually beneficial relationships within school groups; create a collaborative working environment
			
			Incorporate student-centered investigations into existing youth programs
			
			Long-term
			Increase earth systems science literacy among Nah Tah Wahsh students & educators

Table D.5. Provides a description of project 3: U.P. Geoheritage Field Investigations. See supplemental materials for further details.

Situation/ Inputs	Activities	Outputs /Products	Intended Outcomes
Nah Tah Wahsh PSA/Hannahville Indian School: all 4th, 6th-8th, 11th grade students 6 4th-12th grade teachers standards -based science classes School Supports: Dedicated time for follow-up after-school sessions; bus transportation; administrator support U.P. Geoheritage Sites located within the community and across the region GK12 Fellow from MTU, other post-secondary and community experts	U.P. Geoheritage Field Course • 1-week summer institute designed specifically for Nah Tah Wahsh teachers • Visited & studied significant locations that could be visited during the school year • Topics connected to Earth & space science (ESS) & geohistorical examples • Focused on modeling effective pedagogical practices & included team building • Authentic research part of the Kitch-iti-kipi Spring Characterization and the Depas Tributary Water Budget Studies • Incorporate collaborative partners Teacher Lesson Design • school-year mentor/work sessions, • whole group check-ins; individual & • whole group & individual reflection time • integration of ESS and geosite examples into core-science Student Experiences • all students experienced standards-based, ESS learning connected to U.P. geosites • multi-day lessons, with at least one field day • 8th grade and 11th grade students participated in authentic research at Kitch-iti-kipi Spring or Depas Tributary	5 lesson plans created at 5 grade levels and 56 students engaged the learning • 4th grade: What can we learn about Delta County's past by looking at rocks and land formations? @ Peninsula Point, Stonington, MI • 6th grade: How can change in one part of the ecosystem affect change in other parts of the ecosystem? @ Kitch-iti-kipi Spring & Indian Lake • 7th grade: Why does water at Kitch-iti-kipi Spring behave the way it does? Could the Source of the water at the Spring be from Lake Superior? @ Kitch-iti-kipi Spring & Indian Lake • How can rocks & Earth materials provide evidence of Earth's history? @ Hannahville, Rapid River, Harvey & Marquette • How do scientists use stable isotope data in real-world situations? @ Depas Tributary, Hannahville Other outputs: • Development of vertical-aligned, whole school geoscience pathway for Nah Tah Wahsh students • Professional development agenda & accompanying resources • Strengthened partnerships between teachers within the school • Increased pedagogical capacity to deliver outdoor, place-based and ES related learning experiences. • 2 educators presented at MSTA conference	Increase student engagement in ESS learning Increase educator's geoscience pedagogical and content knowledge including place-centric and inquiry-based Build mutually beneficial relationships within school groups; Long-term Increase geoscience literacy in rural U.P. community