**TOWARDS A GEOSCIENCE PEDAGOGY:
A SOCIO-COGNITIVE MODEL**

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ABSTRACT

Students attending schools in poor and historically marginalized communities lack access to curricula that combines both relevant science content and investigative practices—components the National Research Council (2012) has identified as necessary for effective learning. This lack of curricular access is also problematic in that it: (1) undermines student interest and value of the discipline; (2) fails to educate students about science issues relevant to their lived experience; and (3) hinders student preparation to convert science content into actionable knowledge (Basu & Barton, 2007; Buxton, 2010; Brkich, 2014). I have designed a pedagogical model for geoscience learning as an attempt to address this educational opportunity gap.

Geoscience as a content area is particularly important because students attending schools in poor and historically marginalized communities are more likely to be exposed to poor indoor and outdoor air quality (Pastor, Morello-Frosch & Sadd, 2006), have access to poor quality drinking water (Balazs, Morello-Frosch, Hubbard, & Ray, 2011; Balazs & Ray, 2014), and attend schools located near or on brown fields (areas of high exposure to environmental hazards) (Pastor, Sadd & Morello-Frosch, 2004). Given an overall concern for environmental justice (Pais, Crowder & Downey, 2014) and more specific concerns about recent cases of water quality in Flint, Michigan (BBC, 2016) and the greater Philadelphia area (Milman & Glenza, 2016; Rumpler & Schlegel, 2017), the topic of water quality has curricular relevance and potential to engage students in learning geoscience.

Based on the pedagogical model, I designed both a water-quality themed transformative learning experience (intervention), and a comparison experience focused on exploration of geoscience careers. Each experience consisted of activities totaling 220

minutes of instruction that can be completed within 5-6 traditional class periods. I applied a mixed methods approach to examine the student generated data from both experiences. First, I used quantitative analyses to test the efficacy of the model with respect to pre to post and delayed post instructional shifts in interest; self-efficacy; and perceived value, perceived relevance, and application of Earth science content. Secondly, I examined between group comparisons on each measure. Results of repeated measures ANOVA indicated statistically significant and meaningful shifts in knowledge for those students in the intervention group, $F(1, 159) = 7.34$ $p = .007$ $\eta^2 = .044$ (small effect size). Though the analysis did not detect statistically significant gains in interest, results revealed statistically significant and meaningful shifts in perceived value, perceived relevance, and application of Earth science content over time by grade for both the intervention and comparison groups, $F(2, 155) = 7.13$ $p = .001$ $\eta^2 = 0.84$ (large effect size; Tabachnick & Fidell, 2013). I confirmed these results using structural equation modeling (SEM) and path analysis. I also applied SEM and path analysis to the student generated data in order to test the theoretical soundness of the model. Interest, Transformative Experience (or TE, is operationalized as perceived value, perceived relevance, and application of Earth science content), and pre-instruction knowledge were all identified as significant pathways contributing to post-instruction knowledge. Output statistics confirmed that the model is both viable and trustworthy and indicated that it explained 34.4% of the variance. Lastly, iterative qualitative content analysis of student written responses during the intervention revealed elements of TE with respect to perceived value, perceived relevance and application of Earth science content confirming that the intervention was transformative.

This work integrated knowledge from two disciplines—geoscience and education—to present an instructional model designed to support student interest, self-efficacy, TE, and knowledge. Results have implications for science teaching and learning, specifically that contextualizing science is an effective pedagogy. Additionally, embedding both science content and scientific practices in current socio-scientific issues, including issues of environmental injustice, supports knowledge gains, positive shifts in student perception of Earth science content as relevant, valuable, and useful for problem solving; and positive shifts in student application of science content to their lives outside of the classroom context.

This work is dedicated to my mother Gloria.

I am grateful for your unconditional love, encouragement, and support throughout my life
and through this journey. I am, so much because of you. Thank you.

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CHAPTER 1

INTRODUCTION

The Research Problem

How to support students' interest in science learning is an important question in science education research. It is also a concern for schools, and professional organizations such as the National Science Foundation (NSF) that has stated goals to "prepare the next generation of STEM professionals," "attract and retain more Americans to STEM careers," "broaden participation" of demographic groups historically under-represented in STEM, and "close the achievement gaps in all STEM fields" (2017a). Using the perspective of motivational learning theories such as achievement and goal orientations and classroom culture, educational researchers have examined interest in science learning, particularly with respect to the decrease in adolescent student interest during the transition into middle school (Anderman & Young, 1994; Vedder-Weiss & Fortus, 2011). Other researchers have studied interventions supportive of interest development in out-of-school settings (Basu & Barton, 2007; Renninger et al., 2014) and have developed strategies supportive of interest development and transformative learning for within-school settings (Heddy & Sinatra, 2017). Although a pervasive issue, the decline in science interest amongst middle and high school students is not an inevitable aspect of education (Vedder-Weiss & Fortus, 2011). My goal for this study is to better understand how to effectively support student interest; self-beliefs of competency; and perception of science learning as relevant, valuable, and applicable.

Background and Purpose

Interest is essential for learning. As a cognitive and motivational variable, it predicts information-seeking behavior, development of self-efficacy, shifts in perceived

value of academic content, and academic achievement (Renninger & Hidi, 2016). Each of these learning outcomes is desirable in the science classroom, and makes understanding how to design educational experiences that lead to these results an important area of research.

Basu and Barton (2007) and Renninger et al. (2014) each examined the question of how to support interest development for adolescents in poor and under-resourced community schools. Using different approaches to study out-of-school science programs, these researchers arrived at similar results. Basu and Barton (2007) used critical ethnography and interview data to identify factors leading to student “disengagement” (p. 469) from science and the factors that can support student interest in learning science. Their findings suggest that exploration, invention (agency), and explicit connections between the concepts and the lived experience of students during instruction triggered and supported student interest (Basu & Barton, 2007). Student interest was also triggered by working in collaborative learning groups and participating in the social construction of knowledge (Basu & Barton, 2007). Following participation in the out-of-school program, students re-engaged with the science content and demonstrated motivated use by applying it to contexts outside of the learning environment (Basu & Barton, 2007). Renninger et al. (2014) also found pre to post increases in interest in participants of the ICAN intervention, a 5-week “inquiry-informed” (p. 108) integrated science summer workshop. However, in this workshop, although connections were made between science concepts and students’ everyday lives, the students reinforced and developed their own connections through written reflective prompts. The process of reinforcing learning and creating a notebook of concepts and skills learned contributed to pre to post increases in both interest and self-efficacy (Renninger et al. 2014).

There are common threads through each of these studies related to student learning. First, these findings align with the theoretical framework of interest developed by Renninger and Hidi (2016), which states that student interest is triggered by perceived relevance and is demonstrated by voluntary re-engagement with the content. There is also an element of direct experience through scaffolded investigation, and explicit connections between science concepts and students' lives that build self-efficacy (Bandura, 1986; Renninger & Hidi, 2016). Lastly, the findings of both of these studies align with the theoretical framework of Pugh (2002), which states that transformative learning occurs when students value science content, actively use it to understand their surroundings, and perceive it as relevant to their everyday lives. These three common threads illustrate the role of interest, self-efficacy, and transformative learning in general science education.

These socio-cognitive factors are also present in Earth science learning. Research in geoscience education highlights the role of perceived relevance of science content in supporting interest in science learning (Kraft, Srogi, Husman, Semken, & Fuhrman, 2011); direct experience practicing discipline-specific skills in building self-efficacy (Streule & Craig, 2016); and the application of Earth science content in problem solving leading to shifts in perceived value of the content (Blake, Liou-Mark, Blackburn, Chan, & Yuen Lau, 2015). Students are motivated to learn geoscience content (interest) when they feel connected to it (Kraft et al., 2011). Instructors can therefore support interest development by fostering connections between students and Earth science content through field experiences, contextualizing science content within the immediate physical environment (place-based learning), and relating an issue, such as drinking water, to the local community so that students understand the source of their residential water (Kraft et al., 2011). This strategy of embedding science in what may be familiar to

the learners not only fosters student interest but also frames science knowledge as relevant and potentially actionable (Kraft et al., 2011). Instructional strategies can also be used to enhance self-efficacy to learn geoscience. Similar to the participants in the out-of-school science workshops previously described, over the course of a field-based class, undergraduate geology majors in collaborative learning groups apply science knowledge, and practice investigative skills in creative problem solving (Streule & Craig, 2016). During this process geology students “become more independent in thought and more self-motivated in their work as they gain confidence” (Streule & Craig, 2016, p. 103). Essentially, direct experience with science content and practice within groups of learners contributes to students’ self-efficacy. Also, engaging Earth science content and practice through a place-based field study of plume movement through underground public transportation in New York City promoted transformative learning (Blake et al., 2015). Students participating in the three-week Subway-Surface Air Flow Exchange (S-SAFE) internship in collaboration with geoscientists in research laboratories, local law enforcement, and the local public transportation agency had direct experience with air monitoring equipment as they investigated air flow patterns of perfluorocarbon gases in the NYC subway system (Blake et al., 2015), a topic of specific importance in a city in constant preparation against physical and chemical attack. As a result, these students were both more interested in the Earth sciences and perceived the subject as valuable (Blake et al., 2015). Therefore, interest, self-efficacy and transformative learning can be useful constructs in understanding effective instructional strategies in the Earth sciences.

For my dissertation, I build on the work in science and geoscience education and extend it in application to students learning in under-resourced schools in poor

communities. The Earth sciences are important and relevant to human life, and particularly to students attending schools in poor and marginalized communities as they are more likely to be exposed to environmental toxins in air, water and soil (Balazs & Ray, 2014; Pastor, Sadd, & Morello-Frosch, 2004). Given the findings that: (1) meaningful connections between the student and science content supports interest development, (2) direct experience with science content and practice support self-efficacy, and (3) perceived value and application of science content contribute to transformative learning, I have contextualized each of the three constructs—interest, self-efficacy, and transformative learning experience—in the current place-based, socio-scientific issue of exposure to environmental toxins that is relevant to the lived experience of students in poor communities and marginalized communities. More specifically, I want to explore how a water-quality themed academic intervention that incorporates interest development, self-efficacy, and transformative learning, facilitates learning for all students and also for those disproportionately exposed to harmful pollutants.

Research Questions

The following are my research questions:

1. For students who experience instruction that facilitates transformative learning, what are the pre to post and delayed post differences in interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, application of Earth science concepts, and knowledge?
2. Do these learning outcomes differ for students who express more as compared to less awareness of environmental issues facing the local community?

3. What do students' written responses during transformative instruction reveal about their perceptions of value, relevance, and application of Earth science as a field of study?

Significance of the Study

My dissertation work focuses on identifying a pedagogy that would support development of student interest, self-efficacy, perceived value and relevance, and scientific knowledge construction and retention in Earth science. It merges the work in science education research and geoscience education with potential for generating actionable knowledge about supporting interest in geoscience learning for researchers in both fields, classroom teachers, and students.

Definition of Terms

I have listed below key terms used throughout the dissertation and their definitions.

- *Engagement* – Engagement is the level of involvement in a specific task, assignment, or study of academic content (Renninger & Hidi, 2016). Sinatra, Heddy and Lombardi (2015) identify difficulties with defining cognitive engagement given its overlap with other conceptualizations of behavioral and emotional engagement. However, for the purposes of this study, engagement was operationalized as both cognitive, involving the learner's active attention in the learning process, and behavioral in that the learner participates by reading, asking questions, performing academic tasks and self-regulates in order to persist in the learning process (Renninger & Bachrach, 2015).
- *Earth science* – According to Wyssession et al. (2012), developers of a set of Earth science literacy principles, Earth science includes “geobiology and low-

temperature geochemistry, geomorphology and land-use dynamics, geophysics, hydrologic sciences, petrology and geochemistry, sedimentary geology and paleobiology, and tectonics” (p. 95). For the purposes of this dissertation, Earth science and geoscience were used interchangeably, and were operationalized as the study of Earth’s physical structure and composition, and the air and water found at and below Earth’s surface based on the scientific literacy principles of Wyession et al. (2012).

- *Interest* – Interest is both a cognitive and motivational variable that describes information-seeking behavior (Renninger & Hidi, 2016). The intrinsically motivated behavior is characterized by increased attention to the subject and a willingness to freely re-engage in study of the subject matter. Although interest and curiosity have been used interchangeably, they are distinct in the context of transformative learning in that information-seeking behavior fueled by curiosity ends once the answer to the question is found, whereas information-seeking behavior compelled by interest leads to ongoing pursuit of information beyond a single question and is characterized by continual voluntary re-engagement with the topic (Renninger & Hidi, 2016).
- *Scientific practices* – Scientific practices refer to the specific skills of professional scientists as taught in K-12 science classrooms. These practices include: “asking questions; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations; engaging in argument from evidence; obtaining, evaluating, and communicating information” (NRC, 2012, p. 42).

- *Self-efficacy* – Self-efficacy is a self-evaluative belief about one’s skill or competence to achieve a specific outcome (Bandura, 1986).
- *Transformative learning experience* – Transformative learning experiences are defined by three principles: motivated use or application of concepts to everyday life, positive shift in perceived value, and positive shifts in perceived relevance of concepts learned in a school setting (Pugh, 2002).
- *Water quality* – Water quality refers to both the designated use of water and the maximum concentration of a pollutant that will protect the specified use for any given body of water (EPA, 2017). Knowledge of water quality includes understanding what makes water safe for its designated use as determined by performing basic tests such as pH, turbidity, conductivity, and total coliform.

Organization of the Dissertation

This chapter provided an overview of the research problem, purpose and significance of the study, research questions, and definition of key terms used throughout the dissertation. In Chapter 2, I review the literature on the three socio-cognitive constructs examined in the study—interest, self-efficacy, and place-based transformative learning experience. As part of the review, I embed each of the constructs in a relevant socio-scientific Earth science topic related to environmental hazard—water quality. Lastly, I describe the learning context for students attending under-resourced schools in poor and historically marginalized communities and use of students’ lived experience as a viable mechanism to teach Earth science content. In Chapter 3, I outline the research design including description of the school sites, and procedures used in data collection and analysis. I also describe the instruments developed to measure interest, self-efficacy,

transformative learning experience, water quality affect, environmental awareness and knowledge about aspects of water quality. In addition, I report validity and reliability for each multi-item measure and describe how the instruments are used within the scope of the academic intervention. In Chapter 4, I report the results of both quantitative and qualitative analyses before concluding with Chapter 5. In Chapter 5, I review findings from my research and describe limitations, implications for instruction, and implications for future research.

CHAPTER 2

LITERATURE REVIEW

Introduction

Geospatial data confirm that land use decisions have led to a disproportionate environmental risk to benefit ratio for poor and marginalized communities. Children attending schools in these communities are more likely to be exposed to poorer indoor and outdoor air quality (Pastor, Morello-Frosch & Sadd, 2006), have access to poor quality drinking water (Balazs, Morello-Frosch, Hubbard, & Ray, 2011; Balazs & Ray, 2014), and attend schools located near or on areas of high concentration of environmental toxins (Pastor, Sadd & Morello-Frosch, 2004), and are projected to be the most vulnerable to the adverse impacts of climate change (Shonkoff, Morello-Frosch, Pastor & Sadd, 2011). These students are also more likely to lack access to science curricula that facilitates learning the science content underlying their lived experience, as well as the investigative scientific practices to explore it (Basu & Barton, 2007). This lack of educational access effectively represents a gap in opportunity to learn science. Furthermore, the lack of curricular relevance undermines student engagement with Earth science content (Brkich, 2014; Buxton, 2010). Designing instruction around the nested contexts of learners and leveraging the students' physical environment as a mechanism to teach science content and scientific practices can close this educational opportunity gap.

Identifying instructional strategies for students in under-resourced community schools is important and relevant for science learning, particularly learning in the geosciences. The following review focuses on identifying the educational needs of students studying science, with a particular emphasis on examining the overlapping contexts that contribute to the lived experience of students attending under-resourced

schools in marginalized communities. Through an examination of the existing literature I identify a pedagogy that would meet students' academic needs based on findings from three bodies of knowledge—educational psychology, science education, and geoscience education. In addition to these literatures, I explore the unique pattern of exposure to environmental toxins and its potential as a mechanism to teach Earth science content.

I focus this literature review on investigating three constructs: interest, self-efficacy through direct experience, and place-based transformative learning experience. All three constructs are interconnected, related, and contributing components to each other, yet they are also each distinct measures. For example, interest as a socio-cognitive construct predicts several desirable learning outcomes: a student's sense of relatedness to a domain; willingness to participate in science-based activities; academic achievement as demonstrated by knowledge retention; and meaningful engagement with content as demonstrated by value that prompts motivated learning (Ainley & Ainley, 2011; Renninger & Hidi, 2016). Interest “emerges from an individual's interaction with his or her environment” (Krapp, Hidi, & Renninger, 1992, p. 5). Interest development can be supported through intentional instructional strategies, such as physical activity, that allows for students to both choose content and engage with content that would motivate learning (Nenniger, 1992; Renninger and Hidi, 2016). Self-efficacy is an evaluative personal belief about one's capabilities; it has the potential to either support or undermine attainment of an intended goal by affecting motivation (Bandura, 1986). In other words, self-efficacy both mediates “the relationship between knowledge and action” (Bandura, 1986, p. 390) and is generative of the capacity to direct both cognitive and self-regulatory behaviors towards a desired goal at a particular level of performance (Bandura, 1986). Self-efficacy through direct experience allows students to develop a competent skillset

and form of self-referent thinking that would lead to desired academic outcomes (Pajares, 1996; Streule & Craig, 2016). Further, direct experience of scientific practices leads to knowledge construction (NRC, 2012).

Both transformative learning and place-based science inquiry are relatively new areas of educational research. Transformative learning is a novel approach to engaging students with science content and is a mechanism for academic achievement (Pugh, Linnenbrink-Garcia, Koskey, Stewart & Manzey, 2010a). The three defining characteristics of transformative learning experiences are: positive shifts in attitude about the relevance of science, positive shifts in perceived value of science content, and practical use of science concepts in daily life (Pugh & Phillips, 2011; Heddy & Pugh, 2015; Heddy, Sinatra, Seli, Taasobshirazi, & Mukhopadhyay, 2016). Place-based inquiry is scientific investigation contextualized in the immediate environment. Intentional and explicit connections between science concepts and the local surroundings supports learning, makes science content engaging, and improves student academic outcomes (Clark, Majumdar, Bhattacharjee, & Hanks, 2015; Kirby, 2014; Kraft et al., 2011). In addition, place-based science activity demonstrates relevance and utility of subject matter contributing to student perceived value of geoscience content (Blake et al., 2015). As a pedagogical approach, place-based learning has been effective for students of various demographics—K-12 and undergraduate, urban and rural, and those taught by experienced and less-experienced instructors (Blake et al., 2015; Clark et al., 2015; Kirby, 2014). Additionally, it is as an effective strategy for increasing interest in the geosciences amongst groups historically under-represented in STEM (Blake et al., 2015). Given these three constructs individually relate to positive learning outcomes, a pedagogy consisting of interest development, self-efficacy, and place-based transformative learning

is theoretically an effective instructional approach. This assumption plays out in the literature.

For example, direct experience with content not only builds self-efficacy but supports interest development and value of the content (Renninger & Hidi, 2016; Streule & Craig, 2016). As interest develops, the learner experiences transformation—a positive shift in valuing the subject matter under study (Renninger & Riley, 2013). These constructs are independently supportive of knowledge acquisition and together likely to lead to academic achievement. Therefore, based on my reading of the literature, I hypothesize that a place-based transformative learning experience supportive of student interest and self-efficacy would lead to desirable learning outcomes for students and would be an effective approach in providing access to geoscience content and scientific practices for students attending under-resourced schools in marginalized communities.

To examine this premise, I reviewed literature on the three constructs—interest, self-efficacy, and place-based transformative learning experiences. I included discussion of the theoretical background for each construct followed by a brief summary of empirical studies examining the constructs. Next, I contextualized the three constructs in geoscience content, particularly the area of geoscience related to exposure to environmental toxin, to demonstrate curricular relevance to the lived experience of students attending schools in marginalized communities. Building on this idea of curricular relevance, I attempted to center the discussion in the geoscience topic of water resources using the recent crisis of water contamination in Flint, Michigan as a starting point. This case is of particular interest because it is a current case of environmental injustice with particular impact on school-aged children. The case of Flint, a predominantly African American city, is one of lead-contaminated drinking water and

consequently elevated lead levels in children's blood (Abbey-Lambertz, 2016; BBC, 2016a). Lead as a neuro-toxin disrupts childhood growth and development and leads to toxin-induced cognitive difficulties that hinder learning and academic performance over time (Goodnough, 2016). Therefore, though not an isolated example of environmental injustice, I leveraged this case as a means to teach both geoscience content and scientific practices.

Using geoscience as a content bridge, I: (1) situate each of the constructs—interest, self-efficacy, and place-based transformative learning—in Earth science content; (2) identify the educational needs of students attending under-resourced schools in marginalized communities; (3) describe science content that would have curricular relevance for the lived experience of the targeted demographic of students; and (4) present a model of an effective geoscience pedagogy. To conclude the literature review, I provide a brief synopsis of the overall findings, formulate three hypotheses based on these findings, and describe the educational significance of future research.

Socio-Cognitive Constructs: Interest, Self-Efficacy, and Transformative

Learning Experience

My hypothesis is that an instructional strategy for the geosciences designed to support interest development and self-efficacy through a place-based transformative learning experience. Such an experience would meet the academic needs of students including those in under-resourced schools experiencing chronic adversity due to poverty and exposure to environmental toxins.

Interest in Learning

Interest is both a “cognitive and affective motivational variable” (Renninger, 2009, p. 106). It describes the “psychological state of an individual while engaging”

(Renninger & Hidi, 2016, p. 8) with content. This psychological state may consist of “increased attention, effort, concentration, and affect during engagement” (Renninger & Hidi, 2016, p. 9). It also describes the inclination of the individual to re-engage with the content over time, particularly in the case of competing opportunities to engage with content that may be more appealing (Renninger & Hidi, 2016). Although interest is in part a motivational variable, it is different from a construct that is entirely motivational, such as self-determination theory. According to self-determination theory, a geoscience student may exhibit self-regulation in academic study as a goal-directed behavior towards competence or relatedness (sense of belonging) (Deci & Ryan, 2000). However, this motivated behavior would be intrinsic but would not be out of interest for the subject matter. Therefore, this engagement with content is both psychological and motivational but is not affective. Another example is a study of teaching science content and practice through weather data collecting in rural Louisiana (Clark, Majumdar, Bhattacharjee & Hanks, 2015). In this study, the authors found that a student may have engaged with the field-based meteorological activities with enthusiasm (positive affect) because being outdoors led to a sense of autonomy (Clark et al., 2015). This affect however was not due to interest in the science content (Clark et al., 2015). Therefore, interest is not solely a psychological or cognitive variable, nor is it exclusively an affective motivational variable, but rather a combination of the two with an area of overlap with respect to intrinsic motivation.

Intrinsic motivation “concerns active engagement with tasks that people find interesting” and this would be done “even in the absence of operationally separable consequences” (Deci & Ryan, 2000, p. 233). Therefore, interest is concerned with both the psychological state and motivational disposition of the individual. Interest cannot

exist independent of motivation; motivation, on the other hand, can exist independent of interest as with a student motivated by a goal. This makes interest an expanded conceptualization that is both socio-cognitive and motivational. As an expanded construct, interest is a robust and appropriate variable to use in examining geoscience learning (Renninger & Hidi, 2016).

The Four-phase Model of Interest Development

The psychological and motivational components of interest can be described in four progressive phases: triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest (Hidi & Renninger, 2006; Renninger & Hidi, 2016).

Triggered situational interest. Triggered situational interest occurs when a student is initially exposed to content or a novel experience that momentarily piques inquisitiveness (Hidi & Renninger, 2006). This experience may include a sense of relatedness with the subject matter, perceived relevance (Hidi & Renninger, 2006), and positive or negative emotions (Renninger & Hidi, 2016). In a geoscience classroom, an instructor may trigger situational interest by choosing a recent geologic event or hazard as a discussion topic, such as the recent contamination of local water in Flint, Michigan. With the decline of the area's manufacturing economy, tours of the community's post-industrial ruins have been organized to generate a stream of income yet 42% of the population lives in poverty. Associated with declines in the manufacturing economy is a demographic shift—a 21% decrease in population between 2000 and 2015. More recently, the city's water sources have been contaminated with lead. Water resource decisions that led to lack of safe drinking water also led to an erosion of trust in elected officials who failed to act in order to secure potable water for municipal residents. Given

the confluence of social stressors—poverty and environmental injustice—Flint, Michigan would qualify as a city experiencing chronic community level adversity. A geoscience instructor could trigger situational interest by asking details about the nature of the environmental hazard or the impact of exposure to neurotoxins, showing still photos or video of the hazard, or soliciting personal accounts for discussion. At this phase, learners are temporarily attentive to the subject matter (Renninger & Hidi, 2016). To support interest development at this phase, instruction must be designed to help students re-engage with content (Renninger & Hidi, 2016).

Maintained situational interest. The short-term attention characteristic of triggered situational phase is followed by *maintained situational interest* if the following conditions are met: addition of content knowledge, perceived purposefulness of knowledge, and perceived meaningful engagement in the learning process (Hidi & Renninger, 2006). Maintained situational interest is characterized by self-regulated sustained focus over time due to cognitive engagement accompanied by positive affect. In this phase, you see the interdependence of both the psychological and affective-motivational aspects of interest. The student continues to find the topic meaningful and relevant and it is at this stage that the student may consider pursuing opportunities to further understand the subject matter. To support interest at this phase, a teacher can minimize asking content only questions and incorporate questions that direct attention to context for the content. For example, given the topic of water resources, a teacher may ask: What is the difference between surface and subsurface water? What is porosity and permeability? How does subsurface water move from one location to another? What geologic materials are aquifers made of? Alternatively, these questions can be asked in a way that highlights the relevance of the content: Think about your community. Is your

drinking water sourced from surface or subsurface water? Describe how water is taken from the geologic environment to become drinking water. What are the social, environmental, and economic issues associated with providing safe drinking water to a community? With respect to the topic of global climate change's impact on water resources, an instructor may pose a question such as: Given the projected increase in global temperatures, the Intergovernmental Panel on Climate Change (IPCC) has estimated a sea level rise of 3 feet by the year 2050. How would this projected rise in sea level impact coastlines? Do you think the temperature increase would have a differential impact on local communities with respect to access to water or water quality? Why or why not? Questions that combine content knowledge while featuring meaningfulness of content would support interest. Although learners in this phase are interested in the subject matter, they may not persist with completing an academic assignment when confronted with difficulty. Instructors can support learning in this phase by helping the learner use his/her own skillset to make connections between the content and his/her own prior knowledge or experience (Renninger & Hidi, 2016). This establishes curricular relevance and reinforces content value through a constructivist, inquiry-based science activity. This process is effective for all students, and particularly for students experiencing chronic adversity due to environmental stressors that hinder attentiveness, in that it allows students to participate in scientific practices mediated by an active engagement with the content (Perrier & Nsengiyumva, 2003).

Emerging individual interest. The third phase is *emerging individual interest*. Both triggered situational interest and maintained situational interest are dependent on environmental factors (Linnenbrink et al., 2010) as implied by the name. A student with emerging individual interest will begin to think about the content while not directly

engaged in a learning task, and have a self-motivated quest to find answers to questions (Hidi & Renninger, 2006). Though this phase is more dependent on individual student interests, a teacher can still support development in this phase by providing opportunities for the student to see geoscience in his/her environment. For example, just as studies have emphasized geospatial reasoning to draw conclusions about disproportionate environmental risk experienced by marginalized and minoritized communities (for example, Morello-Frosch & Lopez, 2006; Morello-Frosch et al., 2011; Pastor, Morello-Frosch & Sadd, 2006; Pastor, Sadd, & Morello-Frosch, 2004), students can be given the opportunities to investigate questions of interest in their communities using geospatial thinking. Such projects may include creating a map to identify any patterns in the location of polluting industries, waste treatment facilities, and landfills and to identify water quality hazards associated with these land use choices. By targeting both affective and cognitive factors involved in learning, this process supports science learning for all students including those experiencing chronic adversity due to social stressors and exposure to environmental toxins that hinder attentiveness (Perrier & Nsengiyumva, 2003).

Well-developed individual interest. The final phase of interest development is the *well-developed individual interest*. This phase is characterized by student-initiated opportunities to re-engage with the content motivated by perceived value and associated positive feelings (Hidi & Renninger, 2006). Learners who have well-developed individual interest are likely to follow through with completing challenging tasks (Renninger & Hidi, 2016). Even though learners in this phase possess “a relatively enduring predisposition to re-engage a particular class of content over time” (Renninger & Hidi, 2016, p. 13) instructors can support the students’ learning by discussing

opportunities to explore his/her questions of interest or related career choices. For example, following an event, presentation, or a vicarious experience, at the college level a student may be motivated to enroll in a geoscience course, or after completing a general education geology course a student may register for a second course or even major in geology. At the pre-college level, a student may solicit feedback on how to engage in the content through organized activities in the community or seek out the content in libraries, museums, or community-based organizations. Although students may have an intrinsic motivation to study the subject matter, an instructor can contribute to the development of student interest. In addition, for students experiencing chronic adversity due to social stressors, interest can increase attentional capacity and support attention to academic content (Renninger, 1985; Hidi, 1990), reduce overall effort for memory (Hidi, 1990), and serve as a mechanism for self-efficacy and transformative learning (to be discussed in following sections).

Interest in Science Learning

Interest is important in preparing students to learn science content. In a classroom setting the initial stages of interest can be supported by including “autonomy, challenge, computers/technology, group work, hands-on activity, instructional conversation, novelty, and personal relevance” (Renninger & Bachrach, 2015, p. 64) as part of the learning experience. An example in a geoscience classroom could be a student-designed investigative study of an environmental issue relevant to the local community. The investigation would include scientific questions and a series of experiments conducted in collaborative learning groups to collect the data needed to answer those questions. Such an instructional strategy will not only incorporate identified triggers of interest but would also provide direct experience with science content (element of mastery experiences for

self-efficacy) while highlighting the value and relevance of the concepts and practices learned (elements of a transformative learning experience) through the use of reflective prompts.

Reflective prompts have also been used to support interest development. Renninger and colleagues (2014) tested the use of open-ended probes in an “inquiry-informed” (p. 112), 5-week science workshop for middle to high school students. These probes, called ICAN statements, allow students to reflect on concepts and skills practiced during the investigative activities as well as questions they would like to explore (Renninger et al., 2014). These statements were designed to reinforce learning by making explicit to the student what they understand and do not yet understand, reinforce skill development (mastery) and make connections between context and everyday life (value and relevance). Students exercise agency in choosing how to complete the ICAN statements with brief sentences during the course of the activity. The following are examples of probes in biology designed for students aged 10-12 for weeks 1 and 3 of the science intervention (Renninger & Riley, 2015, p. 50). Spelling was not changed in the student responses below:

Week 1 probe: “ICAN measure like a scientist.”

Corresponding student response: “I can measure a pea plant. I measured height, 12cm tall. I measured the number of leaves, 22. I measure weight, 351.4 grams.”

Corresponding student response: “I measured the height of my plant and I measured the levels. I also measured the stim [stem] of the plant.”

Week 3 probe: “ICAN tell you how carnivore teeth are different from herbivore teeth.”

Corresponding student response: “Carnivore teeth are sharp and herbivore teeth are flat. Sharp teeth needed to rip through flesh and flat teeth to grind up plants.”

Corresponding student response: “Carnivore teeth are different from herbivore teeth because carnivore teeth is small and sharp and herbivore teeth is flat and bigger.”

Renninger et al. (2014) found that students who completed more than 60% of the ICAN statements showed gains in conceptual understanding, interest, and value for science compared to students who did not. The act of reflecting on learning allowed students to transition from triggered situational interest based on the novelty of a new activity or experience, to engaging the content (Renninger et al., 2014). The prompts further served as a scaffold for students to incorporate evidence in knowledge statements (Renninger et al., 2014). These prompts can be adapted for the geosciences and serve as a mechanism to support interest development, self-efficacy, and transformative learning.

Academic approaches supportive of interest development lead to conceptual learning, information seeking, and intrinsic motivation that leads to self-efficacy and mastery. These approaches also mediate self-efficacy towards academic achievement (Baram-Tsabari, 2015; Glynn, Bryan, Brickman & Armstrong, 2015; Hay, Callingham & Carmichael, 2015). According to Hidi & Renninger (2006), “the potential for interest is in the person but the content and the environment define the direction of interest and contribute to its development” (p. 112).

In summary, interest as a construct could serve as an important component of a geoscience pedagogy. It addresses specific science learning needs in the affective,

cognitive, and motivational domains, such as facilitating reading and the processing of new information, reducing cognitive load that supports memory, and increasing capacity for attention during learning. Effectively addressing these needs supports ~~to~~ knowledge construction and retention, positive learning behaviors such as information seeking, persistence through challenging academic tasks, self-efficacy, and academic achievement. Appendix A, Table A. 1 details an outline of how interest supports student learning.

Self-Efficacy in Learning

Self-efficacy is an evaluative belief of one's ability to enact or produce a specific outcome (Bandura, 1977). It is task and discipline specific. In other words, it refers to an individual's assessment of their competence to successfully complete a particular assignment (Hardy 2014; Hidi & Renninger, 2016; Pajares, 1996) as opposed to a global assessment of one's ability or skill level (self-concept)—a distinction that I discuss later in this section. As an evaluative belief, self-efficacy “operates partially independently” (Bandura, 1986, p. 391) from the individual's actual skill level (Bandura, 1986, 1993). It is essentially an individual's perception of their ability, not a quantifiable assessment of ability.

Self-efficacy predicts behavior (Klassen & Usher, 2010). It has both a cognitive and behavioral component (Bandura, 1986). The cognitive component is based on personal knowledge of skill and judgment that the individual can perform a task at a desired level of competence (Bandura, 1986). The behavioral component is motivated action where the student would put the skill into effect to achieve a specified task, or motivated inaction where the student may not engage the task at all (Bandura, 1986; Schunk, 1991). Therefore, self-efficacy can either promote or undermine performance.

For example, when tasked with measuring water temperature with a thermometer, a student with the required skill to complete the task, or even a partially developed skill, but with high self-efficacy may choose to attempt the task and persevere in completing the task when confronted with difficulty. On the other hand, a student with the required skill to perform the task but low self-efficacy may opt not to attempt the task or may refuse to complete the task if it proves to be difficult at the outset. According to Bandura and colleagues (1996), self-efficacy is directly connected to a sense of human agency. These authors write: “Unless people believe that they can produce desired effects by their actions, they have little incentive to act” (p. 1206). For both students in the example, self-efficacy, not actual skill, determined performance. While self-efficacy alone will not result in what Schunk (1991) refers to as “competent performances” (p. 209), self-efficacy motivates action upon the individual’s task-related skill set. In other words, the difference in self-efficacy as presented in the posed example, is due to the underlying cognitive process of visualizing either success or failure as dictated by personal evaluation of skill and not the skill itself (Bandura, 1993). Self-efficacy influences and is also dependent on these anticipated outcomes, otherwise known as outcome expectations (Bandura, 1986). Self-efficacy influences anticipated outcomes by reducing “anticipatory fears and inhibitions” (Bandura, 1977, p. 80), supporting the student’s engagement and persistence with the task; in other words, the higher the self-efficacy, the lower the task-avoidant behavior. Self-efficacy is also dependent on anticipated outcomes, in that the student who persists in completing the task will obtain corrective ability-related feedback that reinforces sense of competence and corrective information about the perception of the task itself that serves to reduce anticipatory fears (Bandura, 1977). The cognitive components of anticipated outcomes in combination with perceived ability to perform

competently determine the behavioral component of task-related action. These cognitive processes that predict task-related behavior also influence classroom learning.

In a school setting, self-efficacy is a motivational belief that influences constructive academic behavior, such as self-regulated learning, and predicts academic motivation and achievement (Bandura, Barbaranelli, Caprara & Pastorelli, 1996; Klassen & Usher, 2010). Similar to interest, self-efficacy determines “resilience to adversity, quality of analytic thinking” (Bandura et al., 1996, p. 1206), and persistence through difficult learning tasks to master academic content (Bandura et al., 1996; Klassen & Usher, 2010; Renninger & Hidi, 2016). For example, in a study of mathematical achievement Schunk (1981) found that self-efficacy was the strongest predictor of success. This study involved 56 9- to 11-year old students assigned to three different forms of instruction around solving long division problems. Students in all three treatment conditions had access to “explanatory pages” (p. 96) but experienced different forms of instruction. In the first condition, called cognitive modeling treatment, an instructor modeled problem solving and verbalized problem-solving strategies. In the didactic treatment, the second condition, students’ sole informational resource was the explanatory pages. When students in the didactic treatment encountered difficulty in problem solving, the instructor directed them to re-read the relevant section of text. If the student continued to struggle with the content, the instructor directed the student to re-read the relevant section of text out loud. The third and final condition was the attribution treatment and was given to students in both the cognitive modeling and didactic treatments. In this treatment, the instructor gave feedback to each student, attributing successful completion of the division problem to high effort, and unsuccessful outcomes to low effort. Results of the multiple regression analysis concluded that pre-test self-

efficacy predicted post-test self-efficacy, pre-test persistence and post-test self-efficacy predicted post-test persistence, and that both self-efficacy and persistence predicted accuracy of calculations (Schunk, 1981). Path analysis testing the causal relationships between “treatment and self-efficacy, self-efficacy and persistence, self-efficacy and accuracy, and persistence and accuracy” (Schunk, 1981, p. 100) conclude that self-efficacy is the most significant predictor of math achievement. More specifically, treatment had both a direct and indirect influence on persistence with the indirect influence mediated by self-efficacy (Schunk, 1981). Also, self-efficacy mediated the influence of treatment on accuracy while having direct effects on accuracy and persistence (Schunk, 1981). These findings support Bandura et al.’s (1996) position that self-efficacy contributes to effective analytical reasoning and predicts academic achievement. These findings also align with Bandura’s conceptualization of self-efficacy as a social learning theory in that environmental factors contribute to the development of self-efficacy. Based on the work of both Bandura (1996) and Schunk (1981), classroom instruction intentionally designed to promote self-efficacy in understanding Earth science content and scientific practices may lead to positive academic behaviors and learning outcomes.

The Four Main Sources of Self-efficacy

There are four main sources of self-efficacy—mastery experience (accomplishment), vicarious experience (observation), social persuasion (feedback), and affective states (physiological index) (Bandura, 1986; Schunk, 1991). Mastery experience is the successful completion of a given task accompanied by positive affective assessment of the accomplishment. Otherwise known as enactive attainment (Bandura, 1986), mastery experience requires the student to have direct experience performing a task. This

direct experience then informs the student's evaluative belief of their abilities related to the task. Vicarious experience is appraisal of one's ability based on observing the performance of a person perceived by the student as similar to them. This form of efficacy relies on the person modeling behavior and the student assessing their ability based on the success or failure of the model. Compared to mastery experience, vicarious experience is a weaker source of self-efficacy for two reasons—the student must still perform the task personally, and also the student may become convinced of their inability to perform the task if the model fails to perform the task. Social persuasion is verbal feedback given to the student in order to support the student's belief in their ability to perform a task. This source of self-efficacy can be effective in supporting a student to overcome anticipatory fears of failure but is limited in its effectiveness as subsequent poor performance may undermine self-efficacy. Physiological and affective states provide feedback to the student. Negative emotions such as fear result in task avoidant behavior. Positive emotions such as enjoyment can lead to student engagement with the task. Ultimately, a student will tend to avoid tasks associated with stress or negative emotions. In a classroom setting, teachers can address task-avoidant behavior by supporting the student to reframe their negative perception of the task to one that is more favorable, support the student's sense of competence through verbal feedback about his/her task-specific skills, and finally by explicitly modeling how the task can be completed in a series of smaller tasks.

Of the four sources of self-efficacy, mastery experiences are the most influential on an individual's perceived sense of competence and capacity to produce desired educational outcomes because they are based on the individual's experience (Bandura, 1977, 1986). Successful experiences reinforce self-efficacy and failures undermine it

(Bandura, 1977, 1986). As success is the desired outcome, a student who evaluates the completion of a task positively would be more inclined to either attempt the task or a similar one again (McKim & Velez, 2016). A student who has developed high self-efficacy can then experience failure without much negative impact to their evaluation of competence (Schunk, 1991).

Mastery experiences are practical, aligning with the constructivist ideas of transformative learning experiences—learning by doing (Slavich & Zimbardo, 2012). For this reason, self-efficacy through direct experiences that lead to mastery lends well to educational settings in general and under-resourced school settings in particular. The curricula in under-resourced schools are characteristically reductionist, emphasizing performance on standardized tests for school accountability measures that undermine the goals of education (Ravitch, 2010). With highly publicized statistics of underperforming schools and a pervasive message of an achievement gap, students attending schools in poor and historically marginalized communities may internalize a sense of academic inadequacy and failure. In this case, self-efficacy can serve as a buffer against devitalizing thoughts that can undermine academic performance. For example, when facing a challenging academic task, a self-reflecting student may “engage in self-enabling or self-debilitating self-talk; if they construe their failures as presenting surmountable challenges they redouble their efforts, but they drive themselves to despondency if they read their failures as indicants of personal deficiencies...” (Bandura, 2001, p. 5). Self-efficacy through direct experience that leads to mastery is practical, providing concrete evidence to the student of his/her successful learning experiences, and thereby supporting a self-belief of competence.

Relations between Self-efficacy and Interest

Self-efficacy and interest are interrelated with interest contributing to the development of self-efficacy and self-efficacy supporting the later stages of interest (those beyond triggered situational interest) (Bong, Lee, & Woo, 2015; Renninger & Hidi, 2016). Self-efficacy and interest are both motivational constructs that predict behavior, however self-efficacy is a belief and interest is a psychological state. Interest motivates investigation, an information-seeking behavior. If interest is strong enough, it can reduce anticipatory fears that may be associated with information-seeking behavior. These two constructs are domain-specific and task related. For example, an Earth science student studying water quality may have perceived self-efficacy with respect to using a probe to measure the temperature of a water sample but lack interest in that particular task. On the other hand, a student learning how water travels through an aquifer may have triggered situational interest in measuring porosity and permeability of a soil sample, but not feel efficacious in completing the calculations. Both cases relate to mastery experience, direct experience with a task with the potential for supporting the development of interest and self-efficacy.

Self-efficacy in Science Learning

Studies show that mastery experiences contribute to self-efficacy, self-efficacy supports interest development, and interest further supports the development of self-efficacy. According to Bandura (1986), “People display enduring interest in activities at which they feel self-efficacious and from which they derive self-satisfaction...the satisfactions derived from goal attainments foster intrinsic interest” (p. 242). This relationship is further supported by a study of intrinsic motivation, self-efficacy and interest in high school and college science students conducted by Glynn and colleagues

(2015). Using data derived from the SMQ to measure motivation to learn science, SMQ-II to measure “intrinsic motivation, self-determination, self-efficacy, grade motivation, and career motivation,” (Glynn et al., 2015, p. 193) student interviews, and student essays, the researchers found that interest precedes intrinsic motivation to learn science for both high school and college students, self-efficacy predicts achievement, and student interest can be triggered by explicit connections between the science content and the students’ lived experience. They further imply that student interest can lead to mastery experience as mediated through intrinsic motivation to learn science. These findings are relevant to the Earth science classroom in that theoretically, a water-quality themed academic intervention embedded in the lived experience of students can effectively trigger student interest. Further, the academic intervention inclusive of direct experiences related to water quality testing could result in gains in self-efficacy.

In summary, self-efficacy through mastery, or direct experience, is potentially an important component of a geoscience pedagogy. Direct experience with Earth science content and scientific practices supports willingness to engage in science activities, mediates persistence and completion of academic tasks, and leads to academic achievement. Table A.2 in Appendix A contains a more detailed outline of how self-efficacy through mastery experiences can support student learning in the Earth sciences.

Transformative Learning Experience

Transformative learning experiences (TE) are dependent on triggering situational interest and are defined as “meaningful experiences students can have as a result of their interactions with the subject matter” (Pugh, 2002, p. 1104). TE consists of three components: “(1) active use of the concept, (2) an expansion of perception” (Pugh, 2002, p. 1104), and (3) “experiential value” (Pugh, 2011). Active use is defined as the learner

discussing science concepts with others outside of class and seeing examples of the concept(s) outside of the immediate learning environment (Pugh, 2002). Also referred to as motivated use, it is demonstrated when a student applies science content to a circumstance outside of the classroom context when that application is not required or assigned (Pugh, 2011). Expansion of perception is the change in how students think about the concept (Pugh, 2002), a shift from being a static piece of information to a means of understanding and interpreting the student's surroundings (Pugh, 2011). Expansion of value, or experiential value, is operationalized as increased interest in the content due to a shift in perception of the content's relevance and importance to daily life (Pugh, 2002, 2011).

According to Pugh (2004), transformative learning is demonstrated by a measurable shift in a learner's perspective about his/her environment. In other words, to be transformative, learning must extend beyond conceptual understanding, scientific literacy, demonstrated knowledge acquisition, and "legitimate participation in a science discourse community" (Pugh et al., 2010a, p. 3) to a form of engagement with the subject matter that leads the learner to apply the information in their daily lives thereby expanding how s/he perceives their surroundings. Transformative learning experiences therefore have a behavioral, cognitive, and affective component that encompasses an engagement with the content that transcends the initial learning space to the out-of-school space, or lived experience (Pugh et al., 2010a, b).

There is a substantive difference between the traditional classroom and transformative learning experience. Traditional classroom settings prioritize curricular content and structure over student interest (Kruckeberg, 2006) with the curriculum consisting of a series of discrete and loosely connected facts. In this setting, there is an

emphasis on memorization as opposed to active participation in science, and on breadth versus depth (NRC, 2012). These two emphases hinder conceptual understanding, a critique of science education that existed during the curriculum reform movement of the 1950s (DeBoer, 1991). Traditional educational settings fail to initiate or socialize students into the science community through meaningful engagement with science content and practice, and consequently they obstruct a sense of relatedness to the educational setting or belongingness to the discipline (Basu & Barton, 2007; Kruckeberg, 2006). According to Dewey (1916), “knowledge, grounded knowledge, is science” (p. 248). In the TE framework, when a teacher grounds Earth science knowledge in the lived experience, the teacher is using a strategy that triggers interest and supports students’ perception of Earth science content as relevant. The student then begins to understand that learning the content has direct importance (Dewey, 1913). There is value for the subject matter accompanied by intrinsic motivation to learn when “self finds itself in [the] content” (Dewey, 1913, p. 21). This intrinsic motivation is demonstrated by persistent effort when confronted by an intellectually challenging learning activity because the content has perceived value (Dewey, 1913). Therefore, the geoscience instructor organizes the content around “experiences like theirs [the students’], experiences involving the same world, and powers and needs similar to theirs” (Dewey, 1916, p. 140). In essence, transformative learning is informed by the following idea of education:

To realize what an experience, or empirical situation, means, we have to call to mind the sort of situation that presents itself outside of school; the sort of occupations that interest and engage activity in ordinary life. And careful inspection of methods which are permanently successful in formal education, whether in arithmetic or learning to read,

or studying geography, or learning physics or a foreign language, will reveal that they depend for their efficiency upon the fact that they go back to the type of the situation which causes reflection out of school in ordinary life. They give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking, or the intentional noting of connections; learning naturally results. (Dewey, 1916, p. 119)

This strategy frames geoscience content as valuable because it is purposeful, and the act of learning includes direct experience with the content and reflective judgment (Dewey, 1913). In this respect, transformative learning is a relevant strategy in the geosciences, where learning is active through participation in either classroom-based lab activities or field experiences. Transformative participatory learning in the geosciences would be inductive, allowing students to discover through investigation and problem solving, but also scaffolded, ensuring learning of the fundamental ideas and practices of the discipline, which is similar to the recommendations of the curricular reform movement (DeBoer, 1991). In transformative learning experiences, concepts would be situated in a context accessible to the student. Transformative learning also promotes mastery (which contributes to self-efficacy) of foundational concepts and practices as students cognitively and physically engage the subject matter (Slavich & Zimbardo, 2012).

Transformative Learning in Science

Transformative learning produces positive learning outcomes. For example, in science education, transformative learning has contributed to critical thinking producing conceptual change, knowledge transfer through deep engagement, positive affect and enjoyment of learning, and increased engagement with the content outside of the classroom (Alongi, Heddy & Sinatra, 2016; Heddy & Sinatra, 2013; Pugh, Linnenbrink-

Garcia, Koskey, Stewart & Manzey, 2010a, 2010b). Therefore, teaching science content and scientific practices via a transformative learning experience has the potential to support student learning in the geosciences.

The geosciences are lab and field-based, with content learned through direct experience. Using survey data of undergraduate students, geoscience instructors and professional geologists, Petcovic, Stokes and Caulkins (2014) found that 89.5% of participants value field-based education because it helps students understand what geoscientists do, improves understanding through direct interaction with geologic phenomena, and improves skill through practice. Pyle (2009) posits that the undergraduate geology field course, a standard requirement for the geoscience major, commonly have the following learning objectives: allow students to apply learning; demonstrate mastery of content through data analysis and synthesis; “learn the use and application of equipment, tools, and techniques” (p. 343); and “develop the habits of mind that govern the application of those knowledge and skills with integrity and attention to detail, valuing the conventions, techniques, and communication skills that make geology a rigorous science” (p. 343). In essence, geoscience is learned by doing. Given this active engagement in participatory learning, field-based geoscience inquiry has the potential to increase student motivation to learn, improve conceptual understanding through direct experience, and increase curricular relevance and perceived content value (Kraft et al., 2011).

Earth science teachers can incorporate transformative learning in their instructional approach. Students in local community schools already have connections to their respective communities; transformative learning experiences in the geosciences as an approach would facilitate the development of scientific connections to the community.

This strategy would efficiently leverage the readily available learning space, the students' immediate surroundings, to give access to science as contextualized in the familiar, which is essentially place-based education.

Place-based Geoscience Inquiry

Place-based inquiry leads to positive affect during engagement, improved learning outcomes, knowledge transfer outside of the school context, perceived content value, perceived relevance, and application of science content through an expanded perception of the environment (Blake et al., 2015; Clark et al., 2015; Kirby, 2014). This instructional approach supports curricular relevance, sense of relatedness, and the concept of learning by doing. It also contributes to transformative experience by making explicit connections between science content and scientific practices to the immediate environment or local community. Theoretically, for a learning experience to be transformative, there must be a shift in the student's perception of the value and relevance of the content and a shift in how the student subsequently uses the content to understand other contexts (Pugh, 2011). For example, a geoscience instructor can include water quality testing in discussion of the topic of water resources. Students may identify point and non-point sources of pollution in the catchment area for their community, test water samples from various locations in the watershed, and compare the data to EPA standards for water quality. Through this task students learn content and the scientific practices of formulating a question, designing and implementing an investigation, collaboration, and obtaining and analyzing data (NRC, 2012). In addition, learning science in the context of the community is likely to promote actionable knowledge and motivated use or application of the content to the immediate environment.

In summary, a transformative learning experience is an effective approach to geoscience education in that it leads to perceived value of science content, conceptual understanding, positive affect, motivated use of science concepts, and transferrable knowledge. (See Appendix A, Table A.3 for a more detailed outline of how a place-based transformative learning experience can support student learning in the Earth sciences.) It is an appropriate strategy for traditional geology field-courses and courses taught in urban settings (Blake et al., 2015). Given the emphasis on learning by supporting motivated use of content, perceived relevance, and perceived value, TE has the potential to engage students attending schools in poor communities disproportionately exposed to environmental toxins by leveraging the science content of their lived experience as the context for understanding geoscience concepts. In the following section, I review the literature on chronic adversity and poverty, summarize how these circumstances affect student learning, and identify strategies for addressing the learning needs of students attending under-resourced schools in communities experiencing chronic adversity.

The Influences of Poverty and Chronic Adversity on Learning

Adversity is a part of human existence as it affects all individuals at all income levels (Felitti et al., 1998). Although most experiences of adversity are temporary, such as grief, illness, or abuse, certain factors contribute to prolonged exposure to adversity (Felitti et al., 1998). Due to residential policies that concentrated disadvantage in densely populated areas while promoting expansion of suburbs, residents of urban centers are exposed to additional layers of adversity that are more prolonged than temporary—exposure to violence and disproportionate exposure to environmental toxins. This compound effect leads to what is called toxic stress, chronic adversity, or community level trauma.

Adversity from Psychosocial Stressors and Exposure to Violence

In a seminal study, Felitti et al. (1998) surveyed 8,506 adults aged 19-92 between 1995 and 1997 to understand the impact of adverse childhood experiences (ACEs) on adult health, life outcomes, and academic performance; this is known as the CDC (Center for Disease Control) or ACEs study. The researchers, who defined adversity as abuse, household challenges, and neglect, found that the higher the level of adversity, the greater the likelihood of poor health and early death. In addition, individuals identifying with more categories of ACEs were at greater risk of alcohol and drug abuse, depression and PTSD symptomology, ischemic heart disease, domestic violence, sexual violence, adolescent pregnancy, fetal death, STDs, suicide, eating disorders, obesity, and poor academic achievement (CDC, 2016a; Flaherty et al., 2013). These negative outcomes were mediated by “disrupted neurodevelopment” and “social, emotional and cognitive impairment” (CDC, 2016a). Burke, Hellman, Scott, Weems, and Carrion (2011) tested these findings.

Burke et al. (2011) extended the CDC study to include exposure to violence as an ACE and to examine the relationship between ACEs and diagnoses of “learning/behavior problems and/or obesity” (p. 409). In a community where the two leading causes of death were ischemic heart disease and violence [Building a Healthier San Francisco (BHSF), 2004], Burke et al. (2011) determined through separate logistics regression analysis on data collected from retrospective medical chart review that individuals identifying one or more categories of ACEs were more likely to be diagnosed with learning/behavior problems. Furthermore, there was a statistically significant increase in identification of learning/behavior problems with individuals identifying four or more categories of ACEs (Burke et al., 2011). These findings provide evidence of the negative impact of adversity

and exposure to violence on learning, an impact due to the body's adaptation to chronic stress.

The Physiological Adaptation to Chronic Stress

To ensure survival against life threatening circumstances the body has a stress response system. The human stress response system consists of the “sympathetic-adrenal-medullary (SAM) axis, the limbic system, and the hypothalamic-pituitary-adrenal (HPA) axis” (Kindsvatter & Geroski, 2013, p. 473). The SAM orchestrates automatic responses to stress; the limbic system controls stress-related emotions such as anger and fear; both the SAM and the limbic system facilitate “rapid responses to threat”; and the HPA initiates the transmission of neurological messages and the release of stress-related hormones to support the body's response to threat (Kindsvatter & Geroski, 2013, p. 473). When confronted with a stressful situation this coordinated system is activated to process the stimuli associated with the event and prepare the body for appropriate response—fight or flight. This preparation includes deactivation of body systems that are not needed in defense against the threat and activation of threat-relevant mechanisms producing a state of arousal and is typically followed by a period of calm and rest during which the body can return to homeostasis (Kindsvatter & Geroski, 2013). When this system is repeatedly activated, the body becomes efficient at processing the stress signals as the stressful events reinforce patterns of neurological response (Kindsvatter & Geroski, 2013).

Although this response is an efficient adaptation to danger to ensure survival of the organism, it becomes problematic in the context of chronic exposure to violence as it generates a state of hyper-vigilance in the individual (Harris, 2014; Shonkoff et al., 2012). The cumulative burden resulting from exposure to high levels of stress over

extended periods of time leads to dysregulation of the human response system and consequently, a negative effect on brain development and function (Shonkoff et al., 2012). Through repetition, the activated neurological pathways become stabilized and the traumatized individual begins to respond to both real and perceived threats to safety (Harris, 2014). This is considered an impairment to the stress response system (Busby, Lambert & Ialongo, 2013) and is the point at which chronic stress becomes toxic--in excess of tolerable levels--thereby altering the natural development and functioning of the body's stress-response system (Center on the Developing Child, 2016). Toxic stress drains the body's energy resources thereby reducing a person's capacity to focus on non-threatening subjects such as academics. Toxic stress inhibits concentration and decreases capacity for working memory (Evans & Fuller-Rowell, 2013; Harris, 2014) in addition to hindering connectedness to significant people such as teachers in an educational setting (Busby, Lambert & Ialongo, 2013). Instructional strategies supportive of interest development can be implemented in direct response to the learning needs of students living through chronic toxic stress. More specifically, as both a cognitive and motivational variable, interest supports attention, motivated learning through self-regulation, and memory (Renninger & Hidi, 2016). According to Renninger and Hidi (2016), "as interest develops in an activity, self-regulation also develops as an integral aspect of performance" (p. 87), in fact, "interest is a mediator of self-regulatory processes" (p. 87). In essence, interest facilitates learning (Hidi, 1990). With respect to information processing and memory, general interest and value of the content supports comprehension and information encoding (Hidi, 1990; McDaniel, Wadill, Finstad, & Bourg, 2000). For example, when a text triggers interest, a student expends fewer resources in maintaining attention and gleaned understanding from the text. The

triggered situational interest allows the student's effort to be invested in more efficient processing and encoding of the information (McDaniel, Wadill, Finstad, & Bourg, 2000).

The human brain is wired for information seeking making humans naturally inquisitive. Activities such as exploration, investigation, pursuit of curiosity, and the process of learning itself, although extrinsically rewarding, are also intrinsically rewarding (Gottlieb, Oudeyer, Lopes & Baranes, 2013; Renninger & Hidi, 2016). As a student engages in exploration and information-seeking behavior, the brain's reward system is activated (Gottlieb, Oudeyer, Lopes & Baranes, 2013). In other words, pursuit of learning intended to close an information gap results in a release of dopamine that characterizes internal motivation (Gottlieb, Oudeyer, Lopes & Baranes, 2013). Therefore, instructional strategies supportive of interest development have the potential to increase student capacity to focus on academic content. This is particularly important in communities where exposure to chronic toxic stress hinders students' attentiveness to academics.

The Impact of Chronic Toxic Stress/Community Level Trauma on Learning

Trauma has been correlated to inability to maintain consistent focus on academic subject matter, academic detachment and academic underachievement. Trauma from exposure to violence (ETV) is a significant factor in the lives of students living in poor and historically marginalized communities for two reasons—the high rate of violence and violent crime in cities (Kneebone & Raphael, 2011), and the effect violence as a psychosocial stressor has on the body physiologically and neurobiologically (Buka et al., 2001; Evans & Fuller-Rowell, 2013; Kindsvatter & Geroski, 2013; Korgaonkar et al., 2013). Although violent acts intended to cause emotional or physical harm or death occur in all segments of society and at all income levels, impoverished members of

marginalized communities are particularly impacted by violence (Aisenberg & Herrenkohl, 2008; Violence Policy Center, 2014). The youth of these communities have a high cumulative exposure rate given their nested contexts of home, school, and community, that put them at great risk of negative outcomes from ETV (Boxer & Sloan, 2013). Therefore, the psychosocial stressors of chronic exposure to community violence and poverty and their concomitant neurobiological and cognitive impacts must be considered when strategizing effective instructional strategies for students in poor and marginalized communities. One such approach is support of student attention and focus during learning. McDaniel et al. (2000) suggest that interest leads to an automatic allocation of focus and reduces the burden of channeling cognitive resources for attention. The reduced cognitive load on information processing frees student effort to be invested in comprehension and encoding information.

The Impact of Poverty on Learning

Poverty is also a known contributor to chronic toxic stress. A study examining the impact of poverty (economic need as compared to income) and poverty related factors (housing quality, residential crowding, and environmental noise levels) on cognitive function and physical stress response found that stress response associated with perceived economic insufficiency is measurable. Poverty-related stress is not only detected in infants but is most acute in newborns under 7 months old (Blair et al., 2011). In addition, children exposed to chronic poverty, poor housing quality and who are identified as African American face higher levels of basal stress physiology compared to European American peers (Blair et al., 2011). In other words, not only are African Americans over-represented in deep poverty categorizations of SES (Roy & Raver, 2014), African American children living in poverty experience toxic stress and higher levels of chronic

toxic stress due to poverty related factors with the added burden of social stressors associated with race (Blair et al., 2011; Roy & Raver, 2014). This combination of factors impacts physiological development, health outcomes, and cognitive function even in infancy with effects throughout childhood development. However, exposure to violence and poverty are not the only environmental stressors school aged children face. Children living in poor communities are also disproportionately exposed to environmental toxins from stationary and non-stationary sources. This exposure is inherently scientific in nature and can be leveraged as content for teaching geoscience concepts.

Adversity from Exposure to Environmental Hazards

Exposure to environmental toxins contributes to the chronic adversity members of marginalized communities experience. This exposure is due to stationary and non-stationary sources of pollutants identified by the US Environmental Protection Agency (EPA) as hazardous to human and environmental health. Examples of stationary sources of pollution would be waste treatment, storage, and disposal facilities (TSDF) and Toxic Release Inventory (TRI) facilities such as factories. Mobile sources of pollution are highways, expressways, high-density traffic lanes through residential areas, diesel fueling stations, or depots for transportation vehicles such as buses, trains, and mail delivery vehicles. School-aged children living near any of these sources will have an increased rate of exposure to toxins. Proximity to pollution-generating facilities is also a function of land use decisions and residential policy.

Federal policies like redlining targeted non-European Americans, particularly African Americans, served to undermine access to safe and quality housing. This policy led to racially segregated neighborhoods, the concentration of social and economic disadvantage in urban centers, and the particular relegation of African Americans to the

“highest indices of urban poverty” (Morello-Frosch & Lopez, 2006, p. 181) and material deprivation (Coates, 2014, 2016; Morello-Frosch & Shenassa, 2006). Another outcome of this policy is the concentration of polluting industries in poor communities of color. In the 1980s, this residential practice, in combination with former president Ronald Reagan’s New Federalism, a domestic policy that transferred the responsibility of monitoring environmental and public health to the states without the financial means to do so, led to legal and illegal dumping of hazardous materials in and near residential communities (United Church of Christ Commission for Racial Justice [CRJ], 1987). During this time, the pattern of exposure to environmental hazards and demographic characteristics of the exposed communities seemed to be determined by race or racism. The Commission on Racial Justice (1987) operationalized racism as:

...racial prejudice plus power. Racism is the intentional or unintentional use of power to isolate, separate, and exploit others...Racism confers certain privileges on and defends the dominant group, which in turn sustains and perpetuates racism. Both consciously and unconsciously, racism is enforced and maintained by the legal, cultural, religious, educational, economic, political, environmental and military institutions of societies. Racism is more than just a personal attitude; it is the institutionalized form of that attitude. (CRJ, 1987, p. x)

The pattern of disproportionate exposure to environmental risk is essentially a form of chronic adversity experienced by a community, or community level trauma due to exposure to environmental hazard. This lived experience can be used to teach the science content inherent in the pattern of exposure to environmental toxins. Making meaningful connections between science content and real-world experience is an

approach that would support interest development, and perceived relevance and usefulness of Earth science content—components of both interest and transformative learning experiences (Pugh, 2002; Renninger & Hidi, 2016). The following sections establish the validity of using context to teach geoscience content.

The History of Exposure to Environmental Hazard

This disproportionate pattern of exposure to environmental toxins motivated people towards informed advocacy for environmental justice using both geoscience knowledge and geocoded data. The collective understanding of environmental justice is that “all people and communities are entitled to equal protection of environmental and public health laws and regulations” (Bullard, 1996, p. 493). This principle was first put into law in 1994 when former president William Jefferson Clinton signed Executive Order 12898, “Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations” (US Environmental Protection Agency [EPA], 2017). The executive order followed historic events and mounting evidence that the “spatial coincidence among patterns of environmental hazards and demographic characteristics” (Mennis, 2011, p. 226) was not random. Three historic events preceded the signing of this federal action: the 1982 protest of a contaminated soil landfill siting in Warren County, North Carolina; the 1983 US General Accounting Office (GAO) study of hazardous waste sites in the southeastern United States; and the 1987 United Church of Christ Commission for Racial Justice (CRJ) investigation of national distribution of toxic waste sites.

The historic event credited with launching the environmental justice movement was the 1982 legal contest of the siting of a landfill to hold polychlorinated biphenyl (PCB)-contaminated soil in the predominantly African American community of rural

Warren County, North Carolina (CRJ, 1987; Mennis, 2011). PCBs are a known carcinogen and immune system suppressant (EPA, 2017b; Wisconsin Department of Human Services [Wisconsin DHS], 2016). They are particularly harmful to the physical and cognitive development of children starting with premature birth, low birth weights and weight gains, smaller head circumferences, impaired vision, and poor short-term memory (EPA, 2017b; Wisconsin DHS, 2016). Older children have difficulty being attentive, are “three times more likely to have low verbal IQ scores” and twice as likely to be two years behind in reading comprehension (Wisconsin DHS, 2016). Despite residents’ and allies’ expressed concerns about the impact of PCBs on human health and that the siting was racially motivated, the Federal Court failed to support their claim of a civil rights violation (CRJ, 1987; Mennis, 2011; New York Times [NYT], 1982). Further, the then Governor James B. Hunt refused to stop development of the toxic waste landfill (Brinkley, 1984; NYT, 1982). Instead, he proposed that the EPA detoxify the contaminated soil when “technologically feasible” (NYT, 1982). The landfill was developed by members of the military stationed at Fort Bragg carrying out the operation (NYT, 1982). Although the case opposing siting of the landfill was denied, it motivated other efforts—investigations of the distribution of hazardous waste sites by the US General Accounting Office (GAO) in 1983 and the CRJ in 1987 both found that race dictated the distribution of environmental hazard (Mennis, 2011). The GAO (1983) found that three of the four largest hazardous waste sites were located in areas that were predominantly African American and poor. One such siting was in Sumter County, Alabama which at the time had a population of 90% identified as “Black” with 100% of the Black residents living below poverty (GAO, 1983, Appendix 1). Sumter County was surrounded by two counties that were 84% and 69% “Black” with 93% of the “Black”

population living below poverty (GAO, 1983, Appendix 1). Using discriminant analysis, difference of means test, and matched-pairs, the CRJ (1987) found a strong statistically significant relationship between minority status [here categorized as “Blacks”, “Hispanics”, “Asian/Pacific Islanders” and “American Indians” (p. 2)] in a community and presence of a commercial hazardous waste facility with race being a stronger predictor than household income or property value (p. 13).

The Pattern of Exposure to Environmental Hazard

A review of published studies using census tract and zip code level data, distance (proximity) analysis, event history analysis, multivariate regression, and geospatial technology provide evidence of disproportionate exposure of poor and minoritized communities to environmental hazards (Boer, Pastor, Sadd & Snyder, 1997; Mohai & Saha, 2006; O’Neill, 2007; Mantaay, 2007; Pais, Crowder & Downey, 2014; Pastor, Morello-Frosch & Sadd, 2005). For example, Sicotte and Swanson (2007) examined the relationship between intensity of exposure to environmental hazards and racial, class, and career identification. The objective of the study was to determine if racial/ethnic identification, poverty, membership in the working class, or employment in the manufacturing industry led to increased exposure to air pollutants (Sicotte & Swanson, 2007). More specifically, the researchers wanted to determine whether there were inequalities, not just in exposure, but in the magnitude of exposure to environmental toxins for “racial/ethnic minorities,” the poor, or those in the manufacturing industry (Sicotte & Swanson, 2007, p. 521). For this study, the researchers used the Risk Screening Environmental Indicators (RSEI), a model developed by the EPA to determine the degree of hazard and health risk posed by air polluting facilities referred to as Toxic Release Inventory or TRI facilities. TRI refers to the 650 chemicals identified by the EPA

as causing negative impact on the natural environment and humans with respect to cancer and chronic “significant adverse acute” health problems (EPA, 2017a). Using the RSEI, the researchers were able to develop a hazard score for each census tract in the Philadelphia Metropolitan Statistical Area (MSA). They found that for the Philadelphia MSA (nine counties across Pennsylvania and New Jersey), Hazard Scores increased in racial/ethnic minority, poor, and manufacturing communities (Sicotte & Swanson, 2007). African Americans resided in communities with the highest hazard risk scores overall, working class status was not a predictor of exposure to environmental risk, and there was no statistically significant relationship between “White” and exposure to environmental hazard in any of the nine counties regardless of socioeconomic category (Sicotte & Swanson, 2007). These findings provided evidence of a geospatial pattern of race and exposure to environmental toxins.

Other researchers have confirmed this pattern of disproportionate exposure. In studies conducted by Cushing et al. (2015) and Pais, Crowder and Downey (2014), results showed that African Americans were more likely to be exposed to toxic industrial pollution than European Americans even when accounting for socio-economic status and population density. In a study examining air pollution exposure, Miranda, Edwards, Keating and Paul (2011) found that non-Hispanic Blacks (NHB) lived in communities with the worst measures of particulate matter and ozone air quality. A study in a historically African American community in Orange County, North Carolina showed racial disparities in access to public drinking water and sewer services (Heaney, Wilson, Wilson, Cooper, Bumper & Snipes, 2011; Heaney et al., 2013). This pattern is further supported by the findings of Mantaay (2007) who conducted a geospatial analysis that revealed a correspondence of asthma and air pollution in the Bronx. Mantaay (2007)

found that the Bronx, the NYC borough with the highest concentration of minoritized groups (85.5%) and people living below the federal poverty line (30.7%), has an asthma rate double that of the rest of NYC, and a childhood asthma hospitalization rate in the South Bronx that is 140% higher than the rest of NYC. Across each of the aforementioned studies, there is evidence of an association with race/ethnicity and/or class and exposure to environmental toxins.

This pattern of exposure to environmental toxins and the consequences thereof can inform geoscience education. Discussion and learning experiences at the middle and high school levels can center on the following topics: origin, distribution and use of renewable and non-renewable geologic resources; chemical reactions, airborne pollutants, and what makes a chemical a toxin; dependence on natural resources in our ecosystem; the relationship between lifestyle choices and practices and human health; and energy and human sustainability. These topics are common in geoscience curricula and are found in nationally adopted standards in the physical, life, and Earth and space sciences (NGSS Lead States, 2013). As such, the topics are relevant to all students and teachers can make explicit connections between the topic and the lived experience of students including those disproportionately exposed to environmental toxins. This process has the potential to trigger student interest and demonstrate content value.

Understanding the Pattern of Exposure to Environmental Hazard

Discussions of the disproportionality of environmental burden experienced by poor and marginalized communities give rise to two perspectives. One perspective is that pollution-generating industries are initially sited in areas with low property costs, and subsequently, low-income communities (which may also coincide with historically marginalized racial/ethnic groups) form in the vicinity as these are areas they can afford

to reside and/or find employment. The opposing perspective states that polluting industries are intentionally sited in low-income and historically marginalized communities due to bias. Morello-Frosch et al. (2002) found no evidence of “market-based minority move-in” to areas of high concentration of TSDF or TRI facilities but rather that these pollution-generating facilities were located in predominantly African American and Latino communities in southern California with low socio-economic and political power (p. 152).

In an attempt to identify non-racial explanatory factors for the observed pattern of race and exposure to environmental hazard, Mennis and Jordan (2005) used geographically weighted regression (GWR) in a multivariate analysis of TRI and PBT (Persistent Bioaccumulative Toxic chemical) facility location. The study examined race/ethnicity, population density, census tract level socioeconomic variables, zip code level proximity data, and presence of manufacturing industry (Mennis & Jordan, 2005). The underlying assumptions were that areas of higher population density would also be areas of greater concentration of identified racial/ethnic minoritized groups and pollution-generating industries and therefore, urban concentration and land use would likely explain the observed pattern of racial/ethnic identity and environmental hazard exposure (Mennis & Jordan, 2005). PBTs were of particular interest as TRI chemicals, because in addition to toxicity in small doses, these pollutants are persistent in the natural environment, easily accumulate in human body tissue and are not readily destroyed (EPA, 2017b). Their findings were mixed showing a complex relationship amongst racial/ethnic variables, exposure and land use choices. First, they found that racial/ethnic identity as Black or Hispanic, population density, socioeconomic status of living below the poverty line, presence of industrial facilities in the community and employment in the

manufacturing industry were all significantly associated with exposure to TRI and PBT chemicals. In addition, although the data supports the idea that Black and Hispanic people are disproportionately impacted by environmental hazards, particularly PBTs, this is largely due to the nested contexts of urban-dwelling and poverty (Mennis & Jordan, 2005). Further, although this pattern held true for cities like Camden and Trenton, it did not hold true for Atlantic City, which despite having a large demographic of both Black and Hispanic people, has a low percentage of TRI facilities and subsequently, air pollutants (Mennis and Jordan, 2005). In summary, the study conducted by Mennis and Jordan (2005) did provide evidence of environmental inequity but is inconclusive as to whether land use decisions were made before or after the community developed to address the question of racial bias as underlying mechanism. In other words, given the scope of the study, the authors were not able to determine whether industries intentionally located in marginalized communities or whether members of marginalized communities opted to live in areas with pollution-generating industries due to comparatively low costs of living.

The Complex Associations of Exposure to Environmental Toxins

Geospatial technology has been an important tool in understanding the complex relationship amongst race, class and land use (Downey, 2003; Fisher, Kelly, & Romm, 2006; Jerrett et al., 2001; Mantaay, 2007; Raddatz & Mennis, 2013). Though current research presents mixed results, and there is debate with respect to the appropriate scale for analysis of aggregate data and causal mechanism for the apparent association of race and environmental hazard, the overall pattern observed in the 1980s remains unchanged (Atlas, 2002; Boer, Pastor, Sadd & Snyder, 1997; Bowen, Salling, Haynes, & Cyran, 1995; Fisher, Kelly, & Romm, 2006). Further, whether pollution-generating facilities are

intentionally sited based on economics or structural racial and social class biases, the result is that poor and historically marginalized communities have higher concentrations of polluting industries and consequently higher rates of exposure to environmental toxins. Geospatial data confirms that land use decisions have led to a disproportionate environmental risk to benefit ratio for poor and marginalized communities than predominantly white communities regardless of social class. In fact, after controlling for socioeconomic differences and levels of suburbanization, African Americans “are exposed to neighborhood pollution in much greater numbers than we would expect if race was inconsequential” (Pais, Crowder & Downey, 2014, p. 1210). In addition to the existence of disparate exposure and impacts of environmental toxins on public health, the toxins in low income and marginalized communities are not being remediated nor environmental regulations enforced as would be expected given the rate of exposure (Mennis, 2005; O’Neil, 2007). This creates a circumstance of chronic adversity through chronic exposure to toxic chemicals with the potential to produce deleterious effects on child development and human health.

The Impact of Exposure to Environmental Toxins on Learning

Community level trauma is not individual; it is characterized by a negative impact on a group as a result of a collective experience, which, as in this case, is exposure to environmental toxins. Such environmental toxins affect poor and marginalized communities as demonstrated by historic cases from the 1980s until the present with the most recently publicized being the lead-contaminated drinking water of Flint, Michigan (British Broadcasting Company [BBC], 2016a) and protests of the Dakota pipeline due to concerns about potential contamination of drinking water (BBC, 2016b). This chronic exposure to environmental toxins disproportionately experienced by low-income and

marginalized communities exacerbates the pre-existing psychosocial stressors of poverty and social inequality (Morello-Frosch, Zuk, Jerrett, Shamasunder & Kyle, 2011). This form of chronic community level adversity warrants attention in that the cumulative impact of poverty, social inequality, and exposure to static and mobile pollution sources result in not only negative health outcomes but also measurable differences in academic achievement for school-aged children. The consequences this form of adversity poses include: respiratory and cardiovascular disease, premature births and pollution-related premature morbidity (Morello-Frosch et al., 2011), diversion of limited family resources to treatment of pollution-related illnesses, and increased student absences due to illness. School-aged children are more vulnerable to exposure due to different rates in “absorption, distribution, metabolism, and excretion of chemicals” (Morello-Frosch et al., 2011, p. 881) in addition to the interaction of these chemicals on their growth and development. Exposure to environmental toxins have the following negative impacts on children: increased infant mortality (Morello-Frosch & Lopez, 2006); increased hospitalizations and medical expenditures for treating childhood asthma (Mantaay, 2007); poor short-term memory, visual impairment, and delayed reading comprehension (Wisconsin DHS, 2016); and poor academic performance on standardized tests after controlling for poverty and teacher quality (Pastor, Sadd & Morello-Frosch, 2004; Pastor, Morello-Frosch & Sadd, 2006). Therefore, given these findings on the impact of chronic exposure to environmental toxins, the issue of community level trauma as experienced through environmental hazard is also an educational concern.

From a science education perspective, understanding learning at the intersection of poverty and chronic community-level adversity, informs not only instructional strategy but also content. The geosciences are inherently interdisciplinary and content around

chemistry, epidemiology, energy policy, and urban planning can increase understanding of the complexity of societal issues for students enrolled in a geoscience course.

Promoting curricular relevance of the topic of exposure to environmental toxins through classroom discussion, debate, direct experience water quality testing, and reflection on conceptual understanding and application of science content, is in part an act of convergence—“deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks for addressing scientific and societal challenges and opportunities” (NSF, 2017b). This process could potentially trigger student interest, highlight value of geoscience content, and support motivated use of content, which is transformative.

Applying Understanding of Poverty to Identification of Educational Needs

The goal of this review is not to essentialize or catastrophize the social learning context of poor and historically marginalized communities but rather to center focus on the science education needs of this demographic group—students who attend under-resourced schools in impoverished communities. Students in this learning context are not different in ability or level of interest but rather often learn in a structural context that undermines it. Given this goal, it is important to understand how the unique reality of living in chronic toxic adversity affects student learning. Although some needs are clinical and require specialized attention beyond the scope of science teaching and learning, there are needs that a context-informed geoscience pedagogy can address. (See Appendix B, Table B.1)

Chronic adversity due to exposure to violence and environmental toxins affects student academic performance by disrupting cognitive development and function.

Students exposed to violence have adapted to focus attention on threatening stimuli and

therefore have difficulty focusing on non-threatening stimuli, or classroom learning tasks, and connectedness to teachers (Busby, Lambert & Ialongo, 2013; McCoy, Raver & Sharkey, 2015; Sharkey, Tirado-Strayer, Papachristos, & Raver, 2012). Students exposed to environmental toxins potentially face disrupted neurocognitive development, impaired vision, delayed reading comprehension and reduced working memory capacity (Wisconsin DHS, 2016). Therefore, an instructional strategy designed to meet the academic needs presented would trigger and support interest development to facilitate information processing and knowledge retention (interest), support the affective domain in learning science content (place-based transformative learning), support attentiveness and learning through direct experience of science content and practice (self-efficacy through mastery). In addition to instructional strategy, the geosciences bridge science content to the lived reality of science students enrolled in impoverished community schools in urban, suburban and rural settings. (See Appendix A, Table A.3).

Review Summary and Introduction to the Dissertation Study

In summary, a review of the literature shows that triggering and supporting interest development through curricular relevance, grounding knowledge construction activities in the students' lived experience, using the surrounding community as a field for investigative learning tasks, modeling and extending the opportunity to master science practices, leads to academic achievement. There is theoretical and empirical support that the combination an instructional approach including interest development, self-efficacy through direct experience, and transformative learning would lead to desired learning outcomes such as increased attention, self-regulated learning, increased sense of competence, and transfer of learning demonstrated by students actively applying science concepts to novel circumstances outside of the classroom. Based on this evidence, I

conclude that a transformative learning experiences supportive of interest development and self-efficacy and inclusive of scientific content and practice has the potential to give access to opportunity to learn Earth science content for all students and particularly students from poor community schools in areas disproportionately impacted by environmental hazard. Further, based on the research highlighted in the literature review, I have identified three specific research questions to explore in this study, which I list below with hypotheses.

Research Question 1

For students who experience instruction that facilitates transformative learning, what are the pre to post and delayed post differences in interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, application of Earth science concepts, and knowledge?

For this research question, I hypothesized that the academic intervention would result in pre to post and delayed post increases in Earth science knowledge, application of learned concepts (motivated use), interest, self-efficacy, and perceived value and relevance of Earth science content. I based this hypothesis on both theory and the results of empirical studies. According to the theoretical framework for transformative learning experience as conceptualized by Pugh (2002, 2011), during instruction teachers contextualize science concepts in what is familiar to students. This approach triggers situational interest that in turn motivates students' attention to learn more (Renninger & Hidi, 2016). As teachers incorporate direct experience with experimentation (e.g., asking questions, measuring, observing, and collecting and analyzing data), and scaffolded practice with these skills—approaches that promote student engagement with the subject matter—students develop a stronger sense of competence and increased interest

(Renninger & Hidi, 2016). I further based this hypothesis in the results of empirical studies showing that academic approaches supportive of interest development lead to conceptual learning, intrinsic motivation that leads to self-efficacy, and self-efficacy that mediates academic achievement (Baram-Tsabari, 2015; Glynn, Bryan, Brickman & Armstrong, 2015; Hay, Callingham & Carmichael, 2015). I also based this hypothesis on the work of Blake, Liou-Mark and Lansiquot (2015) and Blake et al. (2015) that provide evidence supporting knowledge acquisition, increased interest, gains in perceived value and relevance of geoscience content through hands-on investigations in the geosciences.

Research Question 2

Do these learning outcomes (interest, self-efficacy, perceived value and relevance, application of science content, and knowledge) differ for students who express more as opposed to less awareness of environmental issues in their communities?

My hypothesis for this research question was that, given the overall potential positive shifts in each of the constructs post intervention, the gains would be greater for students who express more awareness of environmental concerns facing their communities. I based this hypothesis in part in the interest framework of both Renninger and Hidi (2016). Students who experience instruction designed to support interest development are able to self-regulate learning and persist through challenging subject matter, two factors that contribute to academic achievement (Renninger & Hidi, 2016). I also based this anticipated result in part in the work of Basu and Barton (2007) who concluded that perceived value and relevance of a learning activity leads to sustained interest and desirable learning outcomes. Therefore, students who perceive the learning experience as more relevant and valuable, are likely to develop greater interest and

subsequent knowledge gains. However, I acknowledge that a confounding factor in this hypothesis may be goal orientation, a variable that was beyond the scope of this study.

Research Question 3

What do students' written responses during transformative instruction reveal about their perceptions of value, relevance, and application of Earth science as a field of study?

My hypothesis for this research question was based in part on the work of Renninger et al. (2014) and Renninger and Riley (2015) which shows that use of written reflection as prompted by “I CAN...” statements during investigative science experiences support student development of interest and perceived value of the science content. According to Renninger et al (2014), through written reflection students “began to develop a relationship with science that went beyond the triggering of interest” (p. 127). Given the relationship between science and triggered situational interest would include perceived relevance of the subject matter to students’ communities, I anticipated that this academic intervention would lead to positive shifts in perceived value and relevance of Earth science content and motivated use of science concepts and practices related to water quality testing.

CHAPTER 3

METHODOLOGY

To address my research questions, I used a convergent parallel design within a pragmatic paradigm (Creswell & Plano Clark, 2011) and a combination of qualitative and quantitative analysis, to test the efficacy of a water quality themed transformative learning experience. For the purposes of this study, I designed two 220-minute learning experiences for implementation in four school locations in different parts of the country. Each experience consists of four learning activities centered on water quality, however one is embedded in the ongoing environmental crises in Flint, Michigan and the other designed for comparison, is centered on exploration of geoscience careers. I refer to these two learning experiences as the intervention and the comparison, respectively. My investigation examined the following:

- differences at three different time points—pre-instruction, post-instruction, and delayed post instruction—in each of the study variables interest; self-efficacy; transformative experience (perceived value, relevance, and motivated use of Earth science); and knowledge.
- differences in learning outcomes between groups—the intervention and the comparison group.
- differences in learning outcomes for students who express more versus less awareness of environmental concerns in their communities.
- evidence of transformative learning in student generated responses to writing prompts.

In this chapter, I describe the project's design and align analytical approaches to each research question. I also discuss the study's participants, anticipated results, and potential implications.

Participants

The activities for both the intervention and comparison groups were designed and aligned to NGSS standards for both middle and high school, however, participants in the study were all students enrolled in high school science courses that included Earth science content. Although all students enrolled in the classes participated in the learning experiences, only data from those students with both signed assent and consent forms for participation in the study were analyzed (see Appendix C and D). I conducted an *a priori* power analysis using Gpower in order to determine the appropriate sample size for the study (Mayr, Erdfelder, Buchner, & Faul, 2007). A minimum sample size of 120 students was required for the data analysis, given a 95% ($\alpha = .05$) probability of not committing a Type I error, a 90% chance that existing effects will present as statistically significant during analysis ($1 - \beta = .9$), and a medium effect size (Tabachnick & Fidell, 2013). The study had a total of 176 participants (following removal of outlier data) from four different schools across the United States (one private and three public). These students were enrolled in six different courses (Physical Sciences, Earth and Space Science, Earth and Environmental Science, Environmental Science, AP Environmental Science and Biology) taught by four teachers (one per school site). I have provided more details about each school site in the Tables 1-4 below.

Table 1

Characteristics of School Site 01

School Site 01	Characteristics
Number of participants	23
Course(s) Enrolled	Physical Sciences
Grade	9 th
Type of School	Public (Urban)
Primary Languages Spoken	English, Spanish, Tagalog
School-wide demographics (2016-2017):	Black or African American (0.8%) American Indian or Alaska Native (0.3%) Asian (16.6%) Filipino (27.5) Hispanic or Latino (23.5%) Native Hawaiian or Pacific Islander (0.3%) White (21.8%) Two or More Races (8.9%) Socioeconomically Disadvantaged (31%) English Language Learners (9.9%) Students with Disabilities (13.1%) Foster Youth (0.5%)
Other: Graduation Rate (2016-2017)	94.85%

Table 2

Characteristics of School Site 02

School Site 02	Characteristics
Number of participants	7
Course(s) Enrolled	Environmental Science
Grade	11-12 th
Primary Languages Spoken	Not Available
School-wide demographics	Not Available
Type of School	Private (Urban; All-girls)
Other:	Tuition (2018-2019) = \$33,530 Tuition + 7-day boarding = \$62,300 Laptop = \$1,949

Table 3

Characteristics of School Site 03

School Site 03	Characteristics
Number of participants	16
Course(s) Enrolled	Earth and Environmental Science
Grade	11-12 th
Type of School	Public (Rural; Public)
Primary Languages Spoken	Not Available
School-wide demographics (combined Junior and High School for 2016-2017):	Black or African American (1%) American Indian or Alaska Native (0%) Hispanic or Latino (1%) Asian, Native Hawaiian or Pacific Islander (2%) White (96%) Two or More Races (0%) Socioeconomically Disadvantaged (30%) English Language Learners (0%) Students with Disabilities (N/A) Foster Youth (N/A)

Table 4

Characteristics of School Site 04

School Site 04	Characteristics
Number of participants	146
Course(s) Enrolled	Biology (17 in 9 th grade) NGSS Earth and Space Science (36 in 10 th -11 th grade) AP Environmental Science (93 in 11 th -12 th grade)
Grades	9 th , 10-11 th , 11 th -12 th
Type of School	Public (Urban)
Primary Languages Spoken	
School-wide demographics (2016-2017):	Black or African American (0.6%) American Indian or Alaska Native (0.2%) Asian (25.7%) Filipino (3.9%) Hispanic or Latino (14.0%) Native Hawaiian or Pacific Islander (0.1%) White (54.0%) Two or More Races (1.4%) Socioeconomically Disadvantaged (18.0%) English Language Learners (3.7%) Students with Disabilities (8.6%) Foster Youth (0.1%)
Other: Graduation Rate (2016-2017)	96.1%

Location

School sites were selected using purposeful criterion sampling (Creswell, 2013; Creswell & Plano Clark, 2011). School sites 01, 02, and 04 were located in the western United States while school site 03 was located in the Northeast. Given the intervention's

focus on exposure to environmental toxins I provide EPA statistics on community level exposure to environmental toxins for each school site. I operationalize exposure to environmental toxin as geographic proximity to sites of commercial and/or industrial hazardous waste disposal that pose an immediate danger to human and environmental health as determined by the United States Environmental Protection Agency (EPA)—Superfund or CERCLA sites—and proximity to polluting facilities listed as Toxic Release Inventory (TRI) facilities.

Federal legislation under the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authorizes the EPA to remediate hazardous waste sites (EPA, 2011). These sites, informally referred to as Superfund sites, are first inspected and evaluated for potential risk to human health using a Hazard Ranking System (EPA, 2011). If the preliminary testing of soil, air, and water has a score ranked above a pre-determined level for the particular contaminant, the site is then placed on a National Priority List for remediation (EPA, 2017d).

Similarly, the Toxic Release Inventory (TRI) program was established by federal legislation, the 1986 Emergency Planning and Community Right-to-Know Act (EPCRA). The TRI program requires industries to report annual releases of 650 identified toxic chemicals known to cause “cancer or other chronic human health effects, significant adverse human health effects, or significant adverse environmental effects” (EPA, 2017e). Though not a comprehensive list of harmful chemicals, the TRI program was created to regulate identified toxins and make available to the public information about possible exposure to these chemicals. I have listed the EPA identified Superfund sites, TRI facilities, as well as the total amount of waste managed by those TRI facilities for each school site in Table 5 below.

Table 5

Selected Environmental Characteristics of the County for Each School Site

	Number of Superfund (CERCLA) Sites	Number of TRI facilities	Total Waste Managed (lbs.)
School Site 01	0	13	492.0 thousand
School Site 02	10	70	1.1 million
School Site 03	0	9	30.5 billion
School Site 04	18	368	78.4 million

Note. EPA identified hazardous waste sites under the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) are also known as Superfund sites (Environmental Protection Agency, 2017).

To facilitate comparison of learning outcomes as outlined in RQ1, the first criterion is enrollment in a high school science course that contains Earth science content. To facilitate pre to post and delayed post between group comparisons with respect to interest, self-efficacy, perceived value and relevance of Earth science, and knowledge for RQ1 and RQ2, for school sites with multiple classes, class sections were randomly assigned to experience either the intervention or the comparison activities.

Research Design

The current study is a quasi-experimental, within-group and between group comparison design. At the onset of the study, participants completed two instruments—a combined survey instrument consisting of measures of interest, self-efficacy, and transformative experience in Earth science and general science, and a knowledge instrument. The participants in the intervention group then completed 4 activities totaling 220-minutes of instructional time to facilitate changes in interest, self-efficacy, and

transformative experience while students in the comparison group completed 4 parallel activities totaling 220 minutes of instructional time that focused on professions in the geosciences (see Appendix E). The students completed the instruments two more times—immediately following completion of the learning activities and again several days to 2 weeks later. In the following sections I discuss the materials used in the study, including the instruments used to collect quantitative and qualitative data, the transformative learning experience (instructional intervention), and the geoscience career learning experience (comparison). I also detail the procedures used for data collection.

Study Materials

Interest Measurement

I developed a 7-item instrument to measure participants' interest about Earth science and general science (see Appendix F). I developed this instrument based on the theoretical perspective of Renninger and Hidi (2016). For example, in earlier phases of interest development, students who reflect on connections to classroom content as an opportunity “to explore new ideas” is critical (Renninger & Hidi, 2016, p. 74). Therefore, to align with this perspective I created an item that asks, “Earth science is relevant to my everyday life.” Students rated their agreement with these 7 items on a 5-point Likert-type scale, with 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree. Another example of how I developed items from Renninger and Hidi's (2016) framework is their position that interest and engagement within a particular topic or context is strong when students are allowed agency in pursuing lines of inquiry. In an instructional context, engagement (and potentially interest) would be high when students participate in individual projects. Therefore, I created an item that says, “Think about your Earth science and geology classes. Did you work on individual projects?” The full

instrument used a 5-point Likert-type scale, but with this item the choices were 5 = All of my assignments were individual projects, 4 = I was assigned many individual projects, 3 = I was assigned a few individual projects, 2 = I was assigned one individual project, and 1 = No, I was not assigned any individual projects.

I conducted a bench-scale pilot study to evaluate the interest instrument's validity and reliability. I evaluated the interest items separately, however, they were administered together with the self-efficacy and TE measures as a combined survey during the pilot study. Prior to conducting the pilot study, experts in the field of educational research and cognitive psychology reviewed the instrument to help gauge content validity (Creswell & Plano Clark, 2011). I made revisions to the instrument based on their feedback. Thirty-one testers ($N = 31$) fully participated in the pilot study, and during the pilot, I asked testers to provide feedback. Testers provided feedback with respect to wording of questions, clarity of instructions, and length of time for taking the survey. For example, one respondent wrote: "Questions 9 & 17 were a little difficult to get at first, slightly awkward. I was wondering if there may be a clearer or better frequency scale to use that gets more specific than the one in this survey." I incorporated their feedback in the final version of the instrument (Osterlind, 2010).

I calculated the reliability of the interest instrument (IBM Corp., 2017). Specifically, I analyzed internal consistency using Cronbach's alpha, which essentially calculates "the Pearson correlation between all possible pairs of items" (Osterlind, 2010). For the 7-item interest measure, Cronbach's $\alpha = .752$, a value that exceeds the threshold of acceptable reliability (Tavakol & Dennick, 2011).

Self-efficacy Measurement

I developed a 3-item instrument to measure self-efficacy in learning Earth science (see Appendix G). I developed these items based on the perspective of Renninger and Hidi (2016). For example, Renninger and Hidi (2016) state that self-efficacy is “an individual’s beliefs about their own abilities” (p. 82); these beliefs are domain and task specific. Therefore, I created an item that says, “I do well on assignments in my Earth science/geology class.” This item addresses the aspects of self-efficacy that are self-referent belief and task-specific. Students rated their agreement with this item and each of the 3 items on the instrument using a 5-point Likert-type scale, with 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree. A student who feels efficacious in Earth science would agree with the statement while a student with low self-efficacy in Earth science would disagree.

I also developed items aligned with Renninger and Hidi’s (2016) conceptualization of self-efficacy with respect to their perspective on task avoidance versus persistence. For example, in an educational setting, a student with high self-efficacy is willing to engage subject matter and persist when they encounter difficulty with “fewer adverse reactions” (Renninger & Hidi, 2016, p. 83). When a student engages challenging tasks, self-efficacy then becomes a motivational factor that supports continued engagement as opposed to the student choosing not to persist to completion. Bandura (1986) describes this scenario as, “people tend to avoid tasks and situations they believe exceed their capabilities” (p. 393). Therefore, I created another item that asks, “How easy is it for you to study for your Earth science/geology classes?” This item addresses the aspects of self-efficacy related to persistence and affect. Students likewise

rated their agreement using a 5-point Likert-type scale, with 5 = very easy 4 = easy, 3 = depends, sometimes easy, sometimes hard, 2 = a bit hard, and 1 = quite difficult.

I conducted a pilot study to establish validity and reliability for this instrument. Prior to the pilot study, subject matter experts in educational research and cognitive psychology reviewed the items for content validity (Creswell & Plano Clark, 2011). Based on their assessment, I revised the items before using them for the pilot study. Thirty-one testers fully participated in the pilot ($N = 31$). The testers provided feedback with respect to the structure and clarity of the items that was useful in establishing face validity. I used this feedback to further revise the self-efficacy instrument (Osterlind, 2010; see Appendix G).

After establishing both content and face validity, I calculated reliability for the self-efficacy instrument (IBM Corp., 2017). Reliability for the 3-item measure was acceptable with a Cronbach's $\alpha = .761$ (Tavakol & Dennick, 2011).

Transformative Experience Measurement

I developed a 7-item instrument that measured participants' transformative experience in Earth and general science (see Appendix H). The items on the full instrument address three areas of transformative experience outlined by Pugh (2002): active use, expansion of perception, and expansion of value. For example, active use occurs when a student applies Earth science concepts learned in class to aspects of his/her everyday life when not required to do so as part of an assignment (Pugh, 2002). To align with this principle, I included in the instrument the following statement, "I discuss ideas from my Earth science class with friends or family members outside of class." Students responded to the statement as it relates to their experience using a 5-point, Likert-type scale with 5 = often, 4 = sometimes, 3 = perhaps once, 2 = not really, and 1 = never. For

this item, the higher the frequency the greater the transformative experience with respect to active use of Earth science content. The second component of transformative experience is expansion of perception or when a student sees Earth science content embedded in his/her surroundings (Pugh, 2002). I created the following item to measure expansion of perception: “I see examples of what I learned in my Earth science class at home and in my community.” Students again rated how this statement reflects their experience using a 5-point Likert scale with 5 being often and 1, never. Finally, I designed the instrument to measure expansion of value, or the perception of Earth science content as relevant and useful (Pugh, 2002). To align with this principle, I created an item that reads, “I think what I learned in my Earth science class was worth learning.” Still using a 5-point Likert-type scale but with different values, students evaluated their experience as 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree.

I conducted a pilot study to establish validity and reliability for the transformative experience measure. Prior to the pilot study, subject matter experts with cited publications in the area of transformative learning reviewed the items for content validity (Creswell & Plano Clark, 2011). I incorporated their feedback in the subsequent revision of the instrument. Thirty-one testers fully participated in the pilot study ($N = 31$). During the pilot, I requested specific feedback with respect to clarity of the instructions and questions and length of time needed to complete the survey to establish face validity. I used this feedback to further revise the transformative experience measure (Osterlind, 2010).

After establishing both content and face validity, I calculated reliability for the transformative experience instrument (IBM Corp., 2017). Reliability for the 7-item measure was acceptable with a Cronbach's $\alpha = .905$ (Tavakol & Dennick, 2011).

Associations Between the Variables

In summary, as part of the data screening process I computed Pearson's correlations of each of the pilot study variables using SPSS version 25 (IBM Corp., 2017). The Pearson correlation measures both the potential statistical association of the variable relations and the strength of the relationship between the variables (Field, 2013). Results of the analysis show that there were statistically significant associations amongst each of the variables—interest and self-efficacy, interest and transformative learning experience, and self-efficacy and transformative learning experience. Interest and self-efficacy were moderately correlated ($r = .537, p \leq .01$), while interest and transformative learning experience were strongly correlated ($r = .692, p \leq .01$). Self-efficacy and transformative learning experience were also strongly correlated ($r = .759, p \leq .01$; see Table 6).

Table 6

Pearson Correlations, Means, and Standard Deviations for each of the Measured Constructs: Interest, Self-efficacy, and Transformative Learning Experience

Variable	1	2	3
1. Interest	-		
2. Self-efficacy	.537**	-	
3. Transformative Learning Experience	.692**	.759**	-
<i>M</i>	23.7	11.0	27.6
<i>SD</i>	5.27	2.79	5.39

** $p \leq .01$

These associations support the theoretical framework for interest (Renninger & Hidi, 2016). More specifically, the data confirms the perspective that interest supports engagement with content that leads to motivated learning that persists through difficulty (Bandura, 1986; Renninger & Hidi, 2016). When a student chooses to persist through challenging subject matter, self-efficacy develops. These associations also support the theoretical framework for transformative learning in that for instruction to be transformative, it must be contextualized in what is familiar to the student (Pugh, 2002). This strategy naturally triggers situational interest in students and supports their perception of the science content as relevant and valuable (Renninger & Hidi, 2016). Finally, as students perceive science content as relevant and valuable (components of transformative learning), they will be motivated to learn and re-engage the subject matter thereby increasing both self-efficacy and interest (Renninger & Hidi, 2016).

Single Item Measures

In addition to the multi-item measures described above, I created three single item variables. Two of the variables measure student attitudes toward drinking water sourced from home and school (Water Quality Affect) and the third variable measures awareness of environmental issues facing the local community (ENV Awareness). These items are included in Appendix I.

Earth Science Knowledge Instrument

I created a 10-item knowledge instrument to measure understanding of Earth science with respect to water resources and water quality at three different time points—pre, post, and delayed post completion of both the water-quality themed instructional intervention and the comparison activity created for this study (described in a later section). I adapted the knowledge items from two sources, the National Research Council (2012) and the 2015 and 2017 Regents High School Examination of the New York State Education Department in Physical Earth Science. I adapted items from the NRC (2012) identified as essential content and/or scientific practices for Earth science students to understand. For example, I derived an item from the NRC (2012) that reads: “Science is instrumental in addressing problems in our society today, including maintaining sources of clean drinking water.” The item is a slight rewording of a statement describing the role of science in ensuring the safety of water as essential resource. Students responded to this item and each of the 10 items on the full knowledge instrument using a Likert-type scale to rate the degree to which they thought geoscientists would agree with the given statement with 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree. Another example of an item derived from NRC (2012) is, “When Earth scientists design solutions to complex real-world problems, tradeoff considerations are

not necessary.” I negatively worded this item. In other words, this is a statement that geoscientists would disagree with. I also adapted questions from a validated instrument, the NYS High School Regents Exam in physical Earth science published by the University of the State of New York. I chose two questions from publicly available exams on the website for the NYS Education Department that relate to water resources and water quality. For example, I chose a question from the Regents exam and adapted from a multiple-choice question of two sentences and 4 options to Likert-type scale question of three sentences. The adapted question reads as follows (University of the State of New York, 2015, p. 10):

Figure 1. Illustration of laboratory experiment used to measure porosity in 4 sediment samples labeled A, B, C, and D. This figure was retrieved on November 21, 2017 from <http://www.nysedregents.org/EarthScience/815/esci82015-exam.pdf>

Look at the diagram above to rate the degree to which you think that a geoscientist would agree with this statement: “Water was added to each tube to just cover the sediments. The volumes of water added were recorded. This information can be used to determine permeability.”

Referring to the diagram, students considered the Earth science content learned during the classroom activities and responded to the question using the 5-point Likert-type scale with 5 = strongly agree and 1 = strongly disagree.

Instructional Intervention

I created the 220-minute (4 activity) water-quality themed academic intervention as a scaffolded investigation. Two principles guided my design: (a) the Deweyan perspectives of learning by doing and leveraging the lived experience of the student in designing educational experiences, both central to transformative learning experiences and triggering situational interest, and (b) the concept of participation in scientific practice that transforms the learner's perspective (NRC, 2012). Pugh (2017) posits that learning by doing is transformative leading to knowledge construction and knowledge transfer as is applied to "new contexts and novel problems." According to Hidi and Renninger (2006), intentional incorporation of a novel learning experience or one based a topic to which the student can develop a sense of relatedness due to its perceived relevance, can trigger situational interest. Triggered interest leads to motivated learning and consequently knowledge construction. I specifically used these principles because of their relations to transformative learning and interest, and intentionally incorporated in the design of the academic intervention in order to facilitate learning.

Throughout this learning experience, teachers tasked students with investigating an Earth science related case. Given a timeline detailing the actual water crisis that transpired in Flint, Michigan beginning in 2014 [New York Times (NYT, 2016)], students actively participated in the following components of scientific investigation as outlined by the NRC (2012): asking questions, observing, conducting experiments, and measuring and collecting data. Students also practiced prediction and formulating

explanations (NRC, 2012). Table 7 shows the alignment of the learning experiences with the three design principles.

Table 7

Design Principles for the Water Quality Themed Learning Experience (Intervention)

Design principle	Author	Alignment of learning experience	Variables measured
Learning by doing/active learning	“They give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking, or the intentional noting of connections; learning naturally results” (Dewey, 1916, p. 119).	Activity 1, 4: students learn how to plan an investigation and organize the findings for communication Activity 2: Students observe metal corrosion and compare the effects of three different solutions on samples of iron and steel	Transformative learning experience (TE) with respect to expansion of perception of Earth science (perceived relevance) (Pugh, 2017); and interest with respect to triggered situational vs maintained situational (Renninger & Hidi, 2016)

Table 7 (Continued)

Design principle	Author	Alignment of learning experience	Variables measured
Educational experiences embedded in real life experiences	<p>“To realize what an experience, or empirical situation, means, we have to call to mind the sort of situation that presents itself outside of school; the sort of occupations that interest and engage activity in ordinary life. And careful inspection of methods which are permanently successful in formal education, whether in arithmetic or learning to read, or studying geography, or learning physics or a foreign language, will reveal that they depend for their efficiency upon the fact that they go back to the type of the situation which causes reflection out of school in ordinary life” (Dewey, 1916, p. 119).</p>	<p>Activities 1-2, 4 Students are specifically tasked with examining an authentic case of water quality in a North American city—Flint, Michigan</p>	<p>TE with respect to expansion of perception of Earth science (perceived value) (Pugh, 2017); self- efficacy through direct experience in Earth science (Streule & Craig, 2016); physical activities that engage students in scientific practices “enables them to extend what they know in new ways and also positions them to develop value for the content, feelings of self-efficacy, and abilities to self-regulate” (Renninger & Hidi, 2016, p. 102).</p>

Table 7 (Continued)

Design principle	Author	Alignment of learning experience	Variables measured
Participation in scientific practices	“Participation in these practices...makes students’ knowledge more meaningful and embeds it more deeply into their worldview” (NRC, 2012, p. 42).	Activity 2: students measure temperature, pH, and total dissolve solids (TDS) of locally collected water samples	TE through demonstrated value of content (Pugh, 2002); self- efficacy through direct experience in Earth science (Streule & Craig, 2016); and interest development as supported through physical activity and social involvement (Renninger & Hidi, 2016)

Comparison Activity

I created an additional series of water-quality themed comparison activities. The purpose of the comparison activities was to have a set of student data generated from a more traditional curriculum in order to detect any differences in learning outcomes that may be associated with the intervention. This study did not have the true experimental and control group research design. Rather, the logic that motivated implementing a parallel series of activities that were characteristically more traditional was to create a type of baseline for comparison to the transformative learning experience. The comparison activities were traditional in that they were not designed to be a transformative learning experience. Although having a water-quality theme, these

activities were designed as a scaffolded exploration of geoscience careers as opposed to an investigative learning experience. Like the intervention, this series of 4 activities totaled 220 minutes of instruction with each individual comparison activity designed to parallel each individual intervention in terms of length of time for completion. In other words, Activity 1 of the intervention would be completed in a single traditional class period and Activity 1 of the comparison would likewise be completed in a single traditional class period (55 minutes). Similarly, Activity 2 of both the intervention and comparison learning experiences were designed for completion within 2 traditional class periods or 110 minutes. The principles underlying this design decision were to facilitate classroom use and ensure similar instructional dosage. A teacher implementing both the intervention and comparison activities with assigned sections could easily use the activities within the scheduled school day. Also, students in both the intervention group and the comparison group received the similar length of instruction leaving content as the only variable for comparison.

Procedures

Classroom teachers in each of the four schools sites administered the instructional intervention to their Earth science students. Two of the four teachers with multiple classes administered both the intervention and comparison activity to randomly selected sections. Prior to implementation of the instructional intervention and comparison activity, I met with each classroom teacher for specific training on transformative learning experiences, the use of reflective prompts, and a review of water quality testing techniques using equipment purchased specifically for the learning experience. The training ranged in duration from 3-5 hours depending on the teacher's comfort level with using the water quality testing equipment (see Table 8).

Table 8

Teacher Professional Development and Compensation

Project Component	Time Commitment of Teacher	Teacher Compensation
Pre-intervention workshop <ul style="list-style-type: none"> • Outline of collaboration • Feedback on curriculum and alignment with academic standards • Understanding of TE components • Review of supplies to be used over the course of the learning experience—pH measuring strips, metal samples, beakers, salt, vinegar, tap-water • Familiarity with preparing the solutions needed for the corrosivity study • Familiarity with and practice using water quality testing equipment • Review of the comparison activity (for the two teachers with multiple class sections) 	3-5 hours	\$125
Conduct academic intervention, shipping of student generated data, shipping of water quality testing equipment <i>(Note: range depends on number of class sessions)</i>	1-2 weeks	\$150-250
Discussion of learning experience, feedback	2 weeks	\$125
<i>(Optional)</i> Co-authorship of a practitioner piece	Time estimate to be determined	\$150

Following the brief workshop, teachers led the 220-minute water-quality themed academic intervention at each school site per the project outline below (see Table 9).

Over the course of the learning experience, students learned Earth science concepts related to water resources and water quality, and scientific practices such as investigative design, problem-solving, and data collection and interpretation. Additionally, students participated in specific water quality tests and measurements such as temperature, pH, corrosivity, and conductivity (total dissolved solids).

Table 9

Project Timeline Including Dates for Data Collection and Analysis

Activity	Data Collection	Data Analysis
Prior to Activity 1	Conducted workshop with participating classroom teachers	
Prior to Activity 1	Qualitative: field notes of classroom observation, school context and community	Field notes were not needed to address any of the research questions but were used to provide context for the study
Prior to Activity 1	Interest survey; Pre-intervention knowledge instrument	Descriptive statistics and repeated measures ANOVA
1-3	Intervention on topic of water quality	
4	Students summarized and organized data in preparation for group discussion	
Immediately following Activity 4	Students completed student interest survey	Descriptive statistics and repeated measures ANOVA
	Students completed knowledge instrument	
Days up to 2 weeks following Activity 4	Students completed student interest survey	Descriptive statistics and repeated measures ANOVA
	Students completed knowledge instrument	

For the learning experience, the classroom teacher organized students into teams of Earth scientists tasked with constructing an investigative approach for data collection to solve a case of water quality. Using the actual water quality crisis in Flint, Michigan as the context, students worked in collaborative learning teams to identify research questions and the information needed to answer each question, skills that align with NRC (2012) recommendations. For example, during Activity 1 of the learning experience, teachers gave students details of the water crisis in Flint, introduced as City X, in order of their occurrence (see Appendix E). These details include changed color and odor of the tap water, the development of skin rashes, the presence of coliform bacteria, and that the local auto manufacturing plant stopped using the city's water supply because the water was corroding the auto parts. The classroom teacher then asked the students the following questions:

Based on this timeline of events, as an Earth scientist assigned to investigate this case, what would you do?

What questions would you ask?

Notice that the local automobile manufacturing plant stopped using the water because it was corrosive to the auto parts. What does that mean? How could you test water to see if it would be corrosive to car parts?

What information would you like to know?

What is the best way to get that information?

I designed the learning experience so that students would engage in learning both scientific content and scientific practices (e.g., investigative design, experimentation, and problem solving). Each teacher scaffolded students' design of an investigation

incorporating the questions that they wanted to ask. The investigation included direct experience with scientific practices. For example, as part of Activity 2 students participated in two related activities—a study of corrosion and the collection and analysis of locally collected water samples.

To understand how metal corrosion contributed to the water quality crisis in City X (later revealed as Flint, Michigan), students observed the effect of three different water solutions—tap water, saltwater, and vinegar-water—on metals commonly used as pipes. Students made predictions about what they would observe, for example, which metal would be most susceptible to corrosion and the nature of the physical changes they would see in each of the metal samples. Over the course of 3-5 days students observed changes in both the iron and steel samples and recorded their observations. The students then discussed whether the initial predictions were confirmed by their observations and provided possible reasons underlying whether their predictions were confirmed or not. This process engaged students in the scientific practices of asking questions, predicting, observing, reasoning, and formulating explanations (NRC, 2012).

Also, part of Activity 2 was conducting water quality measurements. Using 250mL polyethylene sampling bottles, in teams and individually, students collected water samples from school water fountains and sinks, from the tap in their homes, local streams and creeks, the beach, a pond on a blueberry farm, etc. The students then used multiparameter hand-held probes to measure temperature, pH, and TDS of the locally collected water samples. Students recorded their measurements and compared them to the samples collected by fellow classmates. Lastly, the students compared their measurements to those EPA standards and the water samples data from Flint, Michigan.

During this investigative activity students engaged in measuring, analyzing, and reasoning (NRC, 2012).

Following each activity, students reviewed their learning through reflective prompts. These prompts, modeled after the *ICAN* intervention developed by Renninger et al. (2014), served as a means for students to reflect on their learning, demonstrate understanding, and apply concepts. Teachers were able to use these “I CAN” statements as a type of formative assessment. After completing Activity 2, students respond to the following reflective prompts:

I CAN describe at least three investigative practices that scientists use.

I CAN describe how the scientific practice of investigation can be useful to answer questions affecting my everyday life.

I designed these prompts to allow students to deepen understanding through reflection, give evidence of knowledge acquisition, and provide qualitative evidence teachers can use to assess learning. The culminating activity following completion of all 4 parts of the learning experience was a whole class discussion of its findings and conclusions. This activity allowed students to summarize test results, organize findings, and communicate results and solutions.

Data Collection and Analytical Methods

For this quasi-experimental, pre to post within and between group comparison, I collected quantitative and qualitative data on the following student measures: interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, knowledge and application of Earth science concepts. Following implementation of the water-quality themed academic intervention at each study site, I conducted a combination of quantitative and qualitative data analysis on the knowledge instrument, survey

instrument, and reflective prompts. Table 10 represents data collection and methods of analysis for each research question.

Table 10

Data Collection and Analysis for Each Research Question

Research Question	Data Collection	Methods of Analyzing Data
RQ1. For students who experience instruction that facilitates transformative learning, what are the pre to post and delayed post differences in interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, application of Earth science concepts, and knowledge?	Validated survey instrument to measure transformation with respect to perceived value and relevance of Earth science and motivated use, student interest, and self-efficacy.	Repeated measures ANOVA on Likert scale items (on survey and knowledge instruments)
RQ2. Do these learning outcomes differ for students who express more as compared to less awareness of environmental issues facing the local community?	Survey interest item—ENV Awareness	Sequential linear regression

Table 10 (Continued)

Research Question	Data Collection	Methods of Analyzing Data
RQ3. What do students' written responses during transformative instruction reveal about their perceptions of value, relevance, and application of Earth science as a field of study?	Student generated written prompts during learning experience	Iterative content analysis of written reflections in response to I CAN prompts (on intervention) for emergent themes in evidence of interest, self-efficacy, and transformative learning experience (TE) (Creswell, 2013)

Data Management

All signed consent and assent forms and student-generated artifacts were stored in a secure location—a locked file cabinet within a locked on-campus office. I separated all artifacts of students who were non-participants in the study. A master list of teachers, students, and student identifiers are maintained in a separate password protected file. A second copy is located in a secure file cabinet in a locked office space for storage up to one year following my dissertation defense. Although pre to post knowledge tests may have been used by the classroom teacher to administer class participation credit to individual students, such data were analyzed in aggregate thereby maintaining the anonymity of each participant, which is also consistent with the goals of the project.

Ethical Considerations

I anonymized the names of student participants using the following coding system: a number representing the school site, a double-digit number representing the class period, and a second double digit number representing the student. This coding

system generated a unique identifier for each student participant. I used this unique identifier in place of the student's name thereby guarding the privacy and confidentiality of each student participant.

I compensated teachers for time committed to the project and gave them the option of taking a leadership role in the practitioner community by co-authoring a publication. Table 8 outlines commitment options.

CHAPTER 4

RESULTS AND SUMMARY

Over the course of this project, I collected student generated data and artifacts to address my three research questions. In this chapter, I describe preliminary data screening procedures, the analytical approaches applied to those data, and a summary of the results.

The questions I examined in this study are:

RQ1: For students who experience instruction that facilitates transformative learning (intervention), what are the pre to post and delayed post differences in interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, application of Earth science concepts, and knowledge?

RQ2: Do these learning outcomes differ for students who express more awareness of community exposure to environmental hazard compared to students who are less aware of community exposure to environmental toxins?

RQ3: What do students' written responses during transformative instruction reveal about their perceptions of value, relevance, and application of Earth science content?

Preliminary Data Screening

Preliminary data screening included three processes—calculation of reliability for each instrument used for data collection in the study, identification of outliers, and examination of kurtosis and skewness of data.

Reliability Calculations

Reliability is a measure of an instrument's internal consistency and describes whether the instrument assesses the intended construct. Reliability therefore consists of two parts—error in measurement and replication in order to estimate the error in

measurement (Osterlind, 2010). I have recalculated reliability for each instrument used in the study for three reasons: the instruments developed for the study were used in educational settings that are complex and dynamic environments, are dependent on some aspect of cognitive function that by nature is constantly changing based on internal and external factors, and that the instruments themselves are imperfect measures of the given constructs (Osterlind, 2010). I use the alpha coefficient, the most commonly used indicator, in reporting the outcome (Osterlind, 2010; George & Mallery, 2011; Tavakol & Dennick, 2011). The alpha coefficient is reported as a number ranging from 0 to 1 (Tavakol & Dennick, 2011). An outcome closer to 0 means that the instrument is not reliable in assessing the intended construct given the amount of measurement error (Tavakol & Dennick, 2011). An outcome closer to 1 indicates internal consistency or that each of the items in the instrument are measuring the intended construct (George & Mallery, 2011). Outcomes ranging from .7 to .95 are deemed acceptable (Tavakol & Dennick, 2011) though “minimally acceptable reliability for preliminary research” (Peterson, 1994, p. 381) may be in the range of .5 to .7.

Reliability Calculations for Each Study Instrument.

I recalculated reliability based on classroom data from each of the four study sites. The goal of this analysis is to determine whether the measure is appropriate for continued use in the study.

The Interest instrument was previously a single, 7-item interest measure, however I separated out the items containing Earth science specific content (5 items), and a General Science focus (2 items), in order to conduct a more targeted evaluation of each measure. Although each of the 7 items refer to science interest, and therefore have some inter-relatedness, separating the items is justifiable given the heterogeneity of the

content—interest specific to Earth science versus a more global or general interest in science (Tavakol & Dennick, 2011). The outcomes are presented in the following text.

Reliability calculation for Earth Science Interest (INT-ES) instrument. The Earth science instrument consists of 5 items designed to measure individual interest in Earth science content. The outcome of the reliability analysis for this instrument was a Cronbach's $\alpha = .358$. This low result reflects significant measurement error and therefore low confidence that this instrument measures the intended construct (Tavakol & Dennick, 2011). Therefore, I deemed the Earth science interest instrument to be unreliable. Consequently, the variable, Earth science interest, was not included in the study, and the scores from the instrument were not carried forth in future analyses.

Reliability calculation for general science interest (INT-GEN SCI) instrument. The Earth science instrument consists of 2 items designed to measure individual interest in Earth science content. The outcome of the reliability analysis for this instrument falls within the acceptable range with a Cronbach's $\alpha = .671$ (Tavakol & Dennick, 2011). This result reflects confidence that this instrument measures the intended construct. The General Science Interest instrument is therefore deemed reliable, and the variable, General Science Interest, was carried forth for further analyses in the study.

Reliability calculation for self-efficacy (SE) instrument. The Self-Efficacy instrument consists of 3 items designed to measure individual self-belief of competence in to learn Earth science content. The outcome of the reliability analysis for this instrument was a Cronbach's $\alpha = .442$. This outcome falls within the unacceptable range reflecting low confidence that this instrument measures the intended construct given the amount of measurement error (Tavakol & Dennick, 2011). The Self-Efficacy instrument

is therefore deemed not reliable. Consequently, the instrument was not used for further study and, Self-Efficacy as a variable was not carried forth in future analyses.

Reliability calculation for Transformative Experience (TE) instrument. The Transformative Experience instrument consists of 7 items designed to measure three aspects of transformative learning—perceived value and relevance, and application of Earth science concepts to everyday life circumstances (Pugh, 2002). The outcome of the reliability analysis for this instrument was a Cronbach's $\alpha = .855$. This outcome falls within the acceptable range reflecting confidence that this instrument measures the intended construct (Tavakol & Dennick, 2011). The Transformative Experience instrument is thereby deemed reliable and appropriate for use in the research study. Further, Transformative Experience (TE), as a variable was carried forth for subsequent analyses.

Reliability calculation for Earth science knowledge (KNOW) instrument. The Earth science knowledge instrument was created by drafting items based on water resource content or scientific practices from both the National Research Council (2012) and by compiling items with water resources content from the 2015 and 2017 Regents High School Examination of the New York State Education Department in Physical Earth Science. The instrument was designed with 10 items however, upon duplication and dissemination across the school sites, one item, item 7, was found to have been repeated. I therefore removed item 7 from the analysis, and calculated reliability for the 9-item measure. The result of this procedure was a Cronbach's $\alpha = .597$, interpreted as unacceptable, identifying the instrument as unreliable as a measure in its current form (Tavakol & Dennick, 2011). The procedure further identified item 10 as problematic. In other words, if the item were deleted the instrument's reliability would increase. I

calculated reliability with item 10 removed, resulting in a Cronbach's $\alpha = .637$. This outcome is interpreted as acceptable. Therefore, the 8-item instrument is a reliable measure of the intended construct (Tavakol & Dennick, 2011).

Although the 8-item instrument is deemed appropriate for use in the research study three items were identified as problematic (i.e., lowered the overall reliability of the measure), items 10, 2 and 5. I reason that item 10, shown below as it appears on the instrument, may have decreased the instrument's reliability for two reasons, because it was not clearly aligned with the content of the other questions, i.e. was not clearly related to the other items in the measure (Tavakol & Dennick, 2011), and also it represents a complex Earth science concept.

Look at the diagram below to rate the degree to which you think that a geoscientist would agree with this statement.

Figure 2. Illustration of laboratory experiment used to measure porosity in 4 sediment samples labeled A, B, C, and D. This figure was retrieved on November 21, 2017 from <http://www.nysedregents.org/EarthScience/815/esci82015-exam.pdf>

Water was added to each tube to just cover the sediments and the volumes of water added were recorded. This information can be used to determine permeability.

Whereas the other items on the instrument are related to surface water and water quality, item 10 refers to a subsurface water concept—porosity. It also very specifically targets both a scientific process of measuring pore space between sediment grains, and the need to distinguish between two concepts often confused—porosity and permeability. Therefore, given the potential lack of alignment of content with the other knowledge items, the focus on a specific scientific measurement, and that the item requires students to distinguish between two often confused concepts, this is a likely reason that item 10 decreased the overall reliability of the instrument. Therefore, item 10 was removed and I did not use it to calculate knowledge scores.

The reliability calculation also identified items 2 and 5 as problematic. In other words, if item 2 were deleted the reliability of the instrument would improve from a Cronbach's $\alpha = .637$ to Cronbach's $\alpha = .655$. Similarly, item 5, was problematic in comparison to the other items in the instrument. Considering item 3, for example, if it were deleted, the reliability would decrease from a Cronbach's $\alpha = .637$ to a Cronbach's $\alpha = .579$. Likewise, considering item 8, if it were deleted, the instrument's reliability would decrease from a Cronbach's $\alpha = .637$ to a Cronbach's $\alpha = .577$. However, if item 5 were deleted the reliability of the instrument would decrease from a Cronbach's $\alpha = .637$ to a Cronbach's $\alpha = .627$. Based on this value, it appears that item 5 does not behave like the other items in the instrument. Below are items 2 and 5 as they appear on the knowledge instrument:

2. When Earth scientists design solutions to complex real-world problems, tradeoff considerations are not necessary.
5. Human activities do not have a noticeable impact on water quality.

Both items 2 and 5 are negatively worded. I reason that these two items reduced the overall reliability of the instrument because they may have been difficult to interpret. Upon visual inspection of student responses, students who offered responses that did not align with scientific consensus for item 2 also offered responses that did not align with scientific consensus for item 5. Therefore, I hypothesize that the negatively worded items posed an added challenge for students attempting to make meaning from them. Although these items were problematic, they did not strongly influence the reliability as did item 10. Therefore, moving forward items 2 and 5 were retained for further analysis as part of the Earth science knowledge instrument resulting in an 8-item measure. In addition, given a reliability calculation in the acceptable range for the instrument, I retained knowledge as a variable for analysis in the study.

Reliability calculation for Water Quality Affect (WQA) instrument. The Water Quality Affect instrument is a 2-item measure (included in a combined survey instrument) designed to assess feeling about drinking water. The outcome of the reliability analysis for this instrument was a Cronbach's $\alpha = .537$, which falls within the unacceptable range (Tavakol & Dennick, 2011). This outcome reflects low confidence that the instrument in its current form measures the intended construct. I reason that this result is due to a lack of inter-relatedness of the items. In other words, although both items are related to water quality affect, they are distinct because they are associated with drinking water in two different locations—home and school. For example, item 14 below refers to feeling safe drinking tap water at home as opposed to item 15 which asks about drinking water from the water fountain at school.

14. I feel safe drinking the tap water at home.
 - A. Strongly agree
 - B. Agree
 - C. Neutral

- D. Disagree
- E. Strongly disagree

15. I feel comfortable drinking the water from the water fountain at school.

- A. Strongly agree
- B. Agree
- C. Neutral
- D. Disagree
- E. Strongly disagree

Here it is important to note that each item is worded specifically to address water that is neither bottled nor undergoes additional filtration processes prior to use directing the focus on the water source. However, it is logical that an individual may feel safe drinking tap water at home and feel comfortable drinking water from the drinking fountain at school, and likewise it is possible that an individual does not feel safe drinking the water at either location (see Figure 3). It is also possible for an individual to feel safe drinking water from the tap at home but uncomfortable with drinking water from the water fountain at school, and likewise feel unsafe drinking water from the tap at home but comfortable drinking water from the water fountain at school (see Figure 4).

Figure 3. Schematic of the various configurations of water quality affect for individuals who may have the same affective response to water drinking water sourced from both locations—home and school.

Figure 4. Schematic of the various configurations of water quality affect for individuals who may have different affective response about drinking water sources from home or school. The different possible combinations of affect are justification for treatment of WQA Home and WQA School as separate single item variables.

The items designed to measure Water Quality Affect, though related to feelings about drinking water, more specifically address feelings about two different sources of drinking water. Given the two different sources, it is possible to have a different affect associated with each source. Therefore, the distinction of source of drinking water warrants that the items each stand alone as individual constructs. Moving forward, these constructs are referred to as Water Quality Affect-Home (WQA Home) and Water Quality Affect-School (WQA School). Internal consistency cannot be assessed on a single item measure and therefore reliability was not calculated for these separate items.

The single item measure of environmental awareness has two parts—a dichotomous response of “Yes” or “No” and an open-ended response in follow up. The item is designed to assess whether an individual is aware of environmental issues within their community (see below).

Are there any environmental concerns affecting your community?

- A. Yes
- B. No

If yes, please describe. (Write your description on the lined side of the answer sheet provided.)

Internal consistency cannot be assessed on a single item measure and therefore reliability was not calculated for this item.

In summary, reliability was calculated for each instrument used in the study with the aim of determining whether the scores obtained from the instrument were true or contained a ratio of measurement error that renders the observed score unreliable. Based on reliability calculations Earth Science Interest (INT-ES) and Self-Efficacy (SE) were not examined as part of this study because of low confidence of the instruments' ability to assess the intended constructs. The instruments designed to measure General Science Interest (INT-GEN SCI), Transformative Experience (TE), and Earth science knowledge (KNOW) were confirmed as reliable and their associated variables were carried forward for further analyses in the study. In addition, Water Quality Affect-Home (WQA Home), Water Quality Affect-School (WQA School) and Environmental Awareness (ENV Awareness) were examined as single item variables. Each of these variables were analyzed at three time points—pre, post, and delayed post for a total of 18 (9 multiple-item and 9 single-item) variables.

Data Outliers

I identified outliers in the dataset by calculating *z*-scores for the raw data. This process calculates the mean for the data, sets the calculated mean to 0, and then sets the standard deviation to 1 (George & Mallery, 2011). Each individual score within the dataset is then assigned a standardized score, or *z*-score, which describes its position within the distribution of scores with respect to the mean. From these standardized scores, I assessed which fell within a standard deviation below the mean and which fell a standard deviation above the mean with *z*-scores ± 1.96 , or about two standard deviations

above or below the mean, indicative of outliers (George & Mallery, 2011). Following this standard, 11 students with z -scores of ± 2 on at least 2 of the 9 multiple-item measures described above would be removed from the dataset as outliers. For this analysis however, I chose a more conservative approach to data screening. I chose to identify outliers as those having z -scores equal to ± 3 as a way to include a broader range of student participants in the sample. Applying this conservative approach, I removed 4 student participants from the dataset who had z -scores with an absolute value of 3 on at least 2 of the 9 multiple-item measures described previously. An additional 7 students were removed from the dataset who had missing 2 or more of the 18 measures. The analysis presented in this chapter is based on the dataset created by the more inclusive approach of removing outliers with z -scores with absolute value of 3.

Normality Assumptions Testing: Examination of Skewness and Kurtosis

I examined the normality of the data for each of the multiple-item measures at each time point. General science interest scores were both skewed and kurtotic violating the assumption of a normal distribution. More specifically, general science interest was negatively skewed with skewness values at pre and delayed post greater than -1. Kurtosis values for general science interest were 1.7 at pre and post and 3.3 at delayed post. The scores for both transformative experience and knowledge were all normally distributed for each time point with no values exceeding an absolute value of 1.

Bivariate Correlations

In Table 11 below I have presented Pearson bivariate correlations between all study variables at each time point—pre-instruction, post-instruction, and delayed post-instruction. These correlations are a measure of association between the measures (Tabachnick & Fidell, 2013). In this study there were both significant and non-significant

[illegible]

Table 11 (continued)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
14. WQA	-.047	.038	.117	-.062	.082	.036	-.051	-.034	-.017	.184*	.296**	.200**	.370**	-				
School																		
(post)																		
15. WQA	.027	.020	-.094	.052	-.100	-.067	-.011	.003	-.054	.200*	.251**	.343**	.441**	.442**	-			
School																		
(delayed																		
post)																		
16. ENV	.262**	.308**	.126	.245**	.200**	.220**	.357**	.311**	.305**	-.051	-.109	-.049	-.051	-.086	-.001	-		
Awareness																		
(pre)																		
17. ENV	.175**	.195**	.190**	.232**	.261**	.274**	.272**	.425**	.394**	.004	-.032	.025	-.055	.035	-.065	.525**	-	
Awareness																		
(post)																		
18. ENV	.155	.151	.151	.193*	.177*	.243**	.275**	.374**	.463**	.036	.048	.014	-.109	.019	-.130	.503**	.608**	-
Awareness																		
(delayed																		
post)																		
<i>M</i>	33.84	34.16	34.41	7.11	7.12	7.21	28.43	28.51	29.00	3.78	3.89	3.76	3.38	3.29	3.31	.55	.52	.53
<i>SD</i>	3.737	3.388	3.923	1.716	1.680	1.553	4.717	4.461	4.496	1.011	.955	1.044	1.122	1.048	1.116	.499	.501	.501
<i>N</i>	177	166	153	180	174	156	169	170	153	173	176	153	173	176	154	167	172	152

Note. Table 11 displays bivariate correlations between all measures assessed at three different time points—prior to instruction (pre), post instruction (post), and at after the post instruction (delayed post). In this table the study variables are identified as: KNOW (pre) = pre intervention knowledge; KNOW (post) = post intervention knowledge; KNOW (delayed post) = delayed post intervention knowledge; INT GEN SCIENCE (pre) = general science interest pre intervention; INT GEN SCIENCE (post) = general science interest post intervention; INT GEN SCIENCE (delayed post) = general science interest delayed post intervention; TE (pre) = transformative experience pre intervention; TE (post) = transformative experience post intervention; TE (delayed post) = transformative experience delayed post intervention; WQA Home (pre) = water quality affect about home sourced drinking water pre intervention; WQA Home (post) = water quality affect about home sourced drinking water post intervention; WQA Home (delayed post) = water quality affect about home sourced drinking water delayed post intervention; WQA School (pre) = water quality affect about drinking at school pre intervention; WQA School (post) = water quality affect about drinking at school pre intervention; WQA School (delayed post) = water quality affect about drinking at school delayed post intervention; ENV Awareness (pre) = environmental awareness pre intervention; ENV Awareness (post) = environmental awareness post intervention; ENV Awareness (delayed post) = environmental awareness delayed post intervention

* $p < .05$, ** $p < .01$

The correlation results for environmental awareness are mixed. Pre-instruction environmental awareness shows positive small to medium correlation with knowledge (except at delayed post knowledge), general science interest, and transformative experience with p -values less than .01. Post environmental awareness shows positive small to medium correlations ($r = .2$ to $.3$) with knowledge, general science interest and transformative experience with p -values less than .01. Delayed post environmental awareness is not correlated with knowledge. There are small positive correlations ($r = .2$) between delayed post environmental awareness and general science interest at the pre and post time points with p -values less than .05. Delayed post environmental awareness shows positive medium correlations ($r = .2$ to $.4$) with transformative experience with p -values less than .01. Overall, the measures show positive and significant correlation. Also, despite a high correlation between delayed post-instruction and transformative experience ($r = .8$), there is no evidence of multicollinearity amongst the measures suggesting the variables each measure distinct constructs.

Analysis of Research Question 1: Pre to Post Differences in Learning Outcomes

The goal of my first research question was to determine if there are pre to post differences in interest and self-efficacy to learn Earth science, perceived value and relevance of Earth science, knowledge and application of Earth science concepts for students who experience instruction that facilitates transformative learning (referred to as the intervention condition or group). Based on reliability calculations, both the self-efficacy and Earth science interest instruments were not found to be reliable, therefore self-efficacy and Earth science interest were excluded from the analysis for RQ1 and RQ2. Rather, the focus of this question was to examine differences over time in general science interest, transformative experience with respect to perceived value and relevance

of Earth science and application of Earth science concepts, and knowledge in addition to the single-item variables of water quality affect-home, water quality affect-school, and environmental awareness. Also, given school site 01 did not complete any of the measures at the delayed post time point, the analysis consisted of four school sites for the examination of pre to post differences, and only three of the four school sites for the examination of differences at pre, post and delayed post.

To address RQ1, I conducted a repeated measures analysis of variance (ANOVA) first to detect differences in each variable pre to post and second to detect differences in each variable at all three time points—pre, post, and delayed post. The next step in this analysis examined differences across time by the following contexts entered as between subject factors: school (e.g., school site 01, school site 02, school site 03, or school site 04), intervention (those receiving instruction intended to be transformative or the comparison group), grade (e.g., 9th, 10-11th, 11-12th), and subject (e.g., Physical Science, Earth and Space Science, AP Environmental Science, Biology, etc.). Results show no statistically significant differences in general science interest (INT-GEN SCI), however there were statistically significant and meaningful differences in transformative experience (TE) and knowledge (KNOW).

Follow-up simple effects analysis for non-significant results

As my primary analysis, I conducted a repeated measures analysis of variance (ANOVA) with time as the within subjects factor and school, intervention, grade and subject each as between subjects factors to examine changes in the study's variables. For non-significant results with a relatively low *p*-value, I conducted a follow-up simple effects analysis to reveal any additional information about the variables (Clark-Carter,

2010). This second layer of analysis allowed me to further investigate the nature of the interaction and to potentially reveal any statistical significance (Clark-Carter, 2010).

Analysis for Transformative Learning Experience (TE)

Analysis for TE pre to post. To examine changes in TE, I conducted a repeated measures analysis of variance (ANOVA) using time (pre to post-instruction) as the within-subjects variable. The test did not detect significant interactions between time and school $F(3, 154) = 1.85$ $p = .140$ or time and intervention $F(1, 154) = .087$ $p = .769$. However, the relatively low p -value of .140 for the interaction between time and school prompted me to conduct a follow up analysis to reveal any additional information about the variable. This follow up analysis did show some statistically significant changes in the measure. For example, although there was not an overall statistically significant change in TE by school, simple effects analysis showed a positive and marginally statistically significant shift for school site 01, $F(1, 154) = 3.83$, $p = .052$, $\eta^2 = .024$ (small effect size).

Results of repeated measures ANOVA also showed statistically significant and meaningful interactions between time and grade, $F(2, 155) = 7.13$ $p = .001$ $\eta^2 = 0.84$ (large effect size; Tabachnick & Fidell, 2013) and time and subject $F(5, 152) = 3.04$, $p = .012$, $\eta^2 = .091$ (medium effect size). The follow up simple effects analysis on the repeated measures ANOVA results revealed a statistically significant increase from pre to post-instruction in TE for 9th grade, with $F(1, 155) = 4.21$, $p = .042$, $\eta^2 = .026$ (small effect size), and 10th-11th grade, $p = .019$, $\eta^2 = .035$ (small effect size), but a statistically significant decrease for 11th-12th grade, $p = .034$, $\eta^2 = .029$ (small effect size) (see Figure 5). This result may be due in part to length of academic experience. A potential explanation is that students in the lower grades have less exposure to both the science

content in academic settings and less practice with applying the content to their lived experience thereby making this approach novel. Given the novelty of the approach, there was higher potential for the intervention to have a transformative effect on these students.

Figure 5. Pre to post mean TE scores by Grade with bars showing standard error.

Each grade level showed pre to post-instruction increases except for Grade 11-12th.

Likewise, there were statistically significant increases in TE for students enrolled in Physical Sciences, $F(1, 152) = 4.11, p = .047, \eta^2 = .026$ (small effect size) and Earth and Space Science $F(1, 152) = 5.51, p = .020, \eta^2 = .035$ (small effect size) (see Figure 6).

Figure 6. Pre to post mean TE scores by Subject with bars showing standard error. There were increases in pre to post-instruction TE for both course subjects Physical Science and Earth and Space Science.

Of the six distinct courses involved in the investigation, some were more aligned with respect to subject matter to the science content of the intervention than others. I ranked the courses in terms of alignment content alignment with 1 being the least aligned and 6 the most aligned: Physical Science (rank = 1); Biology (rank = 2); Earth and Space Science (rank = 3); Earth and Environmental Science (rank = 4); Environmental Science (rank = 5); and AP Environmental Science (rank = 6). Results show that positive shifts in

TE were exhibited by students in the Physical Science and Earth and Space Science classes ranked 1 and 3 respectively. If the same logic applies, the lack of overlap between subject matter content in the course and in the intervention provided a greater potential for transformation due to novelty.

Analysis for TE at all three time points—pre, post, and delayed post. Gains were also found at the delayed post time point. Results show a statistically significant and meaningful increase in TE over time by grade, $F(4, 260) = 3.75, p = .006, \eta^2 = .056$ (small effect size). and subject, $F(8, 256) = 2.31, p = .021, \eta^2 = .068$ (small to medium effect size). However, follow up simple effects analysis show that the increase in TE at the delayed post time point only applied to 10th-11th graders, $F(2, 129) = 5.60, p = .005, \eta^2 = .08$ and to those enrolled in Earth and Space Science $F(2, 127) = 5.53, p = .005, \eta^2 = .08$ (medium effect size) (see Figures 7 and 8). The similarity in outcomes for TE by grade and subject reflect the overlap in population—all of the students enrolled in Earth and Space Science were 10th-11th graders.

Figure 7. Figure shows statistically significant differences over time in mean TE for the subject of Earth and Space Science. Mean TE scores are presented for Earth and Space Science course subject at pre, post, and delayed post time points, with bars showing standard error. There were increases in mean TE scores over time for students enrolled in Earth and Space Science.

Figure 8. Mean TE scores for 10th-11th grade at pre, post, and delayed post time points, with bars showing standard error. There were increases in mean TE scores over time for 10th-11th grade students.

Analysis for Knowledge (KNOW)

Analysis for knowledge pre to post. To examine changes in knowledge, I conducted a repeated measures analysis of variance (ANOVA) using time (pre to post-instruction) as the within-subjects variable and group (intervention vs comparison) as the between subjects factor. This test did not detect a statistically significant interaction between time and knowledge by group $F(1, 159) = 6.15, p = .014$. However, given the relatively low p -value I conducted a follow up analysis to further investigate the nature of the interaction (Clark-Carter, 2010). The follow up analysis detected a statistically

significant interaction for the intervention group $F(1, 159) = 7.34, p = .007, \eta^2 = .044$ (small effect size), but no statistically significant differences in knowledge for the comparison group $F(1, 159) = 1.30, p = .255$. The mean scores and standard errors are represented in Figure 9 below.

Figure 9. Figure shows pre to post mean knowledge scores by group (intervention vs comparison) with bars showing standard error. Students in the intervention group exhibited greater knowledge gains pre to post compared to students in the comparison group.

Similarly, repeated measures analysis of variance did not reveal statistically significant differences in pre to post-instruction knowledge by school $F(3, 157) = 1.66, p = .178$. Follow up simple effects analysis however detected statistically significant differences in pre to post-instruction knowledge amongst a few schools in the study. More specifically, there are differences in pre-instruction knowledge between school site 01, $M = 31.7$, and school site 02, $M = 36.5, p = .030$ and in post-instruction knowledge between school site 01, $M = 32.2$, and school site 04, $M = 34.3, p = .039$. These knowledge scores and their standard errors are represented in Figures 10 and 11.

Figure 10. Figure shows statistically significant differences in mean pre-intervention knowledge scores by school site with bars showing standard error. School site 02 had higher mean scores in pre-instruction knowledge compared to school site 01.

Figure 11. Figure shows statistically significant differences in mean post-intervention knowledge scores by school site with bars showing standard error. School site 04 had higher scores for post-intervention knowledge than school site 01.

Analysis for knowledge at all three time points—pre, post, and delayed post.

Results show statistically significant positive shifts in knowledge over time by subject, $F(8, 258), p = .049, \eta^2 = .058$ (small effect size). Follow up simple effects analysis show

that these results were for the course subject Biology, $F(2, 128) = 3.56, p = .031, \eta^2 = .053$ (small effect size).

Figure 12. Figure shows statistically significant differences in mean knowledge scores over time for course subject Biology with bars showing standard error. Students enrolled in Biology had a statistically significant increase between pre and delayed post.

Analysis for Environmental Awareness (ENV Awareness)

Analysis for environmental awareness pre to post. To examine changes in environmental awareness, I conducted a repeated measures analysis of variance

(ANOVA) using time (pre to post-instruction) as the within-subjects variable and group as the between subjects variable. This test detected statistically significant and meaningful differences in the measure over time between the intervention and comparison groups, $F(1,158), p < .001, \eta^2 = .096$ (medium effect size). From pre to post, the intervention group expressed less awareness of environmental issues affecting their community whereas the comparison group expressed more environmental awareness. These results are also seen at the delayed post time point, $F(2,131), p < .001, \eta^2 = .111$ (medium effect size).

Figure 13. Figure shows pre to post intervention mean scores for environmental awareness by group (intervention vs. comparison) with bars showing standard error. Students in the comparison group increased in mean environmental awareness pre to post instruction compared to the intervention group.

Analysis for environmental awareness at all three time points—pre, post, and delayed post. Results show that the Comparison group gained and maintained a greater awareness of environmental issues affecting the community at the delayed post time point than the Intervention group, $F(2, 131) = 8.21, p < .001, \eta^2 = .111$ (medium effect size). The Intervention group had a statistically significant decrease in ENV Awareness pre to post, $p = .017$, with a slight and statistically insignificant decrease in ENV Awareness from post to delayed post, $p = 1.0$ (see Figure 14). These results may be due to students in the Intervention group becoming more aware of how little they know about exposure to environmental toxins in their communities. Students in the comparison group may express greater awareness by the opportunity to engage with the environment through the learning experience. For example, students in the Comparison group participated in sample collection and water quality testing which may have triggered greater awareness of their immediate environment.

Figure 14. Figure shows mean scores for environmental awareness by group (intervention vs comparison) at all three time points with bars showing standard error. Students in the comparison group expressed greater environmental awareness compared to the intervention group over time—pre, post, and delayed post.

There were no statistically significant changes over time for INT-GEN SCI, WQA Home or WQA School for any of the contexts (between-subjects factors).

Parallel Analysis of Standard Versus More Conservatively Constructed Datasets

It is standard practice to identify outliers in the dataset as those having a z -score with an absolute value of 2 (George & Mallery, 2011). For this study, I chose a more inclusive approach of identifying outliers as those with z scores with an absolute value of 3 in order to include a broader range of participants. I present in this section a parallel analysis of both datasets, the dataset created from the removal of outliers with z -scores of ± 3 and that created from the removal of outliers with z -scores of ± 2 for the sake of

comparison. The goal of this parallel analysis is to determine if the results remain consistent with the more conservative versus the standard approach. I conducted a repeated measures analysis of variance (ANOVA) on both datasets for each study variable pre to post and again at all three time points—pre, post, and delayed post. The results are presented in the Tables 12 and 13 below.

Table 12

Parallel Analysis of Statistically Significant Variables Pre to Post

Variable pre to post (with between subjects factor)	Dataset with outliers removed, $z \geq 2 $	Dataset with outliers removed, $z \geq 3 $
KNOW by Intervention	$p = .009$, $\eta^2 = .044$ (small effect size)	$p = .014$, $\eta^2 = .037$ (small effect size)
ENV Awareness by Intervention	$p < .001$, $\eta^2 = .093$ (medium effect size)	$p < .001$, $\eta^2 = .096$ (medium effect size)
TE by Grade	$p = .01$, $\eta^2 = .072$ (small to medium effect size)	$p = .003$, $\eta^2 = .074$ (small to medium effect size)
TE by Subject	$p = .009$, $\eta^2 = .098$ (medium effect size)	$p = .012$, $\eta^2 = .091$ (medium effect size)

Table 13

Parallel Analysis of Statistically Significant Variables at all three time points—pre, post, and delayed post

Variable at pre, post and delayed post (with between subjects factor)	Dataset with outliers removed, $z \geq 2 $	Dataset with outliers removed, $z \geq 3 $
KNOW by Subject	[no statistically significant differences]	$p = .049$, $\eta^2 = .058$ (small effect size)
ENV Awareness by Intervention	$p = .001$, $\eta^2 = .099$ (medium effect size)	$p = .002$, $\eta^2 = .093$ (medium effect size)
TE by Grade	$p = .011$, $\eta^2 = .05$ (small effect size)	$p < .001$, $\eta^2 = .111$ (medium effect size)
TE by Subject	$p = .018$, $\eta^2 = .071$ (small to medium effect size)	$p = .021$, $\eta^2 = .067$ (small to medium effect size)

For the most part, the results of the repeated measures ANOVA for each dataset are similar. The parallel comparison reveals that each study variable with statistically significant differences over time from the conservative approach, also had statistically significant differences over time with the standard approach, however there is one notable exception. For the dataset created from the removal of outliers identified as those with z -scores of ± 3 , KNOW by Subject had statistically significant differences at all three time points whereas there were no statistically significant differences in this variable for the dataset created by the standard approach. This finding confirms two things, the validity of the more conservative approach to identifying outliers, and that the results that were found with the standard approach were maintained for a more broadly defined population.

*Analysis of Research Question 2: Environmental Awareness as a Predictor of
Learning Outcomes*

The aim of my second research question was to understand if the measured learning outcomes—KNOW, INT-GEN SCI, TE—were influenced by ENV Awareness (awareness of environmental issues affecting the local community). In other words, does ENV Awareness predict the measured shifts in the study variables? To address this question, I implemented a sequential linear regression. Regression analysis allows you to model the relationship between a predictor and outcome. The results include output statistics that describe the explanatory power of the modeled relationship. The model may be based on the relationship of a single predictor to an outcome, or several predictors to an outcome as with multiple regression (Field, 2013). For this analysis, I used a sequential linear regression.

Sequential linear regression, unlike multiple regression or stepwise regression, allowed me to prioritize the potential relevance of identified predictors to transformative experience (TE) as a learning outcome. Based on a theoretical understanding of the predictors, I chose the order in which each one was entered into the analysis to build the model. For this study, I identified the following as predictors of transformative experience: School, Subject, Grade, Intervention, KNOW (PRE), INT-GEN SCI (PRE), TE (PRE), and ENV Awareness (POST). Results show that School alone was a statistically significant predictor of post TE, $p = .009$, explaining 4.5% of the variance. School, in combination with Subject, Grade, Intervention, KNOW (PRE), INT-GEN SCI (PRE), and TE (PRE) were stronger predictors of post TE, $p < .001$, explaining 61.9% of the variance. Finally, when ENV Awareness (POST) was added to the model, the

explanatory power increased to 64.8% of the variance which represents a statistically significant change, $p < .001$.

Based on the results of the sequential linear regression, ENV Awareness is a predictor of transformative experience as a learning outcome. In other words, transformative experience is influenced by a student's awareness of environmental issues affecting the local community. This result aligns theoretically with interest and can be situated within the four phases of interest development.

As a construct, interest has both socio-cognitive and motivational components (Renninger & Hidi, 2016). If a student's interest is triggered by the topic of environmental issues (socio-cognitive) they are more inclined to re-engage with that content and invest time and effort (motivational) in developing content knowledge associated with that topic (Renninger & Hidi, 2016). This transition from a point of initial interest to pursuit of learning more about the topic is a move from triggered situational interest to maintained situational interest and is a precursor to learning motivated by perceived relevance and value of the content. Therefore, it is reasonable that ENV Awareness (environmental awareness) predicts TE.

Analysis of Research Question 3: Evidence of Transformative Experience in Student Writing

For my third research question, I aimed to identify any existing evidence of TE (transformative experience) in student writing. Specifically, the question asks: *What do students' written responses during transformative instruction reveal about their perceptions of value, relevance, and application of Earth science content?* For this analysis I selected student writing in response to a total of five ICAN prompts completed

at the end Activities 1, 2 and 3. A content analysis was conducted on written responses to the following prompts:

1. I CAN describe the components of a scientific investigation. (Activity 1)
2. I CAN describe at least three investigative practices that scientists use.
(Activity 2)
3. I CAN describe how the scientific practice of investigation can be useful to answer questions affecting my everyday life. (Activity 2)
4. I CAN explain how the atmosphere, geosphere, and hydrosphere are interconnected in the water cycle. (Activity 3)
5. I CAN describe how Earth science can be useful to answer questions affecting my everyday life. (Activity 3)

The responses were studied specifically to identify elements of TE that fell into three categories—perception of value, perception of relevance, and application of Earth science content.

In order to obtain a range of student abilities, students were selected based on scores on the KNOW (PRE) measure. Students with scores in the bottom third, middle third, and top third who completed all four tasks in the intervention were selected for examination. A total of 10 students were chosen based on these criteria. Their written responses were read repeatedly to identify evidence of the three components of TE. The responses were then categorized according to content. For example, the following written response shows perception of value:

Prompt: *I CAN describe how Earth science can be useful to answer questions affecting my everyday life.*

Written response: “I can question the rapidly changing earth and what I can do to help protect it and make a change.” Student 40108

The student here highlights the scientific practice of critique or critical thinking with the phrase “I can question.” The student further expresses a willingness to go beyond applying knowledge, towards behavioral change, acting on learned science content. This willingness is evidenced by the words “what I can do...” and “make a change...”. It appears the student internalizes knowledge and sees a purpose to it, a value, in that it informs individual/personal action. This response is therefore categorized as an example of perception of value. Additional examples of written responses for this category are included in Table 14.

Table 14

Student Written Responses as Examples of the TE Component: Perception of Value

Prompt	Student Response
I CAN describe how the scientific practice of investigation can be useful to answer questions affecting my everyday life. (Activity 2)	“more aware of harmful elements/chemicals answer/solve questions education” Student 40610
I CAN describe how Earth science can be useful to answer questions affecting my everyday life. (Activity 3)	“Earth science can be useful to answer questions affecting my everyday life in that it is very important where a person lives and the earth they live on can impact you in that I can affect your health which is very important. This can also help me to explain everyday things that happen such as waste and issues with land use, etc.” Student 40517

In response to the prompt, *I CAN describe how the scientific practice of investigation can be useful to answer questions in my everyday life*, Student 40426 wrote (presented below verbatim):

“When we are observing, we can see the effects and how this cause changes to environmental science. When we know the results, we know how our actions can affect the Earth.”

Here, the student does not communicate any specific science content, but does highlight a direct connection between the scientific practice of observation and applying the understanding gained from observation to making informed decisions about Earth. I categorized this response as an example of perception of relevance as the student showed the relevance of a scientific practice to everyday life. Additional examples are included in Table 15 below.

Table 15

Student Written Responses as Examples of the TE Component: Perception of Relevance

Prompt	Student Response
I CAN describe how Earth science can be useful to answer questions affecting my everyday life. (Activity 3)	“Every action we do is affecting the environment with various effects after another. Environmental science is caused by human actions.” Student 40426
	“Earth science is useful and affects my everyday life because it contains various branches of science such as geology, oceanography, and astronomy. Our lives are shaped by Earth science and the disasters on Earth are not in our control. Our landscapes has been shaped by natural processes such as tectonics, weathering, and biological activity over billions of year. We use natural materials <u>everyday</u> from building stores and oil for energy.” Student 40522

Table 15 (Continued)

Prompt	Student Response
	“Water quality effects my health. Investigating that water is safe is necessary for the economy.” Student 20105

In response to the prompt, *I CAN describe how Earth science can be useful to answer questions affecting my everyday life*, Student 10302 wrote (presented below verbatim):

“Earth science can affect my everyday life because for drinking water. I need rain in the [ABC] Mountains leading to the [XYZ] resivor.”

I categorized this response as an example of application of Earth science content. In this response, the student demonstrates understanding of their local watershed. They also share knowledge of not only the source of drinking water for the community, but the connection of that source which is the snowpack in the [ABCs], to the reservoir connected to the mountain range—the [XYZ reservoir]. Finally, the student communicates this understanding in a personalized way, using the words “I need rain...”. This response is therefore an example of applying specific Earth science content to everyday life (see Table 16 for additional examples).

Table 16

Student Written Responses as Examples of the TE Component: Application of Earth Science Content

Prompt	Student Response
I CAN describe how the scientific practice of investigation can be useful to answer questions affecting my everyday life. (Activity 2)	<p>“The scientific process can help you solve problems.” Student 10302</p> <p>“Scientific practice of investigation is able to keep citizens safe by questioning water quality in our cities.” Student 40108</p> <p>“Science explains how things work.” Student 30112</p> <p>“The knowledge in Earth Science explains why things happen, and we can use it to influence our decisions.” Student 30112</p>

Content analysis of student generated written responses during the intervention revealed that all three components of transformative experience. More specifically, students expressed perceived value of content by framing it as actionable, perceived relevance of content through explicit connections between concepts and health of environmental concerns, and application of Earth science concepts to decision-making. The results of this qualitative analysis of student writing show that the intervention was a transformative learning experience.

SUMMARY OF RESULTS

The goal of my investigation was to examine the efficacy of a pedagogical approach centered on interest and transformative learning. I have designed three research

questions to address this overarching goal. Using a combination of quantitative and qualitative analytical approaches I discovered the following:

- positive shifts pre to post in transformative experience by grade, course subject, and school site;
- statistically significant increases in knowledge pre to post for the intervention group;
- statistically significant increases in knowledge pre to post for students enrolled in Biology;
- statistically significant positive shifts in environmental awareness pre to post for the comparison group;
- positive shifts in environmental awareness for the comparison group were maintained at the delayed post time point;
- a parallel analysis confirmed the statistically significant results evident in a standard approach to dataset construction and a more conservative approach;
- environmental awareness is a predictor of the stated learning outcomes—knowledge, general science interest, and transformative experience; and
- student writing in response to I CAN prompts show evidence of the three aspects of transformative experience—perceived value, perceived relevance, and application of Earth science content.

These outcomes provide evidence that a pedagogical approach informed by the socio-cognitive constructs of interest development, transformative experience, and knowledge retention supports positive learning outcomes. However, as a final test of my model, I ran an SEM with path analysis. This quantitative analytical technique is

designed to confirm the statistical significance of structured relationships between independent and dependent variables that contribute to an overall theoretical model. The relationships or statistically significant “paths” contribute the explanatory power of the overall model. For this study, I examined both the nested contexts of students—School, Grade, and Subject—otherwise indicated as independent variables. I also examined the study variables—KNOW, INT-GEN SCI (indicated in the model simply as INT), and TE—as dependent variables. The model is presented in Figure 15 below.

Figure 15. Structural equation model and path coefficients for study variables.

Statistically significant paths are represented by a solid line; statistically insignificant paths are represented by a dotted line. Independent variables include: School, Grade, and Subject. Dependent variables include: knowledge, interest, and transformative experience. In this diagram, the study variables are labeled: KNOW (PRE) = pre-instruction knowledge; KNOW (POST) = post-instruction knowledge; KNOW (DELAYED POST) = delayed post-instruction knowledge; INT (PRE) = general science interest pre-instruction; INT (POST) = general science interest post-instruction; INT (DELAYED POST) = general science interest delayed post-instruction; TE (PRE) = transformative experience pre-instruction; TE (POST) = transformative experience post instruction; TE (DELAYED POST) = transformative experience delayed post-instruction.

* $p < .01$

I based the construction of this model on the theoretical frameworks of interest (Renninger & Hidi, 2016), transformative experience (Pugh, 2002), and knowledge. Output statistics confirm that the model is viable and the results trustworthy. The Average Variance Inflation Factor (AFVIF) is 2.108, which falls within the ideal range. A Tenenhaus (GoF) index of 0.586 indicates a large goodness of fit. And lastly the model explains 34.4% of the variance. These statistics confirm that the model accurately reflects the data and has reliable results.

Further, the results of the SEM confirm those previously found by other analytical techniques. For example, like Pearson bivariate correlations, the SEM confirms statistically significant relationships amongst each of the study variables—KNOW, INT-GEN SCI, and TE. More specifically, KNOW (PRE) is a statistically significant contributor to INT (PRE), $\beta = 0.32$, and TE (PRE), $\beta = 0.43$ at a level of $p < .01$. Likewise, KNOW (POST) contributes to both TE (POST), $\beta = .10$, $p = .08$, and INT (POST) $\beta = .10$, $p = .09$; and TE (POST) contributes to KNOW (DELAYED POST) $\beta = .13$, $p < .01$, and INT (DELAYED POST), $\beta = .14$, $p = .03$. Similar to the results of repeated measures ANOVA, the SEM confirms that School Site is not a significant contributor to student learning outcomes, but Grade, $\beta = 0.29$, and Subject, $\beta = 0.35$, are statistically significant factors at a level of $p < .01$.

From this analysis, I also found that the Intervention was not a significant contributor to INT-GEN SCI (POST) or TE (POST). The Intervention however was a statistically significant contributor to KNOW (POST), $\beta = -0.15$; $p = .02$. (Note, this negative correlation is due to coding. The Intervention was coded as 1 while the Comparison Group was coded as 2. Therefore, the negative sign here indicates that the variable with the lower code is statistically significant in this relationship).

Finally, based on the combination of both quantitative and qualitative analysis, the data show that a geoscience pedagogy informed by interest development and transformative experience leads to student learning.

CHAPTER 5

DISCUSSION

In this chapter, I review and summarize the results of my analysis as they relate to the supporting the stated learning outcomes—interest, self-efficacy, transformative experience, and knowledge. I also discuss the limitations of the study, potential lines of inquiry stemming from testing this pedagogical model, and implications for both classroom instruction and future research.

Summary of Findings

The goal of my dissertation research was to test the efficacy of a pedagogical model informed by the socio-cognitive constructs of interest, self-efficacy, and transformative experience. This assessment would be based in part by pre to post and delayed post shifts in each of these measures in addition to shifts over time in knowledge scores. During the course of data screening, the self-efficacy instrument was not found to be reliable, so I focused the analysis on general science interest, transformative learning experience, and knowledge as learning outcomes.

For research question 1, I sought to understand if there were differences over time in each of the multi-item variables—general science interest, transformative learning experience, and knowledge. I anticipated pre to post gains in each learning outcome with any gains sustained at the delayed post time point. I also anticipated that the gains would be greater for those students in the intervention group. Quantitative analysis yielded mixed results. Repeated measures ANOVA did not detect statistically significant differences in general science interest. Results of repeated measures ANOVA revealed statistically significant and meaningful gains in TE over time by grade, $F(2, 155) = 7.13$ $p = .001$, $\eta^2 = 0.84$ (large effect size; Tabachnick & Fidell, 2013) particularly 9th, $F(1, 155)$

= 4.21, $p = .042$, $\eta^2 = .026$ (small effect size), and 10th – 11th, $p = .019$, $\eta^2 = .035$ (small effect size), though not 11th- 12th. There were also statistically significant and meaningful gains over time by course subject, $F(5, 152) = 3.04$, $p = .012$, $\eta^2 = .091$ (medium effect size), particularly Physical Sciences, $F(1, 152) = 4.11$, $p = .047$, $\eta^2 = .026$ (small effect size), and Earth and Space Science, $F(1, 152) = 5.51$, $p = .020$, $\eta^2 = .035$ (small effect size). These gains pre to post in TE were maintained at the delayed post time point. And although there were no statistically significant differences in TE overall, follow up simple effects analysis did detect a positive and marginally statistically significant shift in TE for school site 01.

Results did not support my hypothesis that there would be positive shifts over time with the greater gains experienced by the intervention group. The data shows that there were gains for both groups with no statistically significant difference between groups. This was an interesting finding that merits detailed examination but as an initial step in exploring this issue I present a few potential reasons for this finding. Possible explanations could be that both activities were novel enough to affect interest that contributes to transformative learning in both groups; including the water quality measurement of water samples collected by the students, an activity that both groups had in common, may have been adequate dosage to detect TE; or the comparison activity focused on geoscience careers actually supported transformative learning for students. For this study, I only conducted qualitative content analysis of the reflective prompts from the intervention group which aligned with research question 3. However, expanding this analysis to both groups may provide information that can be used to understand whether the testing water samples emerges as a common theme in student reflections. An expanded investigation may also provide information about whether the comparison

activity also contained elements that are supportive of transformative learning. Presently, without pursuing this line of inquiry, there is anecdotal and theoretical support that the intervention and comparison activities were both novel and transformative.

Based on teacher feedback from all four school sites, both the intervention and comparison activities were novel for different reasons. For example, the intervention was novel in addressing a current environmental issue with an environmental justice component. In Activity 3 of the intervention, students were asked if exposure to environmental toxins depended on geographic location. They then examined demographic data provided from the Census Bureau including population, median household income, average educational attainment. They added information that they obtained from the EPA website on location of Toxin Releasing Inventory facilities, Superfund (CERCLA) sites, and average annual amount of total wastes released (lbs.) to the air, water and land for their location. They compared these data to four other locations to see if there may be a pattern that emerges of socio-economic indicators and exposure to environmental pollutants. Looking at data in the context learning science content and scientific practices was a novel component to the curricula for these classes. The comparison activity was novel in that it made explicit connections between the science content and professions in the geosciences. In Activity 1 and 3 of the comparison activity students learned how scientists use both content knowledge and scientific practices to solve real-world problems such as energy, climate change, and balancing both development and resource conservation in urban planning. In this aspect, both learning experiences may have contributed to shifts in student perception of the value and relevance of Earth science content—two of the three components of transformative learning. This finding merits exploration and, depending on the outcome of that

investigation, a shift in my characterization of the comparison activities (see Implications for Future Research).

In the meantime, however, I tentatively conclude that for students who experienced instruction that facilitates transformative learning, there were statistically significant shifts in TE—perceived value, perceived relevance, and motivated use (application) of Earth science content—over time. And that these gains were experienced for both the intervention and comparison groups. This conclusion would align theoretically with the four-phase model of interest (Hidi & Renninger, 2006). Situational interest was triggered in both the intervention and the comparison group. For the intervention, students worked in collaborative learning groups acting as teams of investigative Earth scientists who were engaged in a study of a recent water quality crisis. The intervention's scaffolded re-engagement maintained this interest via science content and associated scientific practices (i.e., collecting, analyzing, and comparing water quality data). For the comparison, students' interest was likely triggered by learning about careers related to the Earth science content. The comparison's scaffolded exploration of these careers, including required educational background and associated salary ranges, potentially maintained this interest. For both activities, interest potentially contributed to transformative experience by supporting shifts in perceived value and relevance of Earth science and application of science content.

Like TE, there were also mixed results for knowledge as a learning outcome. Statistically significant pre to post gains in knowledge were detected for the intervention group though not for the comparison group. Analysis revealed gains in knowledge at all three time points overall by course subject, and particularly for students enrolled in Biology. An interesting finding of SEM and path analysis is that pre-instruction

knowledge, though a statistically significant contributor to post-instruction knowledge, was not the sole contributor to post-instruction knowledge. This analysis showed that the intervention itself produced statistically significant pre to post gains in knowledge. That the intervention alone, regardless of student background knowledge, contributed to post-instruction knowledge gains is an important finding with implications for science instruction. This finding suggests that the intervention leads to student learning of Earth science content and scientific practices; however, the mechanism for this increase may merit further exploration.

Interest and TE would theoretically contribute to post-instruction knowledge. In this study, findings revealed that there were no statistically significant differences over time in interest. Additionally, both the intervention and comparison activities were found to be transformative. This may suggest that the mechanism for knowledge acquisition is more complex than my model currently describes. Alternatively, the content of the intervention may have been more aligned with the content in the knowledge instrument thereby producing observed increases in knowledge scores for students in the intervention group than those in the comparison group.

In summary, with respect to research question 1, a combination of quantitative analyses provide evidence that the model was effective in supporting stated learning outcomes in students. With respect to transformative experience and knowledge, these outcomes were maintained at the delayed post time point. This durability may suggest that students in the intervention group continued to engage with the science content outside of the immediate learning context. The analyses also present a confounding result for further investigation, that the comparison activity also led to positive shifts in TE over time.

For research question 2, I sought to understand if environmental awareness was predictive of learning outcomes. In other words, does awareness of environmental concerns facing the local community affect student knowledge acquisition, general science interest, and transformative experience? Results of a sequential linear regression showed that environmental awareness was indeed predictive of positive shifts in knowledge, general science interest, and transformative experience for the comparison group. These results confirm my hypothesis that students who express greater awareness of environmental issues facing the local community would experience positive shifts in each of the learning outcomes. This aligns with the concept that instruction that triggers a pre-existing interest motivates learning (Renninger & Hidi, 2016). However, this finding is interesting in that the gains were found in the comparison group and not for the intervention group.

For research question 3, I conducted a qualitative content analysis of student written responses during transformative learning. Students in the intervention group responded to I CAN prompts. These responses were studied iteratively for evidence of transformative learning. This examination yielded evidence of all three components of transformative experience—perceived relevance, perceived value, and application—in student writing. This finding is interesting in that it is qualitative data that confirms quantitative results. Quantitative analyses detected pre to post increases in TE by grade, course subject and school site. This result is corroborated by qualitative analysis.

Limitations of the Study

Results of both quantitative analysis of student data and qualitative content analysis of written responses to reflective prompts provide evidence of the partial efficacy of this pedagogical model. The data, as summarized above, bears some evidence

that an instructional approach embedded in a transformative learning experience designed to be supportive of student interest and knowledge acquisition is effective in leading to desired learning outcomes. These results must also be considered in the context that of limitations in both the study's design and implementation.

Comparison Design

This project was designed as a quasi-experimental study. As part of the design I created two separate learning experiences—one designed as a transformative experience and the other intended to align with a more traditional approach to learning Earth science. Part of both experiences students conducted water quality measurements on locally collected water samples. This activity engaged students in both groups in the learning of science content and scientific practices. The comparison activity was distinct in its focus. It was characterized by a scaffolded exploration of geoscience careers as opposed to an investigative study of an actual and current case environmental crises. Also different were any design elements supportive of TE. However, it is unclear whether these differences were enough to classify the comparison activity as truly not supportive of TE. Making explicit connections between science content and geoscience careers may have provided a transformative experience for those in the comparison group. This aspect of the comparison activity reinforced fundamental components of transformative experience—perceived relevance and perceived value. Likewise, the students in the comparison activity conducted water quality tests on water samples they collected from the local community. This introduced a place-based component to the comparison activity that may have potentially reinforced a shift in applying science concepts learned to the students' immediate environment. The presence of TE components in the comparison activity may have effectively nullified a clear comparison of a transformative

learning experience and a more traditional learning experience. In fact, this study may have been a comparison of two transformative learning experiences.

Along those lines, I did not design the study as a controlled experiment. In other words, an experiment closer to a controlled experiment would include the intervention group compared to similar grade-level science classes that did not participate in the intervention but did complete the same measures. This structure would allow for a comparison of the intervention with the adopted curriculum as opposed to a comparison of what may be essentially two different interventions.

Quasi-experimental Design and Fidelity of Implementation

Inherent in quasi-experimental design are concerns about fidelity of implementation. Across schools sites there was variance. For example, the students at school site 01 did not complete the delayed post measures. In fact, school-wide events such as the week before Spring Break dedicated to exploring electives and senior exhibits with all classes required to attend resulted in more than a two-week lapse in between activities. In addition, the students in the comparison group were mistakenly given Activity 1 from the intervention. Although the error was corrected for the following activities it is unclear how this exposure may have influenced student learning. On the other hand, at school site 02, the students did not use the same water quality testing equipment. As part of the study, I provided each school site with hand-held multi-parameter probes to measure temperature, pH, and TDS. Such equipment was not common or accessible in school sites 01, 03, and 04 which made using such equipment a novel experience for those students. However, at school site 02, the students were not only accustomed to conducting water quality measurements in the field as a regular part of the course, they used probes that were far more sensitive and capable of detecting

specific solids dissolved in a water sample. Whereas the multiparameter probes gave a reading of aggregate TDS, the probes used at school site 02 were able to identify whether the dissolved solids detected were phosphates, nitrates, etc. For the learning experience, the teacher at school site 02 opted to use the field equipment the students were accustomed to in lieu of the equipment that I could provide. This could present questions of uniformity of experience.

Lastly, due to the unique school-wide schedule of AP exams and finals, at school site 04, the students did not have a full two weeks between completing the post and delayed post measures. For some sections, these measures were taken only within days of each other.

Instrumentation

Content validity was established for each multi-item instrument. I also bench tested each multi-item measure and calculated reliability based on participant results. The calculations from the bench test results were quite different from the results following implementation in the school sites. In fact, I removed the self-efficacy and Earth science interest variables from the study because of low reliability of the measures. This may be due to differences inherent in the populations—the bench test was done with out of high school professional adults as opposed to school-aged students. These results reflect an error in my logic about the norming process.

According to Osterlind (2010), instruments at the development stage should be “administered to a group of persons broadly appropriate for the test and similar to most future examinees” (p. 186). This administration would yield scores that would be similar in range and characteristics to the future test population (Osterlind, 2010). This would allow for scores from implantation stage of the research study to be compared to the

scores from the instrument's development with the scores from the developmental stage considered as "norms" (Osterlind, 2010). I erroneously assumed that it would be appropriate to "norm" the instrument on an adult population given little developmental influence on interest, competency beliefs, or attitudes towards science. This assumption was based in part by work on conceptual change and evidence-based reasoning. For example, Lombardi and Sinatra (2012) found that undergraduate students held misconceptions about climate change based in part by conflation of short-term weather events and long-term climatic changes. Instruction that provided accurate scientific conceptualization of both weather and climate, evidence of global warming temperatures induced by greenhouse gases, and comparison of the present climatic changes with past climate shifts led to conceptual change (Lombardi & Sinatra, 2010). They found that accurate scientific understanding reduced misconceptions related to climate change. This was also true with middle school students' beliefs about human-induced climate change. As with the undergraduate students, middle school students adopted the scientifically accepted model of climate change following instruction that included science content in addition to student critical examination of evidence, and comparison of alternative explanations with respect to the lines of evidence (Lombardi, Sinatra, & Nussbaum, 2013). These two studies showed that the learning processes did not differ between the two populations—undergraduate and middle school—despite differences in age and educational experience. However, this principle only partially played out in the case of my study.

In addition to norming the instruments on a demographic group similar to the intended group of study, the self-efficacy measure in particular can be improved in two ways. First, it can be improved by increasing the number of items on the measure.

Additional content validated items would improve the instruments ability to measure the intended construct. Secondly, I can revise items to make them more reader friendly. One item in particular had the potential to be difficult to read and therefore to respond to:

- How likely are you to raise a question in your Earth science class?
- A. Very likely
 - B. Likely
 - C. Neutral
 - D. Somewhat not likely
 - E. Not at all likely

The intended goal of this item was to address avoidant behavior and persistence in getting help to support understanding. However, the wording of the multiple-choice options do not align well with spoken English and could pose difficulty in understanding the meaning of the option and consequently responding to the item.

The reliability results for the general science interest, transformative learning experience, and knowledge measures were accepted during the bench test and during implementation with the high school population. The reliability results for the self-efficacy measure did not. It is unclear why there are mixed results but a principle to inform future research would be to norm instruments on a population similar to the anticipated study population.

Also, regarding instruments used in the study, scheduling the delayed post measure just 1-2 weeks after the post measure may have contributed to survey fatigue. Teachers commented that students questioned why they had to complete a task they had already completed. Although the teachers were informed during the training of the logic underlying the implementation scheduled the students were not. This problem could potentially be addressed by changing the order of the survey items without changing the

items themselves. Making the instruments slightly different while maintaining the content of each measure and each item within the measure may address issues of survey fatigue.

The Pedagogical Model

I designed a model of geoscience pedagogy in which a place-based transformative learning experience supportive of student interest development and self-efficacy would lead to increases in knowledge, interest, self-efficacy, and transformation operationalized as positive shifts in perceived relevance, value and application of Earth science. I tested whether this model could effectively yield the stated learning outcomes. This test took the form of embedding each of those constructs in a place-based water-quality themed investigative experience. I conceptualized this model in the schematic below (Figure 16).

Figure 16. Conceptualization of model of geoscience pedagogy.

Results of structural equation modeling and path analysis support this conceptualization. More specifically, SEM results confirm that the intervention is a statistically significant contributor to post-instruction knowledge. Based on results discussed in this study, I would like to put forth a revised model for future investigation.

Figure 17. Revised conceptualization of model of geoscience pedagogy. Solid lines represent relationships investigated as part of the current study. Dashed lines represent relationships to explore as future lines of inquiry.

The revised model incorporates each of the socio-cognitive variables investigated as part of this study as well as the comparison activity. As previously discussed, the comparison activity may also contain elements that are supportive of transformative

learning. The dashed lines represent relationships that I could investigate through an expanded qualitative examination of student written responses during instruction.

Implications for Instruction

In this work I present an instructional approach for teaching Earth science content and scientific practices. This model suggests that place-based investigative learning experiences supportive of student interest development and transformative learning leads to gains in both those learning outcomes in addition to knowledge acquisition. Practically, the model specifically and the intervention as a whole present a few evidence-based practices that can translate to the science classroom:

- Use the local community as a science laboratory. During the intervention, students learned science content and scientific practices by conducting water quality measurements on samples collected in the community. The community can be an educational resource and when used as such, may potentially reinforce the perceived relevance of science learning.
- Incorporate written reflection to support student learning. I CAN prompts can be used to support student reflection on inquiry focused science activities. Responses allow students to review and reinforce key concepts and skills learned during class.
- Embed science content and scientific practices in current and relevant socio-scientific issues. Making explicit connections between what is learned in the classroom and the real-world experiences support student interest development and perceptions of relevance and value of science.

Implications for Future Research

Results of repeated measures ANOVA in conjunction with the findings of the SEM reveal statistically significant and meaningful shifts over time in knowledge and transformative experience. This data is partial confirmation of my model and hypothesis that this pedagogical approach supports student learning and leads to transformative learning. I am heartened by these results, however, there are confounding findings and questions remaining that I would be able to investigate given my current dataset. For example:

- Extended Question 1: I did not include self-efficacy as a variable of study given the low reliability of the measure. Therefore, self-efficacy was not included in any of the quantitative analyses. It may, however, be present in student writing. Using iterative content analysis, I can explore whether self-efficacy emerges as a theme in student writing. This analysis would answer the following question: Is there any evidence in student-generated open-ended responses that would lead to understanding how the intervention influenced their competency beliefs? What is the nature of that evidence? Also, is there any evidence in student writing that would lead to understanding how the comparison activity may have contributed to self-efficacy?
- Extended Question 2: When creating the student dataset for this study, I chose a conservative approach and only removed scores that fell outside of the third quartile. This approach was inclusive, allowing for a student demographic with a broad range of characteristics. Results of quantitative analysis showed statistically significant shifts in knowledge

over time. An interesting line of inquiry would be to explore how the intervention was experienced by the students with scores falling within the lowest range. What is the nature of the learning outcomes for students with lowest pre-instruction performance scores on the knowledge assessment? Is there evidence that this approach was effective in providing an effective educational opportunity for all student participants?

- Extended Question 3: I conducted a qualitative content analysis of student writing to identify any evidence of transformative experience in student writing. This analysis yielded evidence of all three components of TE—perceived relevance, perceived value, and application of Earth science content—in written responses to I CAN prompts. Renninger and Riley (2015) observed that after 3-5 weeks of responding to I CAN prompts, middle school science students began to produce more complex responses to the reflective prompts. Simple responses became more developed and elaborative (Renninger & Riley, 2015). Is this pattern of change from simple to more complex responses present in student responses over the course of the learning experience? Although the learning experience is a total of 220 minutes, or one week of traditional class periods, is there an observable difference in content with respect to elaboration in student responses over the course of the instructional time period?

These three questions stem from and expand my current research. There is also one question that is related to but is beyond the current scope of this work and that is

exploration of other themes that may be present in student writing. NASA uses the term “spinoff”. According to NASA (2018), a spinoff is “a commercialized product incorporating NASA technology or expertise that benefits the public.” These products include air purifiers, an atomic oxygen product used to sterilize surfaces in an ambulance, and software to predict climate change and air quality (NASA, 2018). I do not propose a commercialized product but rather a spinoff investigation that may offer a public educational benefit.

In response to the I CAN prompt, *I CAN describe how Earth science can be useful to answer questions affecting my everyday life*, Student 40108 wrote: “I can question the rapidly changing earth and what I can do to help protect it and make a change.” I previously described how this written response showed elements of the scientific practice of critique and also a willingness to act on knowledge. An aim of my work was to frame Earth science content as actionable. This framing is inherent not only in the design of the intervention as a scaffolded investigation of a water quality crises but also in the comparison activity which is a scaffolded exploration of geoscience careers. Yet, willingness to act on science understanding was not examined as an outcome for this study. This presents a line of inquiry based in but diverging from the current study. Does this pedagogical model inclusive of student reflection on a transformative learning experience lead to student willingness to act on learning? If so, what does the transition from learning science content and scientific practices look like? I am interested in exploring whether there are learning outcomes undetected by the current combination of quantitative and qualitative approaches.

Epilogue and Concluding Thoughts

I have designed an instructional approach that merges socio-cognitive learning theory and geoscience content. I intentionally designed this pedagogical model to address the educational gap that exists in under-resourced schools in poor and historically marginalized communities of access to investigative science that combines both science content and scientific practices and is relevant to the lived experience of the student. However, none of the participating school sites reflect the characteristics of a historically marginalized community experiencing chronic toxic adversity due to poverty-related factors, exposure to violence, or structural racial discrimination. Additionally, the intervention was not implemented in a community facing, or one that has faced a case of environmental injustice similar to that of Flint, Michigan. Although this study not specifically examine chronic adversity and community level trauma, the social stressors that contribute to adversity and trauma have deleterious effects on student learning.

The focus of my dissertation work in identifying a socio-cognitive model of a geoscience pedagogy has both scientific and societal outcomes: (1) to improve learning outcomes for students, (2) to engage students from historically marginalized communities in geoscience, and (3) to generate actionable knowledge for both geoscience education researchers and teachers. With intended outcomes 1 and 2, society benefits as students disproportionately affected by environmental hazards are empowered through geoscience education to understand and advocate for fair, just, and sustainable environmental policies. Similar to the sentiment that Robert Moses (2001) expressed about math literacy and algebra, I think that science literacy, and geoscience in particular, can support environmental equity and justice for historically marginalized communities. The impetus

of my future work aligns with President Barack Obama's (2016) perspective that "we need science" because it is "how we will overcome the challenges we face: unleashing the power *of* all of us *for* all of us" (p. 34).

By advancing our understanding of the socio-cognitive contributors to science students' learning, this work may make an appreciable contribution to education research, in general, and geoscience education research, in particular. This work has further implications with respect to access to relevant geoscience content for students attending schools in impoverished communities.

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APPENDIX A

REVIEW OF EACH CONSTRUCT AND ITS POTENTIAL CONTRIBUTION
TO A GEOSCIENCE PEDAGOGY: INTEREST, PLACE-BASED
TRANSFORMATIVE LEARNING, SELF-EFFICACY

Table 17

Identification of science learning needs that can be addressed through support of interest development

Interest	Academic needs addressed by support of interest development (Hidi, 1990; Renninger & Hidi, 2016)	Potential learning outcomes
Affective	Facilitates reading and processing new information	<ul style="list-style-type: none"> • Knowledge acquisition • Enthusiastic engagement with science content and practices
Cognitive	Reduced cognitive load when processing new information and organizing it into memory	Knowledge construction and retention
Motivational	Self-regulated behavior that allows the student to persist through difficult tasks	<ul style="list-style-type: none"> • Increased capacity for attention thereby enabling learning • Academic achievement, desired academic results

Table 18

Identification of science learning needs that can be addressed through mastery experiences that support development of self-efficacy

Self-efficacy through mastery	Academic needs addressed by mastery experience (Bandura, 1986)	Potential learning outcomes (Renninger & Hidi, 2016)
Affective	Positive affect motivates continued engagement in learning/academic tasks	<ul style="list-style-type: none"> • Task completion • Willingness to re-engage with subject matter
Cognitive	<ul style="list-style-type: none"> • Sense of competence and confidence • Constructive beliefs when confronted with failure 	<ul style="list-style-type: none"> • Task completion • Willingness to re-engage with subject matter • Knowledge construction and retention
Motivational/Behavioral	<ul style="list-style-type: none"> • Intrinsic motivation • Persistence when confronted with failure 	Academic achievement

Table 19

Identification of science learning needs that can be addressed through place-based transformative learning experience in geoscience

Place-based transformative learning	Academic needs addressed by place-based transformative learning experiences (Pugh, 2002, 2011)	Potential learning outcomes
Affective (positive)	Motivated learning	<ul style="list-style-type: none"> • Increased capacity for attention thereby enabling learning • Sense of belonging to the science community • Knowledge acquisition
Cognitive	<ul style="list-style-type: none"> • Inductive learning, discovery • Expansion of perception • Conceptual change and knowledge transfer 	<ul style="list-style-type: none"> • Perceived content value leads to motivated engagement in learning process • Agility of knowledge enabling application in real life • Knowledge acquisition and retention
Behavioral	<ul style="list-style-type: none"> • Active engagement • Active use of concept 	<ul style="list-style-type: none"> • Motivated use/application of science concepts outside of the learning space • Informed decision-making; science literacy • Knowledge retention

APPENDIX B

SUMMARY OF FINDINGS FROM REVIEW OF LITERATURE ON CHRONIC
ADVERSITY DUE TO EXPOSURE TO VIOLENCE (ETV) TRAUMA AND
EXPOSURE TO ENVIRONMENTAL HAZARD

Table 20

Identification of science learning needs in under-resourced schools located in poor and historically marginalized communities

Chronic adversity	Academic needs presented by the sources of chronic adversity (Evans & Fuller-Rowell, 2013; Harris, 2014; Perrier & Nsengiyumva, 2003)	Strategy that can potentially meet the academic need
Exposure to violence (ETV)	<ul style="list-style-type: none"> • Hypervigilance • Hindered connectedness to the school setting and individuals within the school context • Reduced attentiveness to academic subject matter • Decreased working memory capacity 	<ul style="list-style-type: none"> • Engage in direct experience of science content and practice to increase attentiveness and interest • Science investigation in collaborative learning groups to provide sense of connectedness • Curricular relevance and place-based investigation to support connectedness to science content
Poverty	<ul style="list-style-type: none"> • Decreased working memory capacity 	<ul style="list-style-type: none"> • Direct experience of science content and practice to support encoding of information
Exposure to environmental toxins	<ul style="list-style-type: none"> • Reduced attentiveness • Hindered cognitive processing • Difficulty with reading comprehension 	<ul style="list-style-type: none"> • Engage in direct experience of science content and practice to increase attentiveness and interest • Curricular relevance to increase interest and thereby attentiveness

APPENDIX C

SAMPLE STUDENT ASSENT FORM

Title of the research study: Developing interest in Earth science students

Name and Department of investigator: Shondricka Burrell, Doctoral Student, Department of Teaching & Learning

This study involves research. The purpose of the research is to develop approaches to teaching Earth science that lead to retention of knowledge content and understanding of scientific practices, application of understanding, and student confidence to learning Earth science.

What you should know about a research study:

- You are invited to participate in a research study.
- Someone will explain this research study to you.
- You volunteer to be in a research study.
- Whether you take part is up to you.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide, it will not be held against you.
- Feel free to ask all the questions you want before and after you decide.
- ***By signing this assent form, you are not waiving any of the legal rights that you otherwise would have as a participant in a research study.***

The estimated duration of your study participation is for the entire school year. The instructional activities that are part of this study will be given four times throughout the year and each will take about 4 or 5 class periods. These activities are part of normal classroom instruction and are not extra assignments.

The study procedures consist of **responding to survey questions and completing some instructional activities.**

The reasonably foreseeable risks or discomforts are **only minimal. You may become uncomfortable when answering some questions and participating in some of the activities. You may also become tired from reading and answering the questions on the surveys and participating in the activities.**

The benefit you will obtain from the research is knowing that you have contributed to the understanding of this topic **and you may gain greater understanding about Earth and space science topics.**

The alternative to participating is **to not be in the study, which would not affect your schoolwork or grades. Your schoolwork will not be used as part of this research.**

Please contact the research team with questions, concerns, or complaints about the research and any research-related injuries by calling Shondricka Burrell at (xxx) xxx-xxxx or e-mailing shondricka.burrell@temple.edu.

This research has been reviewed and approved by the Temple University Institutional Review Board. Please contact them at (215) 707-3390 or e-mail them at: irb@temple.edu for any of the following: questions, concerns, or complaints about the research; questions about your rights; to obtain information; or to offer input.

☐ **I give permission for my school work to be used in the research study and to be photographed during participating in the learning activities associated with the study.**

☐ **I do not give permission for my school work to be used in the research study and to be photographed during participating in the learning activities associated with the study.**

Confidentiality: Efforts will be made to limit the disclosure of your personal information, including research study records, to people who have a need to review this information. However, the study team cannot promise complete secrecy. For example, although the study team has put in safeguards to protect your information, there is always a potential risk of loss of confidentiality. There are several organizations that may inspect and copy your information to make sure that the study team is following the rules and regulations regarding research and the protection of human subjects. These organizations include the IRB, Temple University, its affiliates and agents, the study sponsor and its agents, and the Office for Human Research Protections.

Your signature documents your permission to take part in this research.

Signature of participant

Date

Printed name of
participant

Signature of person
obtaining consent

Date

Printed name of person
obtaining consent

APPENDIX D

SAMPLE PARENTAL CONSENT FORM

Title of the research study: Developing interest in Earth science students

Name and Department of investigator: Shondricka Burrell, Doctoral Student, Department of Teaching & Learning

This study involves research. The purpose of the research is to develop approaches to teaching Earth science that lead to retention of knowledge content and understanding of scientific practices, application of understanding, and student confidence to learning Earth science.

What you should know about a research study:

- Your child is invited to participate in a research study.
- Someone will explain this research study to you.
- You volunteer for your child to be in a research study.
- Whether your child takes part is up to you and your child.
- You and your child can choose not to take part in the research study.
- You and your child can agree to take part now and later change your mind.
- Whatever you decide, it will not be held against you.
- Feel free to ask all the questions you want before and after you decide.
- ***By signing this consent form, you are not waiving any of the legal rights that you otherwise would have as a participant in a research study.***

The estimated duration of your study participation is for the entire school year. The instructional activities that are part of this study will be given four times throughout the year and each will take about 4 or 5 class periods. These activities are part of normal classroom instruction and are not extra assignments.

The study procedures consist of **responding to survey questions and completing some instructional activities.**

The reasonably foreseeable risks or discomforts are **only minimal. Your child may become uncomfortable when answering some questions and participating in some of the activities. Your child may also become tired from reading and answering the questions on the surveys and participating in the activities.**

The benefit you will obtain from the research is knowing that you have contributed to the understanding of this topic **and your child may experience a deeper level of learning about fundamental Earth and space science concepts, such as the distinctions between weather and climate.**

The alternative to participating is **to not be in the study, which would not affect your child's schoolwork or grades. Your child's schoolwork will not be used as part of this research.**

Please contact the research team with questions, concerns, or complaints about the research and any research-related injuries by calling Shondricka Burrell at (xxx) xxx-xxx or e-mailing at shondricka.burrell@temple.edu.

This research has been reviewed and approved by the Temple University Institutional Review Board. Please contact them at (215) 707-3390 or e-mail them at: irb@temple.edu for any of the following: questions, concerns, or complaints about the research; questions about your rights; to obtain information; or to offer input.

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Confidentiality: Efforts will be made to limit the disclosure of your personal information, including research study records, to people who have a need to review this information. However, the study team cannot promise complete secrecy. For example, although the study team has put in safeguards to protect your information, there is always a potential risk of loss of confidentiality. There are several organizations that may inspect and copy your information to make sure that the study team is following the rules and regulations regarding research and the protection of human subjects. These organizations include the IRB, Temple University, its affiliates and agents, the study sponsor and its agents, and the Office for Human Research Protections.

Your signature documents your permission for the named child to take part in this research.

Printed name of child

Signature of parent or guardian

Printed name of parent or guardian

Date

☐ Parent
☐ Guardian (See
note below)

Note on permission by guardians: An individual may provide permission for a child only if that individual can provide a written document indicating that he or she is legally authorized to consent to the child's general medical care. Attach the documentation to the signed document.

_____	_____
Signature of person obtaining consent and assent	Date
_____	_____
Printed name of person obtaining consent and assent	Date

APPENDIX E

OUTLINE OF WATER QUALITY-THEMED LEARNING EXPERIENCE

Outline of Water Quality-themed Learning Experience in Earth Science

Shondricka Burrell

Temple University

College of Education

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Motivated by the water crises in Flint, Michigan, this investigative learning experience was designed for students to engage in using Earth science content for problem solving. The learning experience consists of 4 activities related to water quality and connects these concepts to scientific practices related to inquiry and problem-solving. The activities are designed to:

- support student learning of Earth science as it relates to water resources and water quality
- have direct experience with scientific investigation
- understand science as relevant to everyday life

It also focuses on the following aspects of 3-dimensional learning: asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, engaging in argument from evidence, communicating information. With respect to the three spheres of scientific activity recommended by the NRC (2012), students will participate in: questioning, observing, experimenting, measuring, predicting, reasoning, and explaining. Students will also engage in the scientific practices of collaboration and communication.

Outline of Learning Activities

Prior to Activity 1: Complete student interest survey (15minutes) and knowledge pre-test (15minutes)

ACTIVITY 1

This activity focuses on investigative design for problem solving. Working in collaborative learning teams, students will assume the roles of investigative Earth scientists tasked with solving a “case” based on provided details. The educational goal of this activity goals for students to design an investigation to answer a scientific question.

In this activity students will: ask questions; design an experiment; collaborate; take measurements; predict; observe; and respond to reflective prompts about their learning.

Activity 1	Components of the Learning Experience	Academic Standards Addressed
	<p>Session Name: What would you do? (45 minutes)</p> <p>Introduction: How would you conduct a scientific investigation to solve an Earth science problem?</p> <p>Part 1</p> <p>Problem: You are an Earth scientist and part of a team of Earth scientists assigned to investigate a case. The case takes place in a poor, manufacturing city in the United States. We will call the city, City X. This is what you know so far:</p> <ul style="list-style-type: none"> • On April 25, 2014, residents of City X noticed that the water was no longer clear when they turned on the tap. Not only was the water a rusty yellow color, it didn't taste like it used to and it smelled different. Soon residents began to develop rashes on their skin. • August- September 2014 coliform bacteria are found in the city's tap water. City officials tell residents to boil the water before they drink it. • In October 2014, a local auto manufacturing plant stops using the city's water supply because the company is concerned that the water is corroding the auto parts. • In February 2015, the governor of the state announces that although the residents of City X are concerned about the color, smell and taste of the water, that there is no threat to human health. 	<p>Skills targeted:</p> <p>asking questions, planning and carrying out an investigation, collaboration, communication</p> <p>Middle School Standard:</p> <p>MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.</p> <p>High School Standard:</p> <p>HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.</p>

Activity 1	Components of the Learning Experience	Academic Standards Addressed
	<ul style="list-style-type: none"> • On February 18, 2015, lead is detected in the water at the home of a resident in City X. The lead was measured at 104 parts per billion in the drinking water. • On February 27, 2015, an expert at the Environmental Protection Agency (EPA) says that the procedure used to measure lead in the water may not provide accurate results. On March 3, 2015, the water is retested and was measured at 397 parts per billion. • On July 02, 2015, an EPA expert reassures the mayor of City X that the measurements are inconclusive. • From January to June of 2015, the blood of school-aged children was tested. After tests for local school children showed high levels of lead in the blood, the Department of Environmental Quality announced that the city should take steps to minimize corrosion in the pipes that transport water to local homes and businesses. • On September 24-25, 2015, a group of doctors urged City X to change its water source based on the high levels of lead found in children's blood. • On October 1st, 2015, findings from a team of federal epidemiologists confirmed the results that the doctors had from blood tests—the finding that there are high levels of lead in the blood tested in children living in City X. • On October 16, 2015, City X changes its source of drinking 	

Activity 1	Components of the Learning Experience	Academic Standards Addressed
	<p>water and the residents in the city are advised to use water filters and to only drink water that has been filtered.</p> <ul style="list-style-type: none"> • City X takes steps to reduce water corrosion. • January 5 and 16th, 2015, there is a state of emergency declared for the city and the county to address the problem. • In January 2016, the Chief Medical Examiner reported an increase in calls to the Safe Drinking Water Hotline about skin rashes. • A local pediatrician also reported seeing more patients with skin rashes. But the Department of Health declared that there wasn't a scientific link between the skin rashes and the water. The Department of Health declared that the water was safe to use for bathing. • Based on this timeline of events, as an Earth scientist assigned to investigate this case, what would you do? • What questions would you ask? • Notice that the local automobile manufacturing plant stopped using the water because it was corrosive to the auto parts. What does that mean? How could you test water to see if it would be corrosive to car parts? • What information would you like to know? • What is the best way to get that information? 	

Activity 1	Components of the Learning Experience	Academic Standards Addressed
	<p>Part 2</p> <p>Each investigative team can share/report their questions and preliminary investigative approach.</p> <p>Part 3</p> <p>Discuss (teacher-led discussion):</p> <ul style="list-style-type: none"> • the scientific practice of investigation that includes asking questions, observations, experimentation, measurement, and interpretation of data collected. • how the questions and the student-identified approaches to addressing these questions fit into an investigative design. • experiments provide information in the form of results. • the difference between experimental results and evidence <p>Review science lab safety ahead of water quality testing outlined in the second part of this activity. (Instructor)</p> <p>Students will bring in collected water samples to be used in Activity 2. These water samples can be taken from home, from school, or an outdoor field location. (See section “Water Sampling for Classroom Testing” for sampling procedures.)</p> <p>Reflective prompt (formative assessment):</p> <p>I CAN describe the components of an investigation.</p>	

ACTIVITY 2

Working in collaborative learning teams, students will perform various investigative tasks—prediction, observation, and measurement.

For students, the educational goals of this activity are to:

- observe chemical reaction of an acidic solution and chalk
- observe the changes in metal samples (iron and steel) immersed in solutions of various acidity
- compare changes in metal samples with respect to susceptibility to corrosion
- make connections between the metal used in the experiment and potential problems with water quality when these metals are used in plumbing
- test the quality of water samples they collected with respect to temperature, pH, and electrical conductivity/total dissolved solids (TDS)
- compare their results with EPA standards

In this activity students will: collaborate; take measurements; predict; observe; and respond to reflective prompts about their learning.

Activity 2	Components of the Learning Experience	Academic Standards Addressed
	<p>Session: What makes drinking water corrosive to pipes and automobile parts? Investigating the relationship between pH of water and metal (65 minutes)</p> <p>Introduction (instructor-led demonstration): Setup beakers for tap water, salt-water and vinegar-water and either chalk or a seashell. Students will test the pH of each liquid (using pH paper) and predict which acidity level would produce an observable reaction. Discuss logic for predictions. Students will make observations and compare the reactions observed. Students can then see if their predictions were confirmed. Discuss whether predictions were confirmed and what was learned from the process whether the predictions were or were not confirmed.</p>	<p>Skills targeted: asking questions, experimenting, predicting, reasoning, explaining</p> <p>Middle School Standard: MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.</p>

Activity 2	Components of the Learning Experience	Academic Standards Addressed
	<p>Part 1</p> <p>Problem: You are an Earth scientist and part of a team of Earth scientists assigned to investigate a case in a poor manufacturing city in the United States, which we will call City X. Based on what you know so far, do you think this is a problem primarily with the geosphere, hydrosphere, or atmosphere? Why do you think so?</p> <p>Based on what you know so far, where do you think City X is located?</p> <p>Review science lab safety.</p> <p>Part 2</p> <p>In City X, as in most urban communities, water is treated at a local water treatment facility. The water has to meet EPA standards for safe drinking before leaving the facility. What are those standards? Each student views table of water quality standards.</p> <p>Why are these standards important?</p> <p>Recall that residents of City X described the tap water as a rusty yellow color and mentioned that the water didn't taste like it used to and it smelled different. These residents also began to develop rashes.</p> <p>Recall that the local auto manufacturer stopped using the water because it was corroding the auto parts.</p> <p>Two pieces of information that can help investigators understand the problem is pH and Electrical Conductivity/Total Dissolved Solids (TDS).</p> <p>[The following two measurements can be done simultaneously with some groups assigned to pH and others assigned to TDS.]</p> <p>Part 3</p> <p>Students will perform water quality tests.</p>	<p>High School Standard:</p> <p>HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.</p>

Activity 2	Components of the Learning Experience	Academic Standards Addressed
	<p>Measure the temperature for your water sample. (See handout “Water temperature protocol” for multi-parameter probe.)</p> <p>Test the pH of your water sample. (See handout adapted from GLOBE protocol for pH with an electrical conductivity less than 200mS/cm. Students will use for multi-parameter probe for this measurement.)</p> <p>Record your measurements.</p> <p>What is the average pH of the water samples for your team? How does this compare to the EPA standards? Is your sample acidic enough to have an immediate reaction with a seashell (or piece of chalk)? What did you observe? And why?</p> <p>Measure electrical conductivity/Total Dissolved Solids (TDS) (See section “Electrical Conductivity Protocol”. Students will use for multi-parameter probe for this measurement.)</p> <p>Record findings Compare findings to EPA table.</p> <p>Part 4 Although water leaving a water treatment facility must meet EPA safety standards, the local auto manufacturer in City X stopped using the water because it corroded car parts and residents complained of the odor, color and taste of the water. How is this possible? What happened to the water as it left the water treatment facility? What do you think? Consider how is water transported from the water treatment facility to a home or business? Think about our initial demonstration and prediction. How can this relate to the problem we are investigating in City X?</p>	

Activity 2	Components of the Learning Experience	Academic Standards Addressed
	<p>(Instructor) Set up a test for corrosion using various metal samples (eg. iron, and stainless steel).</p> <p>Student teams will describe each metal sample. Students can place each metal sample in a labeled glass jar for their team.</p> <p>Teacher will introduce the acidic liquid in each jar before closing the lid.</p> <p>(If classroom space is limited, this can be adjusted from a set for 5 teams to a single setup for the entire class).</p> <p>Two representatives from each student team will make daily observations over the next two weeks.</p> <p>Reflective prompt (formative assessment): I CAN describe at least three investigative practices that scientists use.</p> <p>I CAN describe how the scientific practice of investigation can be useful to answer questions affecting my everyday life.</p>	

OPTIONAL FOR ENRICHMENT:

Introduction: What does a scientific experiment look like?

Look at this [video featuring Neil deGrasse Tyson in an interview with James Corden.](#)

What was the scientific experiment conducted here?

What question was the experiment designed to answer?

Which scientific practices can you identify here?

Are there any scientific practices that may be missing from the video but are important to consider for your investigation? If so, what are they and why are they important?

How can you tell the difference between observation, and evidence that can be used to answer your question?

How can you tell the difference between evidence, and information that can be used to confirm bias? (How was this addressed in the video?)

ACTIVITY 3

The educational goal of this activity is for students to compare data and formulate data-based explanations.

In this activity students will: ask questions; collaborate; compare data; formulate potential explanations; and respond to reflective prompts about their learning

Activity 3	Components of the Learning Experience	Academic Standards Addressed
	Session: Can Earth science be used to solve problems or answer questions in our society? (55minutes)	Skills targeted: Analyzing and interpreting data, constructing explanations
	Introduction: Where does your drinking water come from? Illustrate your answer. Don't forget to label specific components of the water cycle in your illustration.	Middle School Standard: MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
	Consider each of the spheres involved in the water cycle. Are there any questions related to the water cycle and the spheres that may be important to this Earth science investigation?	
	Part 1 The city you are investigating is Flint, Michigan. Have you heard about this city? If so, what do you know about the current water crisis in this city? <u>Watch this video of a family living in Flint, Michigan.</u>	High School Standard: HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be

Activity 3	Components of the Learning Experience	Academic Standards Addressed
	<p>Optional <u>video that reviews timeline of events</u>.</p> <p>Based on what you already have learned about the city, and what you have learned from the video, would you like to revise your investigative questions? If so, what are some new questions you would like to include in your scientific investigation?</p> <p>Part 2</p> <p>Using EPA compiled statistics, compare your water quality measurements to EPA standards. Are there any similarities? Differences? What could account for differences?</p> <p>Compare your water quality measurements to the water quality measurements for water samples in Flint, Michigan. Are there any similarities? Differences? What could account for differences?</p> <p>Part 3</p> <p>Does environmental quality depend on your location? Using EPA maps, compare exposure to environmental toxins for your area. For this task you will compare:</p> <ul style="list-style-type: none"> • number of Superfund sites • number of EPA identified facilities that release toxins into the environment each year (Toxic Release Inventory facilities) • median household income for the community • median property value for the community • and the amount of pollution in pounds released into to the air, water and soil by facilities that release 	<p>solved through engineering.</p>

Activity 3	Components of the Learning Experience	Academic Standards Addressed
	<p>toxins (Toxic Release Inventory facilities)</p> <ul style="list-style-type: none"> • Compare this exposure to at least three other cities outside of your state. <p>* Students assigned to make observation of metal corrosion must record daily descriptions. It may be ideal to assign two students per investigative team.</p> <p>Reflective prompt (formative assessment): I CAN explain how the atmosphere, geosphere, and hydrosphere are interconnected in the water cycle.</p> <p>I CAN describe how Earth science can be useful to answer questions affecting my everyday life.</p>	

ACTIVITY 4

The educational goal of this activity is for students to summarize and interpret their findings.

In this activity students will: ask questions; collaborate; compare data; formulate potential explanations; communicate their interpretations; revise their conclusions; and respond to reflective prompts about their learning

Activity 4	Components of the Learning Experience	Academic Standards Addressed
Part 1	<p>Session: How do you interpret the results of the Earth science investigation? (30minutes)</p> <p>Students will:</p> <ul style="list-style-type: none"> • summarize each procedure and the findings/results of each investigation • review concepts and scientific practices learned • report out thoughts about the experience <p>Students will complete student interest survey (15minutes)</p>	<p>Skills targeted: analyzing and interpreting data, constructing explanations</p> <p>Middle School Standard: MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.</p> <p>High School Standard: HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.</p>
Part 2	<p>Students will complete knowledge post-test (15minutes)</p>	

APPENDIX F

SURVEY INSTRUMENT TO MEASURE INTEREST

Consider your perspective on Earth science and your experience studying Earth science in school when responding to these questions.

1. Earth science is relevant to my everyday life.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
2. Earth science is connected to other sciences like Chemistry, Physics, and Biology.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
3. Earth science is connected to other classes I have taken like History, Government, Art, English, and Economics.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
4. Think about your Earth science class. Did you work on individual projects?
 - A. We are assigned lots of individual projects
 - B. We are assigned many individual projects
 - C. We are assigned a few individual project
 - D. We are assigned one individual project
 - E. No, there are no individual projects
5. Think about your Earth science classes. How often did you work on team projects?
 - A. We are assigned lots of group projects
 - B. We are assigned many group projects
 - C. We are assigned a few group project
 - D. We are assigned one group project
 - E. No, there are no group projects

6. I watch science programs on television and/or online ____.
- A. Often
 - B. Sometimes
 - C. A few times
 - D. Perhaps once
 - E. Never
7. I discuss science events with people and/or visit science museums ____.
- A. Often
 - B. Sometimes
 - C. A few times
 - D. Perhaps once
 - E. Never

APPENDIX G

SURVEY INSTRUMENT TO MEASURE SELF-EFFICACY

1. I do well on assignments in my Earth/Environmental science class.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
2. How easy is it for you to study for your Earth/Environmental science class?
 - A. Very easy
 - B. Easy
 - C. Depends, sometimes easy sometimes hard
 - D. A bit hard
 - E. Quite difficult
3. How likely are you to raise a question in your Earth science class?
 - A. Very likely
 - B. Likely
 - C. Neutral
 - D. Somewhat not likely
 - E. Not at all likely

APPENDIX H

SURVEY INSTRUMENT TO MEASURE TRANSFORMATIVE LEARNING

1. I discuss ideas from my Earth science class with friends or family members outside of class.
 - A. Often
 - B. Sometimes
 - C. A few times
 - D. Perhaps once
 - E. Never

b. Describe a topic that you learned in your Earth science class and later shared with someone outside of class. (Write your response on the lined side of the answer sheet provided.)

2. I see examples of what I learned in my Earth science class at home and in my community.
 - A. Often
 - B. Sometimes
 - C. A few times
 - D. Perhaps once
 - E. Never

b. Please describe a time you noticed an example of what you learned in your Earth science class outside of class. (Write your description on the lined side of the answer sheet provided.)

3. I think about things I learned in my Earth science class during the week.
 - A. Often
 - B. Sometimes
 - C. A few times
 - D. Perhaps once
 - E. Never

b. Which topic did you find yourself thinking about outside of class? What made you think about it? (Write your response on the lined side of the answer sheet provided.)

4. I think what I learned in my Earth/Environmental science class is worth learning.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
5. After taking my Earth/Environmental science class, I see my environment differently.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
6. My understanding of science influences some of my lifestyle decisions such as transportation, food choices, recycling, and purchases.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree
7. My interest or knowledge of science influences some of my decisions such as places I visit, thoughts about voting and social issues, and blog or magazine subscriptions.
 - A. Strongly agree
 - B. Agree
 - C. Neutral
 - D. Disagree
 - E. Strongly disagree

APPENDIX I

SINGLE ITEM MEASURES: WATER QUALITY AFFECT HOME (WQA-HOME),
WATER QUALITY AFFECT SCHOOL (WQA-SCHOOL), AND ENVIRONMENTAL
AWARENESS (ENV AWARENESS)

WATER QUALITY AFFECT HOME (WQA-HOME)

I feel safe drinking the tap water at home.

- A. Strongly agree
- B. Agree
- C. Neutral
- D. Disagree
- E. Strongly disagree

WATER QUALITY AFFECT SCHOOL (WQA-SCHOOL)

I feel comfortable drinking the water from the water fountain at school.

- A. Strongly agree
- B. Agree
- C. Neutral
- D. Disagree
- E. Strongly disagree

ENVIRONMENTAL AWARENESS (ENV AWARENESS)

Are there any environmental concerns affecting your community?

- A. Yes
- B. No

If yes, please describe. (Write your description on the lined side of the answer sheet provided.)

APPENDIX J

KNOWLEDGE INSTRUMENT

Below are statements about water quality. Rate the degree to which you think that geoscientists agree with these statements.

A= strongly agree B= agree C= neutral D= disagree E= strongly disagree

1. Public policy affects freshwater supply options. (NRC, 2012, p. 7)
2. Science is instrumental in addressing challenges that confront society today, including maintaining supplies of clean water. (NRC, 2012, p. 9, 43)
3. Engineers use Earth science knowledge to understand the nature of soil and water flows. (NRC, 2012, p. 45)
4. Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources, including freshwater supply. (NRC 2012, p. 191)
5. Human activities do not have a noticeable impact on water quality. (NRC, 2012, p. 47)
6. Testing the pH (acidity) of water is a method for monitoring and minimizing human impact on the environment. (NRC, 2012, p. 52)
7. When Earth scientists design solutions to complex real-world problems, tradeoff considerations are not necessary. (NRC, 2012, p. 83)
8. Earth scientists can design solutions to complex real-world problems using scientific knowledge and evidence. (NRC, 2012, p. 83)
9. Look at the diagram below to rate the degree to which you think that a geoscientist would agree with this statement.

Water was added to each tube to just cover the sediments and the volumes of water added were recorded. This information can be used to determine

permeability. (NYS HS P.S./Earth Science Regents Exam, August 2015, p. 10)

10. Look at the diagram below to rate the degree to which you think that a geoscientist would agree with this statement.

Water infiltrating downward from location A would usually be greatest when the soil is both porous and permeable. (NYS HS P.S./Earth Science Regents Exam, January 2017, p. 9)

The Water Cycle