EFFECT OF PROFESSIONAL DEVELOPMENT ON TEACHERS' UNDERSTANDING OF INTERDISCIPLINARY EARTH SCIENCE CONCEPTS

by

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of

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ABSTRACT

The Critical Zone describes the interactions that support life on Earth among the biosphere, geosphere, hydrosphere, and atmosphere. To truly understand the complex processes, scientists must look outside their immediate focus: geologists, biologists, hydrologists, and physicists collaborate to see how their research fits together. Teachers can do the same and use critical zone concepts to bridge across subjects and from the classroom to the real world. Unfortunately, K12 teachers may not have the requisite knowledge or research experience to feel confident in incorporating critical zone topics into their classes, and professional development services provided by scientists may not properly meet those needs. A three-day professional development program, the result of a collaboration between a research group, Critical Zone Network Drylands Hub, and a non-profit science center, Insights Science Discovery, was developed to support teachers with including place-based, cross-curricular instruction. This mixed-methods study aimed to measure the impact on teachers' knowledge of the related concepts and their confidence in teaching it. Teachers were assessed, surveyed, and asked to draw an image or mental representation of the critical zone model and identify related academic disciplines. Both teachers and contributing scientists were surveyed to learn how their motivations for participating in professional development compared to one another. Mental models increased in their complexity and accuracy of CZ components. This result, combined with a modest improvement in their performance on assessments and a substantial increase in confidence towards including CZ concepts in their curriculum, could indicate that the PD successfully impacted teachers and actions in the classroom. Surveys also revealed that teachers and researchers share many of the same motivations for participating in PD. Ultimately, both groups shared that contributing scientists could be better informed about the teachers' context and needs, making PD content more relevant and applicable to better support student motivation and learning.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

Insights Science Discovery Center is a non-profit organization in El Paso, Texas, that provides professional development programs and partners with research grants to provide K12 workshops, summer camps, and pop-up activities that relay higher education research efforts into community outreach. In 2022 alone, the organization directly served over 2,775 students. The Critical Zone Collaborative Network (CZNet) is composed of multiple research clusters that focus on critical zone (CZ) concepts in various ecosystems. The CZ refers to the total surface of Earth that supports life, including the geosphere, atmosphere, and hydrosphere, as well as all the interactions among them (Rasmussen et al., 2010). Portrayal of the complex, multi-layered concept is best done visually in illustrations and models, as seen in Figure 1. Insights partnered with the Drylands Cluster to provide education and outreach services to the greater El Paso area.

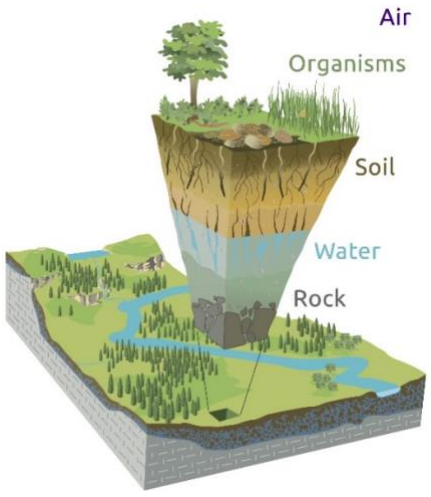

Figure 1. Illustration of the Critical Zone and its components. Modified from Chorover, J., R. Kretzschmar, F. Garcia-Pichel, and D. L. Sparks. 2007. Soil biogeochemical processes in the critical zone. Elements 3, pp. 321-326. (Artwork by R. Kindlimann).

In Year 1 of the program, 2020, I met with CZ scientists to learn about their topics of interest and the scientific processes they utilized in researching the critical zone in dryland environments with observatories in Idaho, New Mexico, and far west Texas. In Year 2, I developed three hands-on activities (modules), and graduate students were trained to present the activities to community members at public outreach events. Year 3 had two components; first, I extended the three modules into elementary, middle, and high school lesson plans. Then, I coordinated a three-day teacher professional development (PD) program to connect local teachers with the curriculum and directly with scientists and university students involved in the research project.

While the ultimate test of professional development is how it impacts the teachers' actions in the classroom, this study focused on more immediate impacts: how teachers' content knowledge was affected, what aspects of the PD they considered effective, and how the motivations of the teachers and scientists related to each other and the goals of the PD. The concept of the critical zone and its cross-curricular extensions are not well known by science teachers and the public alike. By understanding how teachers can be supported in incorporating CZ concepts, this information can be shared with other members of the CZNet as well as incorporated into future PDs offered by Insights and myself. An additional benefit can be gleaned by observing how the instruments performed and could be adapted for evaluating other PDs.

Focus Questions

A mixed-methods research plan was developed to study the effect of the three-day PD, collecting qualitative data in the form of drawings and surveys and quantitative data with

assessments and Likert-type statements. A mental model of a concept reflects a person's "conceptual understanding, prior experience, and pre-existing knowledge" (Katz et al., 2021, p. 1178). Inspired by how scientists also use illustrations to communicate their understanding of CZ systems and interactions, this study asked participants to sketch what they pictured when they imagined the critical zone. My focus question was, How do teachers' mental models of the dryland critical zone change after professional development that includes interactions with scientists?

My sub-questions included the following:

1. How are teachers' knowledge of and confidence towards incorporating geology concepts affected by attending the PD, and what aspects of the PD make the most impact?
2. What motivates researchers to participate in education and outreach efforts, and how does this correlate to the teachers' motivations and goals for attending the PD?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Introduction

Science educators are typically teachers, while science communicators consist of researchers. Studies, like a review done by Kohen & Dori in 2018, revealed that science communicators and educators have various perspectives on what constitutes effective professional development (PD) and how to measure that effectiveness. Identifying common goals between the two can help education and outreach providers plan and coordinate these PDs in ways that are valuable to their program goals and the participants' goals. Because the critical zone (CZ) encompasses numerous disciplines, it can serve as a vehicle for effective teaching strategies such as place-based education, cross-curricular and real-world connections, and experimentation. While there are many ways to elicit and gauge someone's thinking, drawing and sketches can be valuable tools, and there is support for utilizing deductive and inductive techniques for analysis.

Geology and Place-Based Education

One of the ultimate goals of the education and outreach arm of the Critical Zone Collaborative Network (CZNet) grant is to encourage students to choose academic paths that would lead them to environmental and geological career fields. However, regardless of the path a child takes, informal and outside learning environments can provide valuable experiences that can foster students growing into adults who understand and appreciate their community and can

therefore make informed decisions about it (Bestelmeyer et al., 2018; Subramaniam, 2020). In a study concerning the use of insects in environmental science curriculum, Weeks and Oseto (2018) highlighted the importance of students making connections to the local ecosystem and realizing that the "environment is an extension of themselves so its health is as important as their own" (p. 1). Traditional science lesson plans may lack the relevancy to students' lives needed to make an impact. Almquist et al. (2011) go further in stating that curriculum development needs to build on teachers' and students' prior experiences with their environment and should focus on "local landscapes that were meaningful and accessible to teachers and their students" (p. 38). Because of these points, different learning environments and different types of pedagogy can be used to supplement and support classroom teaching (Watermeyer, 2015) instead of being seen as a distinct and stand-alone approach to learning (Subramaniam, 2020).

Incorporating informal and authentic learning experiences into the curriculum can also support teachers in having students actually "do" science, thus improving their understanding of science as a process and making connections to big-picture ideas, such as inequity and conservation (Katz et al., 2010, p. 1172). Including geology concepts, even in other science subjects, can highlight real-world problems where students apply their content knowledge and skills across different academic disciplines to study phenomena and communicate their findings (Burrows et al., 2021). However, for teachers to actually add authentic learning experiences in the field or classroom, they must feel comfortable with the content, technology, and techniques (Almquist et al., 2011).

One helpful method in bridging the divide between science education and how scientists do science is including research scientists in developing curricula and administering PD that

supports the curriculum. Studies by Burrows et al. (2021), Fore et al. (2015), and Passow (2020) revealed that teachers appreciated the interactions with faculty researchers and, to quote one participant, the stories shared by scientists helped them provide new perspectives for students, mainly that science is "messy, unpredictable, and frustrating… but can be deeply rewarding, and deeply human." (Passow, 2020, p. 7).

Effective Science Professional Development

The literature reveals several key features that need to be considered for PD to effectively inspire change. The first aspect is understanding how teachers learn, and researchers agree that firsthand experience and expansion of content knowledge are crucial. Gray (2017) found that inquiry-based courses that combined pedagogy alongside science content improved teachers' self-efficacy based on pre- and post-surveys and stated that "people teach the way they were taught" (p. 69). Other studies concur, asserting that, for educators, "experiential understandings shape their prior knowledge into scripts for teaching" and thus can "limit their views on instruction and professional development" (Subramaniam, 2020, p. 2). Professional developments that had teachers practice activities before taking them to their classes, such as those done in the study by Bestelmeyer et al. (2018), had optimal results, with teachers continuing to utilize the curriculum and borrow materials years after the PD.

Studies agreed that mixed approaches to professional development are effective. These include hands-on activities, field experiences guided by researchers, resource databases, collaboration, reflection, and alignment to standards (Almquist et al., 2011; Burrows et al., 2021; Capps & Crawford, 2013; Huan et al., 2022). Teachers that reflect on their experiences better understand their own styles and teaching philosophies, enabling them to take informed actions,

such as incorporating new strategies and resources (Huang et al., 2022). PD that includes reflection prompts encouraging participants to identify the relationship between their newly acquired knowledge and their previous teaching practices is crucial in promoting teacher change (Capps & Crawford, 2013).

Methodology

There is somewhat of a disconnect between the viewpoints held by science communicators providing the professional development service and science educators who are receiving the service. The science communication group emphasizes the process of science and the use of dialogue to endorse more participation by citizens in scientific realms. Meanwhile, educators tend to be product-focused, particularly on content knowledge and understanding (Kohen & Dori, 2018). Kohen and Dori (2018) described the "deficit model" held by science communicators that adopt a one-direction model of dialogue in which the public or audience is deficient in knowledge. Fore et al. (2015) and Pompea and Russo (2021) extended this to teachers, stating that scientists tend to view teachers and schools as groups that need fixing instead of as experts in their field of education and equal in value to the scientists' expertise. Productive PD needs to be mindful of teachers' awareness of their contexts and their ability to immediately connect the PD experiences to their prior experiences with their students, understanding their students' capabilities and the related limitations (Fore et al., 2015).

There are numerous methods of measuring how a PD impacts a teacher's knowledge, views, and attitudes towards the PD topic (in this case, the critical zone). Content assessments gauge teachers' knowledge, with pre-post assessments providing the most substantial evidence (Huang et al., 2022). A study on 20 teachers conducted by Capps and Crawford (2013) utilized a

pre-post assessment to gauge the impact of their professional development; the researchers concluded that the PD helped improve teachers' content knowledge, although pinpointed limitations, such as the test-retest effect (p. 1971). Beliefs and confidence can be measured with 5-point Likert-type surveys, such as the one used by Gray (2017), and open-ended questions to gather specific feedback, such as "favorite" part of the PD or what they plan to include (Almquist et al., 2011, p. 3). Additionally, characteristics of open-ended responses can be tallied and used to generate word clouds that can quickly and meaningfully visualize the most frequent terms and provide a holistic view of the data (Kohen & Dori, 2018).

Sketches made by participants also provide valuable, if hidden, information. According to Katz et al. (2010), drawings are a "means of visually representing ideas, and had the potential to reveal unforeseen information" (pp. 1178-1179). Soliciting mental representations of complex ideas, such as the critical zone, are built on teachers' prior experiences and can reflect how they have modified their ideas through new knowledge (Subramaniam, 2020). Analyzing these drawings can take two approaches. The sketches can be coded according to a pre-developed scheme, depending on the presence or absence of evidence indicating a category (Katz et al., 2010). Capps and Crawford (2013) and Subramaniam (2020) identified characteristics first, created groupings based on similar content, and revisited and coded the drawings based on the categories.

Studying how a scientist-involved professional development affects teachers involves understanding why environmental and cross-disciplinary education is essential, how teachers process PD and implement its resources, and how the effect of the PD can be measured accurately. The literature shows that intentional and mindful coordination of teacher learning

experiences can have a measurable impact on teachers' content knowledge, beliefs, and actions in the classroom.

CHAPTER THREE

METHODOLOGY

Introduction

The study aimed to investigate how professional development (PD) could affect science teachers' knowledge and confidence towards teaching critical zone (CZ) topics and how their motivations and beliefs towards PD compare to that of the scientists providing the PD. To research these questions, data on the single cohort were collected before and after the PD experience and compared as a mixed-methods, descriptive study. The research methodology for this project received an exemption from Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

Demographics

The PD took place in El Paso, Texas, and was open to teachers in the immediate area, including nearby New Mexico (although all participants taught in Texas schools). Due to grant limitations, the PD program was capped at 30 teachers and limited to those that taught science for grades 6 - 12. The registration process was self-selected, the PD was advertised through different newsletters and social media, and interested teachers signed up. A stipend of $200 was provided to participants, and 15 hours of continuing professional education credits (certification renewal requires 150 hours every five years). Ultimately, three additional teachers were allowed to attend, and we had three teachers not show up, so the total sample size was still limited to 30.

The participant demographics were somewhat aligned with Texas state-wide demographics, the PD participants were 73.3% female versus a state percentage of 75%, and the participants had an average of 11.3 years of experience versus a state average of 11.2 years of experience (Landa, 2022). A bar graph displaying the years of experience can be seen below in Figure 2. This region of West Texas has nine school districts and over 300 schools. However, participation was skewed: only five districts and twelve schools were represented, with seven out of thirty participants from the same middle school.

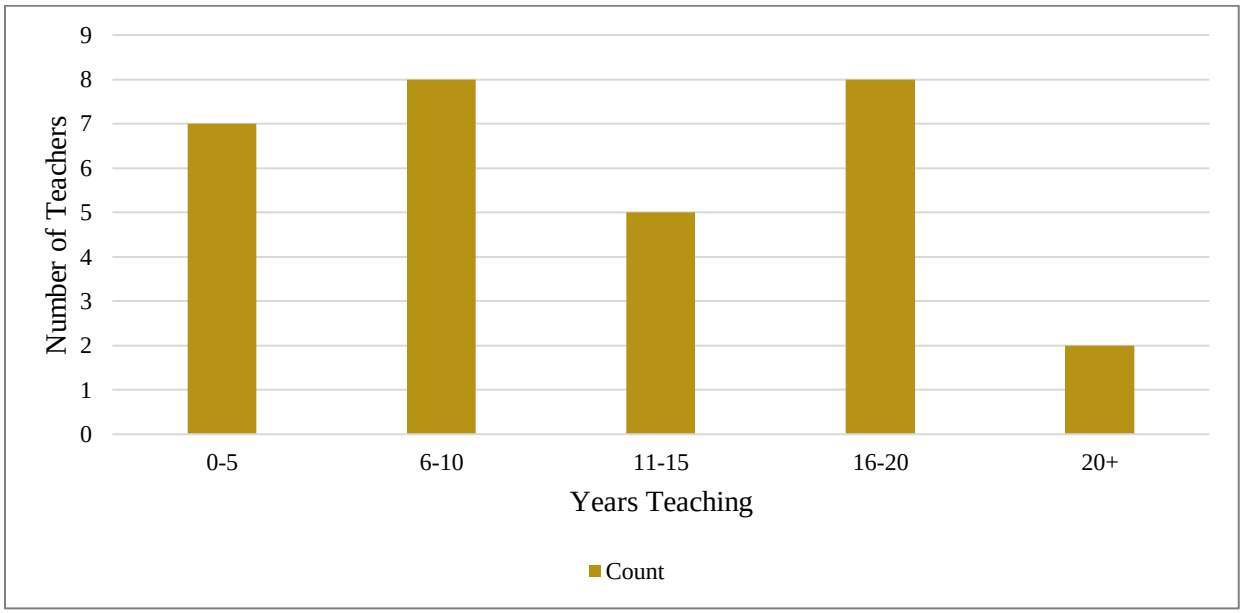

Figure 2. Years of teaching experience held by participants, (*N*=30).

The districts represented by the teachers differed from overall state demographics in multiple aspects. According to statistics reported in the Texas Tribune Public Schools Explorer, in 2021, the represented districts had a higher percentage of Hispanic students, 80%+ compared to the 60% state average, and economically disadvantaged students, 80% plus compared to the 53% state average. The districts also had a much higher percentage of Hispanic teachers, 70%+,

compared to a state average of 30% (Murphy et al., 2022). PD participants were not surveyed on their race or ethnicity.

The participants' grade levels and subject areas varied; 17 teachers reported teaching middle school, while 13 were high school teachers. Eight teachers taught more than one subject or grade level, and physics teachers were the most prominent after middle school, as shown in Table 1 below. Interestingly, only one teacher taught environmental science, a subject that would most explicitly incorporate critical zone concepts.

Table 1. Subjects taught by participants, (*N*=30).

Subject	# Teachers Teaching
Middle School Science (6–8)	17
Physics	7
Chemistry	2
Biology	2
Math	1
Environmental Science	1

Treatment

The treatment occurred throughout a 3-day professional development program from Thursday, November 4th, 2022, through Saturday, November 5th, 2022. The bulk of the PD was a collaboration between myself, my Insights colleagues, and the faculty researchers on the team. Upon registering online, teachers were emailed information on the location of the workshop as well as a link to the voluntary pre-survey and pre-assessment as a Google Form. Teachers were also allowed to complete these instruments on the morning of the first day while waiting for the program to begin. On arrival, teachers were given a folder containing handouts and paper to hold their sketches, thoughts, and ideas. Once most participants were present, the

PD opened with an introduction. The first task was for teachers to use pencils and markers to sketch a “mental model” of what they imagine the critical zone is and highlight related career disciplines. The data collection section will describe the reasoning for using a “mental model” and more details on the prompt.

Thursday and Saturday of the PD took place in several rooms reserved at the local university. Each presenter had a PowerPoint presentation and was asked to share their most recent findings emphasizing how they “do” science, the tools they used, how they communicated their findings, and the applications of their research on small or large scales. They were also encouraged to share personal anecdotes and ideas on how their research focus could be incorporated into the classroom. Teachers engaged in hands-on and collaborative activities taken from one of the three modules or a lesson plan by another CZNet partner. The days ended in a reflection activity, where teachers were given time and reflection prompts to encourage them to process their experiences. The schedule is shown in Table 2.

Table 2. Schedule of the 3-day program.

Thursday	Friday	Saturday
Greet teachers/Model	Travel to Orchard	Field Trip Reflection
Introduction	Travel to Orchard	Hydrologic Systems
Dryland Watersheds	Introduction and Tour	Saturation Activity
Dryland Watersheds	Eddy Covariance Tower	Geophysics (Virtual)
GIS and ArcGIS	Eddy Covariance Tower	Observations Activity
Carbon Stores	Lunch	Observations Activity
Lunch	Lunch	Lunch
Lunch	Subsurface Properties	Lunch
Water Pathway Mapping	Tree Circumference	Greenness Index
ArcGIS Stories	Greenhouse Gas Tag	Biosphere Activity
Carbon Cycle Game	Travel from Orchard	Survey/ Model
Reflect + Info Next Day	Travel from Orchard	Closing Statements

Friday consisted of a field trip to a local agricultural field where research (including data used in one of the modules) was and is currently taking place. Scientists and research students accompanied teachers and engaged them in scientific practices, such as interpreting data collected by a weather tower. Teachers also conducted experiments with simple materials that could be considered “schoolyard science.” Teachers calculated a tree’s biomass by measuring its circumference, recorded temperature at different depths, and collected samples to use on Saturday or take back to their classroom.

The PD program ended with asking teachers to re-draw their mental model of the critical zone again and revisit their related disciplines list in addition to voluntarily taking the post-assessment and post-survey in a Google Form. As teachers completed their sketches, they voluntarily submitted the handouts of the mental models and related disciplines list.

Data Collection and Analysis

Six instruments were developed and administered throughout the professional development to gain a broad perspective on teachers' knowledge about the critical zone, their confidence towards teaching it, and researchers' points of view. Table 3 lists the instruments and their alignment with each research question. On the assessments and surveys, four independent variables were measured for comparison: the teachers' grade level and subjects currently teaching, the certification area(s) held by the teacher, and the number of years the teacher has taught.

Table 3. Data triangulation matrix. Shaded cells indicate that quantitative data was collected from the instrument.

	Main Question	Sub-question 1	Sub-question 2
Drawing and Narrative of CZ	✓		
Related Disciplines List	✓	✓	
Reflection on Drawing, Narrative, & List	✓	✓	
Pre- and Post-Assessment		✓	
Pre- and Post-Survey		✓	✓
Researcher Questionnaire			✓

The pre- and post-assessments (Appendix B) were the same. They consisted of 15 multiple-choice questions that addressed common misconceptions in Earth Science, Physics, Chemistry, and Life Science and were all topics covered by the PD presenters and activities. The questions were developed, validated, and published by an NSF-funded Harvard project called Profession Development Models and Outcomes for Science Teachers (PDMOST). The questions were validated by Harvard and Smithsonian researchers and were used to evaluate the effectiveness of various professional development programs and their features. Teachers'

performance on the assessment provided quantitative data that would reveal the extent of their knowledge of these subjects and if/how it changed after the PD experience. For each question, the percentage answered correctly was calculated and compared.

The Pre-Survey (Appendix C) contained six open-ended questions to gauge teachers' knowledge of the scientific process and some of their attitudes and beliefs about teaching CZ concepts. The Post-Survey (Appendix D) contained several Likert-type statements and open-ended questions to assess the PD's quality and some of the same questions as the pre-survey to determine if there was a change in attitudes or beliefs. The qualitative responses, combined with the assessments, could support conclusions related to sub-question 1, which aspects of the PD impacted teacher learning, and if the teachers themselves were aware of the effect. I collaborated with one of the program's co-principal investigators to ensure that these questions were valid; we each wrote questions, and she and other colleagues reviewed them and approved them.

Using the mental model allows teachers to creatively express their thoughts about the concept of the critical zone and their prior experience with it (Subramaniam, 2020). The term "mental model" was chosen instead of a more detailed prompt like "scientific model of the interactions within a critical zone" because the second prompt could potentially restrict teachers from sharing their interpretation of the concept or discourage them from attempting to sketch if they did not feel they knew enough to describe those interactions. Inspired by the methodology used by the published studies in the literature review, teachers were also asked to write a narrative describing "what is happening" in the sketch, hopefully allowing my interpretations to be more valid. The handouts can be seen in Appendix E.

Visual representations of the critical zone include well-defined features, and as such, a deductive approach can determine accuracy, while an inductive approach can reveal actual teacher takeaways. Each drawing was analyzed for characteristics such as: to what extent below and above the surface the CZ extends, what earth systems or features are included or labeled, what abiotic or biotic factors are incorporated, and other categories that reveal themselves upon analysis. On the last day of the PD, teachers drew the critical zone and narrative again and identified what features they changed and why they chose to change them. The accuracy of the drawing triangulated with their narrative of the drawing and performance on the assessment would reveal how teachers' knowledge has changed and in what ways. Their responses to why they changed their sketches would hopefully point to what aspects of the PD had the most significant impact on their mental representation of the CZ.

Another instrument used to provide quantitative data related to teachers' concepts of the critical zone is a list of career disciplines or fields that teachers select as related to studying the critical zone. Teachers and science communicators alike sometimes present scientific knowledge and research narrowly without integrating other research focuses and skills (Burrows et al., 2021). However, geology is a subject that encompasses all scientific fields as well as engineering and anthropological ones. A list of disciplines (Appendix F) was given to teachers, and they were asked to highlight the ones they thought were related to studying the critical zone. Teachers were prompted to repeat the task on the last day. An increase in the number of related disciplines could indicate that the teacher realized how they could incorporate CZ concepts into their own subject matter. Triangulating the data collected from the mental models and related disciplines in

conjunction with their ideas reported in the survey will hopefully support stronger conclusions concerning how each participant's understanding of the CZ changed and in what ways.

Finally, on the Monday after the PD, an open-ended questionnaire (Appendix G) was sent to the faculty researchers and graduate students who participated in the PD regarding their motivation and experience with education and outreach efforts. The reasons listed were compared to those listed by the teachers to see if there were similarities or disparities regarding the desired outcomes of the PD and their experiences with science education. The deadlines and dates for treatment and instrument implementation are shared below in Table 4.

Table 4. Instrument and treatment schedule.

Activity	Category	Date
Registration + Pre-Assessment + Pre-Survey	Instrument	October 2022
PD Day 1: Presentations	Treatment	November 3rd, 2022
PD Day 1: Drawing + Narrative	Instrument	November 3rd, 2022
PD Day 1: Related Disciplines List	Instrument	November 3rd, 2022
PD Day 2: Field Trip	Treatment	November 4th, 2022
PD Day 3: Presentations	Treatment	November 5th, 2022
PD Day 3: Re-Drawing + Narrative Reflection	Instrument	November 5th, 2022
PD Day 3: Related Disciplines Reflection	Instrument	November 5th, 2022
PD Day 3: Post-Assessment + Post-Survey	Instrument	November 5th, 2022
Researcher Questionnaire	Instrument	November 7th, 2022

CHAPTER FOUR

DATA ANALYSIS

Results

Change in Mental Models of the Critical Zone

The study aimed to observe how teachers' drawings of the critical zone (CZ), knowledge of it, and confidence toward teaching changed after a three-day professional development workshop. Assessments and surveys were done virtually, while drawings and academic discipline lists were completed on physical handouts. The handouts were picked up at the end of the PD, and teachers (N=30) were prompted to submit their papers voluntarily. Ultimately, 13 complete and ten incomplete sets were collected, resulting in 14 before models, 23 after models, 15 before lists, and 21 after lists.

Drawings were analyzed and manually coded in two rounds using the qualitative data analysis software NVivo. First, defining characteristics of the CZ were identified and looked for in each illustration: living things, atmosphere, rocks, and water. Multiple representations of the same thing, like rainwater and groundwater, were counted as one. The atmosphere was counted if the sketch included gas molecules, wind, or an interaction with another feature. Plants, animals, and humans were coded individually. The percent of drawings that had each characteristic before and after the PD can be seen below in Figure 3. In the before pictures (n=14), rocks, water, and plants were most prevalent and included in over 50% of the drawings. This trend also emerged in the after drawings (n=23), with atmosphere represented in more than 70% of the drawings. Other than plants, animals saw a slight decrease in representation, while

people saw a slight increase. Atmosphere saw the most significant jump, growing from being included in only 21% of drawings to 74%. This increase may have been due to how often the atmosphere was addressed throughout the three days. Two presentations covered greenhouse gases and using "greenness indices" to indicate carbon storing; two activities explored carbon cycling throughout the critical zone and releasing carbon dioxide from rocks.

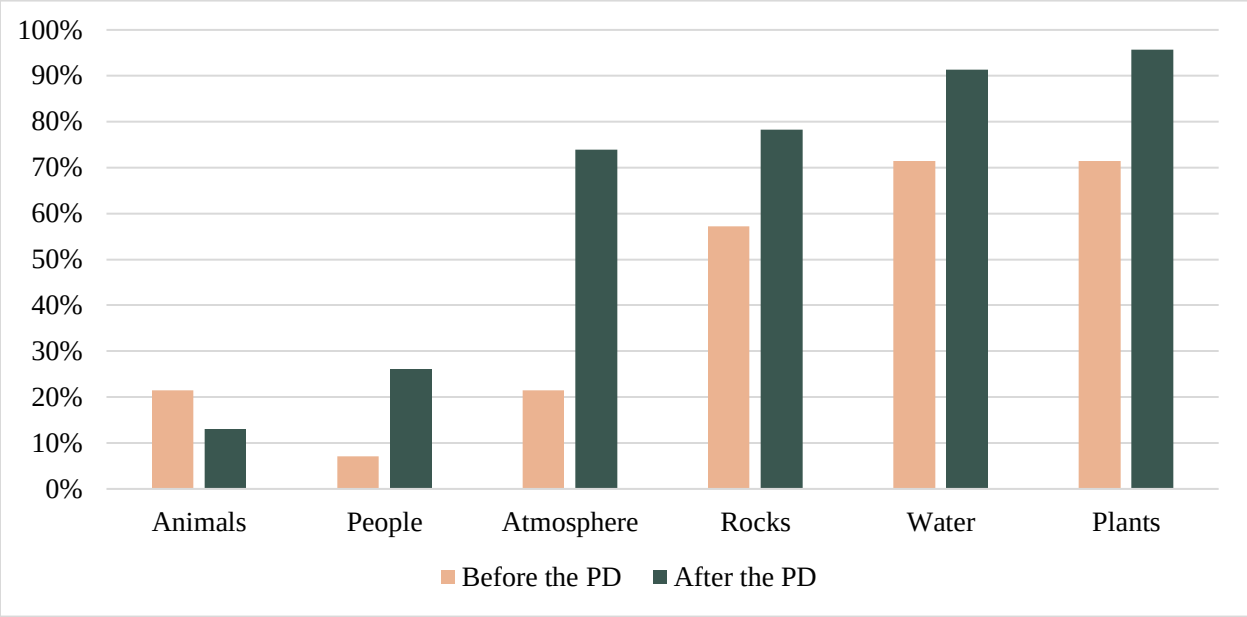

Figure 3. Percent of components included in the models. Data shown includes drawings made by teachers before the PD (*n*=14) and after the PD (*n*=23).

When asked to reflect on why their drawings changed, teachers (*n*=16) referenced increased content knowledge, with 56% mentioning learning, understanding, seeing, and knowing. One teacher wrote, "I understand/ became knowledgeable on the critical zone." Additionally, 50% stated that they saw how topics were connected or related, illustrated by this quote: "I have better understanding. My first image was more in connection of only pollution. Where now I understand its a variety of connections to our land and how it connects to many aspects of life."

As the drawings were analyzed, other features revealed themselves, including if color was used, what perspective the pictures were done in, and if specific interactions between spheres were included or labeled. The vast majority of before and after drawings (*n*=37) were from a sideways perspective of an environment, more than 60%. The remaining drawings represent a top-down environment, a list of words, or disconnected sketches/icons. The number of interactions increased from only 50% of pictures including them to 87% after the PD. Several before-and-after sketches encompass these changes and are shown below in Figure 4.

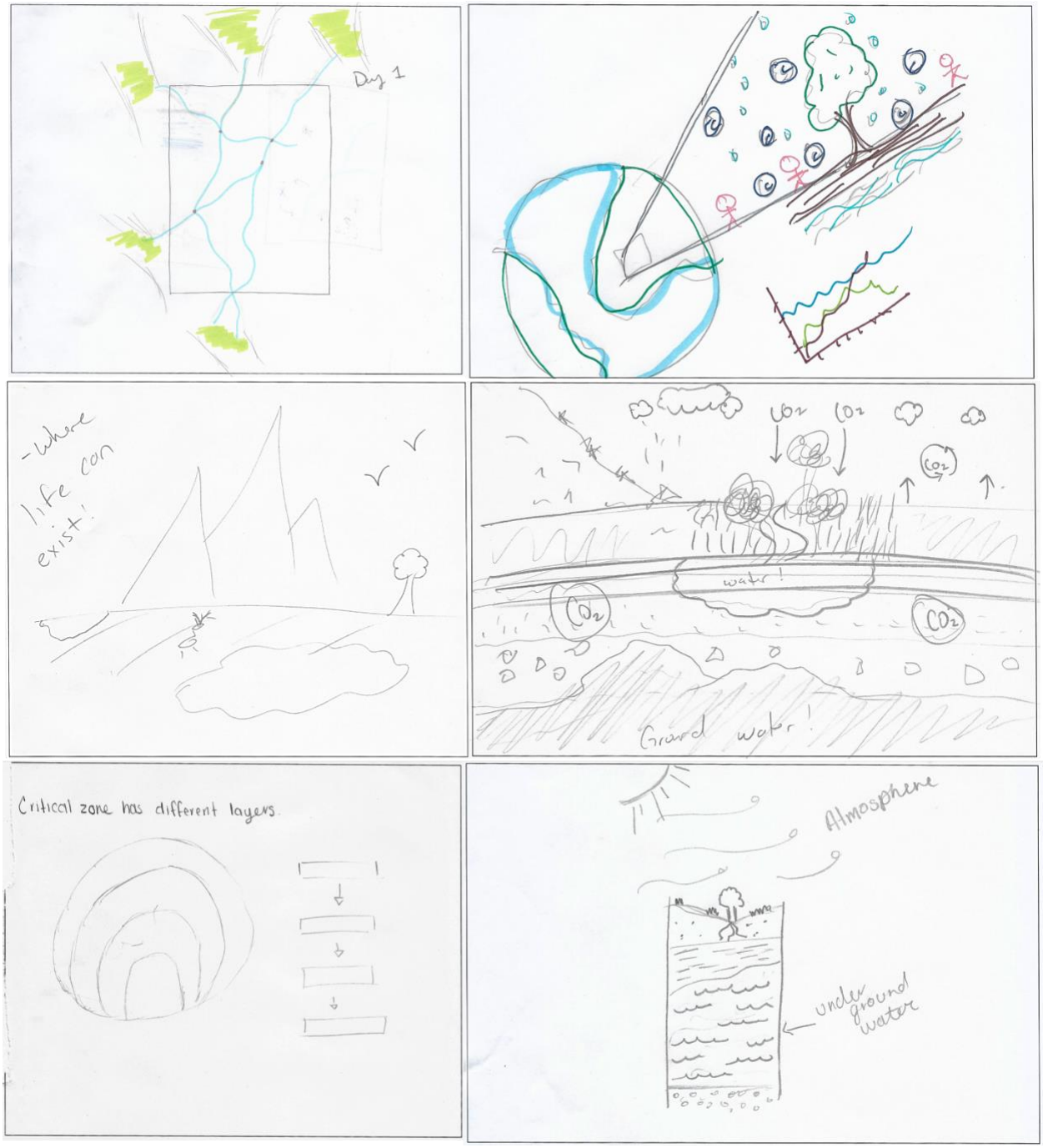

Figure 4. Three model samples were selected to represent changes in the drawings. Drawings on the left were done before the PD, and drawings on the right were done after.

The top sample shows color, a movement from a top-down view to a slice view, and the inclusion of molecules that appear to represent the atmosphere. The middle example has a before drawing that includes many CZ characteristics, while the after-drawing has the addition of arrows that can represent a movement of matter. The description accompanying this drawing accurately describes the CZ and reads, “Showing all aspects of the critical zone from highest points to where life is and interacts. The highest points can be mountains and lowest is where the ground water ends.” The bottom sample has a before drawing that references layers but is unlabeled, making it unclear what constitutes those layers and how far they extend. The after-drawing features all the CZ's abiotic and biotic components and labels the extent of groundwater below.

The academic discipline lists asked teachers to highlight careers they thought were related to studying the critical zone. There was an increase in the number of disciplines selected, shown in Figure 5, from an average of 16 out of 33 disciplines before the PD to 25 out of 33 disciplines after, with five participants circling all the disciplines. Earth sciences was the only discipline selected by all participants in the before lists, including the sole discipline selected by 2 participants before the PD. This trend could have been due to how the PD was advertised; the “slice” of Earth imagery may have influenced teachers’ initial concepts of the critical zone. After the PD, it was joined by several other disciplines that were also picked by all participants, including agriculture, economics, education, geography, life sciences, mathematics, and physics. The connections among these fields were reinforced throughout the session, including the field trip to the farm, data collection and calculations, and presentations by a physicist and biologist. After the PD, performing arts and gender studies were the least selected by participants, 45% and

35%, respectively. One participant explained their increase from 8 disciplines to 22: “I included way more subjects because the critical zone is so complex it requires teams from all different backgrounds.”

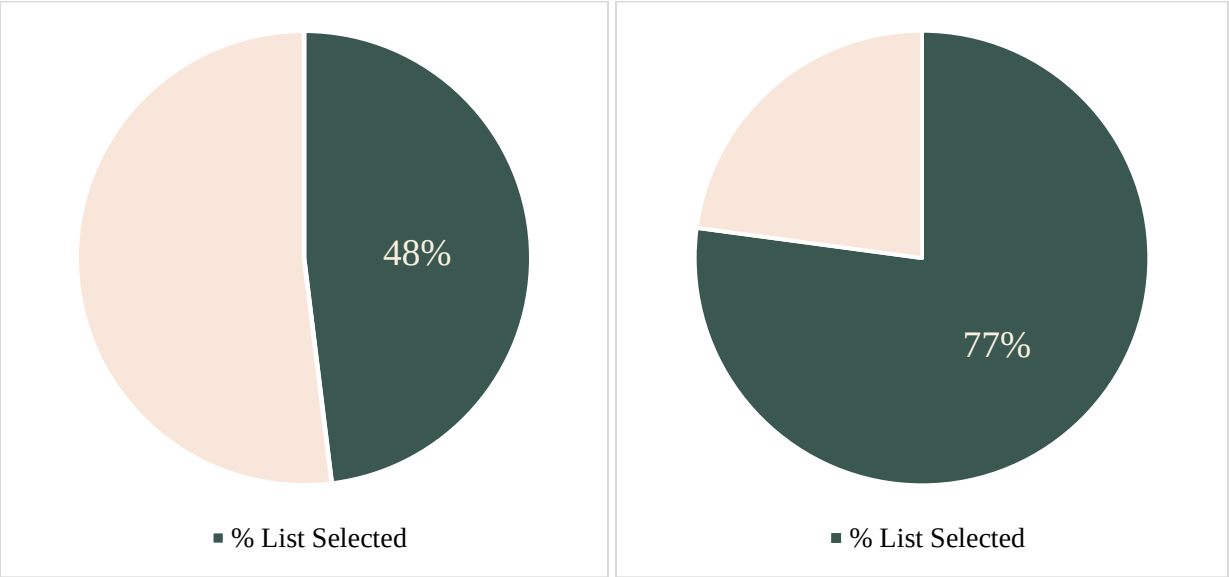

Figure 5. The percent of academic disciplines highlighted as related to studying the CZ. The left chart shows the percent selected before, and the right chart shows the percent selected after the PD.

On average, participants selected 12 more disciplines after they experienced the PD. One teacher justified their decisions on the before-list: “I feel as though psychology is not related to the critical zone because it is a human-based science while the critical zone is far more based in Earth Science.” Afterward, when they circled all the disciplines, they explained, “All disciplines above are needed, as they all can contribute to the research, advocacy, and education of these zones.” The categories that experienced the most significant increase from before and after were law, from being selected by only 3 participants to 17 participants, and computer science, which increased from being picked six times to 19 times.

Change in Content Knowledge and Confidence

While the drawings aimed to reflect participants' idea of the critical zone as an entire concept, their understanding of specific topics was measured with the same 15-question multiple-choice assessment before and after the PD. A Likert-type and open-ended survey aimed to learn more about their confidence level with teaching geology concepts and what aspects of the PD impacted them. The average score increased from 48% before the PD to 60%. The before average was brought down by an outlier score of 6%; without it, the average increases to 50%. The spread of results can be seen in Figure 6 below.

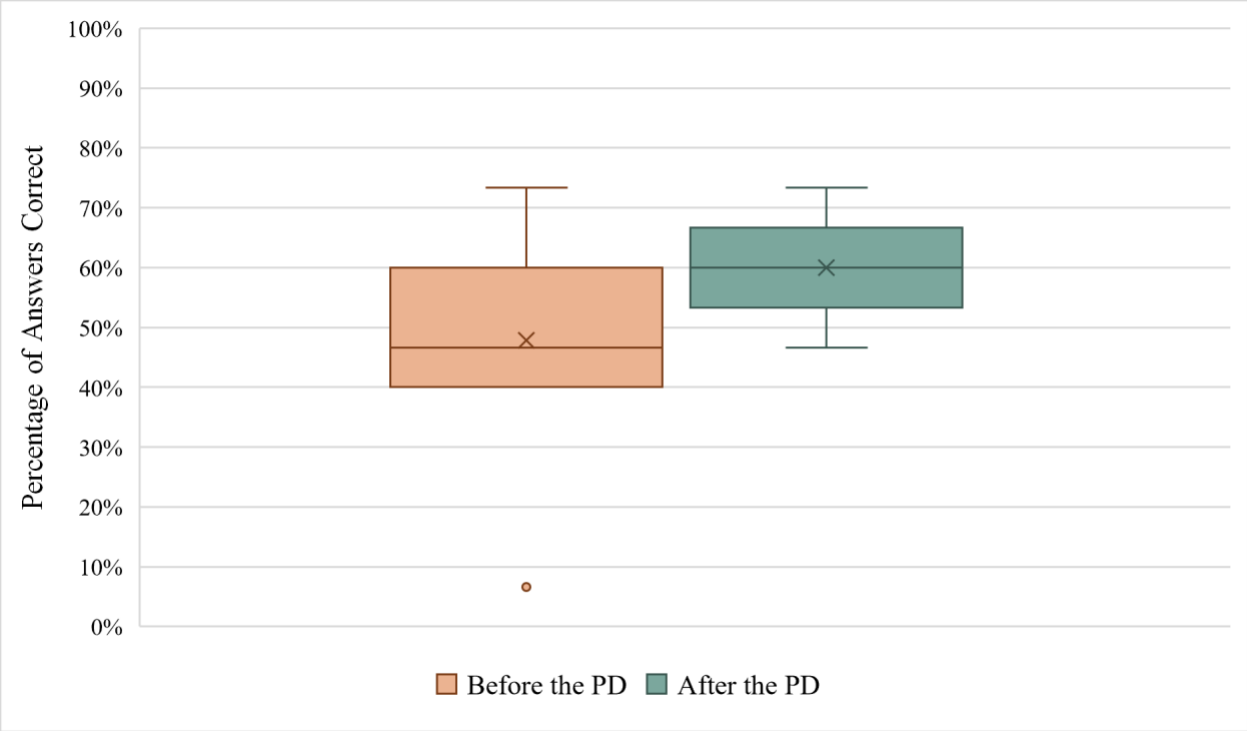

Figure 6. The range of knowledge assessment scores. The data shown is from before the PD (*n*=11) to after the PD (*n*=12). After the PD, the median and mean (indicated with an X) were higher, and the range of scores was smaller. The highest score possible was 100%, and the lowest was 0%.

Several questions showed increased correct responses, particularly those concerning sound waves, erosion, and the water cycle. Almost all participants, 11 out of 12, got the question concerning the water cycle correct, perhaps because the water cycle was explicitly addressed in a lesson demonstration that had teachers model the journey of water through the nearby environment. Others saw a decrease in correct responses, including the flow of matter and energy, climatology, and rocks & soils. Very few people got the question about the flow of matter and energy correct; only one participant responded correctly, and zero participants answered the climatology question correctly. This was an interesting result because teachers responded correctly that the sun contributes the most energy to Earth's surface but incorrectly identified fossil fuels as the most important impact on Earth's climate and not energy transferred from the sun. This result could represent how difficult it can be to rectify misconceptions if the approach is not pointed and intentional. One question was almost the same in the percent correct response: it addressed where to find groundwater. The changes can be seen in Figure 7.

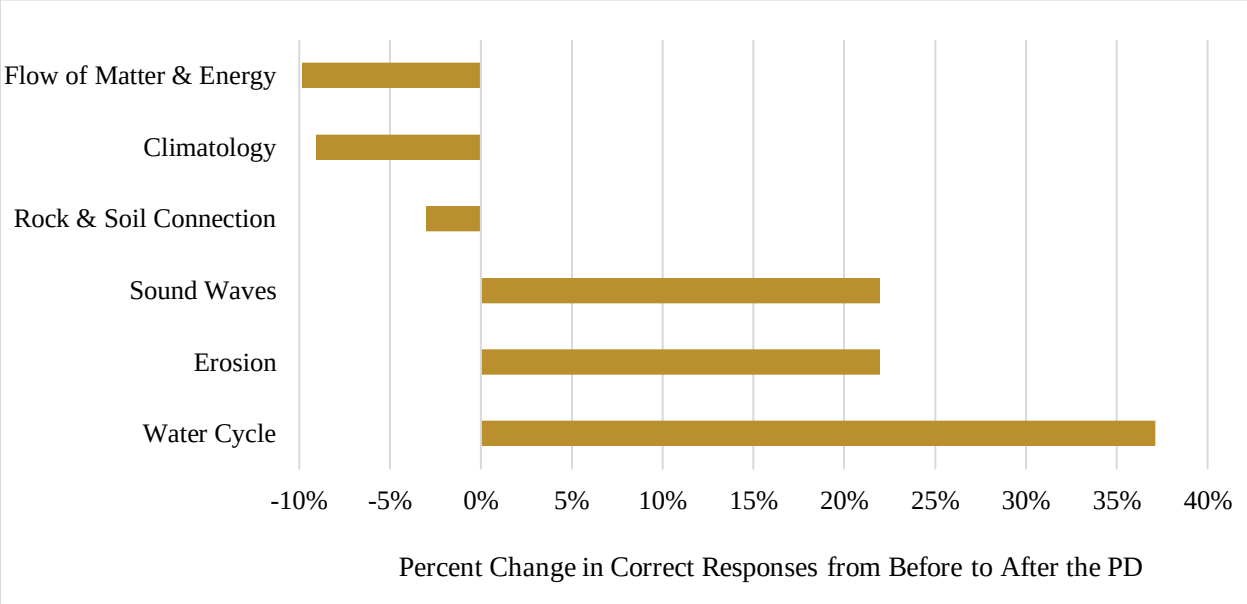

Figure 7. Changes in percent correct response for individual questions. Data shows the change from before the PD (*n*=11) to after the PD (*n*=12). Positive changes indicate that the question received more correct responses in the post-assessment.

The modest increase in scores correlated with a reported increase in content knowledge; all participants agreed or strongly agreed that the program content improved their knowledge. All but two teachers (*n*=13) agreed that they learned enough about the CZ to feel comfortable incorporating CZ concepts into their classes. The responses can be seen in Figure 8. When asked how participating in the PD resulted in increased understanding, teachers gave credit to the hands-on activities "…hands on where you understand what you are doing and be able to relate it the classroom" and that the information was relevant "…instructors and activities were insightful and in-depth, giving great examples for use in my classroom."

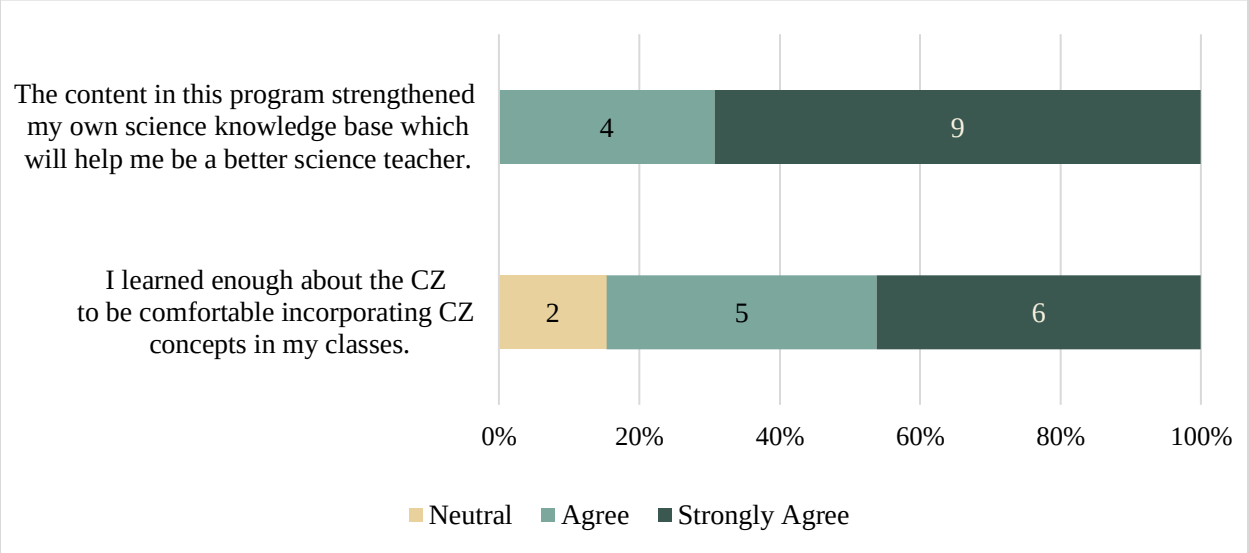

Figure 8. Teachers' responses to learning Likert-type questions, (*n*=13). The two statements concern what they learned in the PD.

The Likert-type survey also asked about teachers' confidence levels, and their responses to questions concerning their confidence and plans can be seen in Figure 9. Interestingly 85% of teachers agreed or strongly agreed that, as a result of attending the PD, they felt more prepared to include field activities in their classroom, more confident to use new technologies, and planned to directly use the CZ lessons they experienced or develop their own. All teachers reported that the PD inspired them to use various instructional strategies.

On the survey, teachers shared their comfort level with teaching geology concepts. Before the PD, their concerns included lack of content knowledge and where to find resources, "Not comfortable, I do not have a lot of background knowledge on the topic. I also do not know where to find resources I can use in a lab." as well as how to connect geology to their subject area, "I would love to do it but I find it challenging to spiral the content in a physics class." After the PD, teachers shared an increase in comfort level, "more comfortable now than I was before coming to this training. I do not have any major concerns," while still recognizing their

challenges: “My only concern is gathering the materials.” and “There is a limited amount I can teach.”

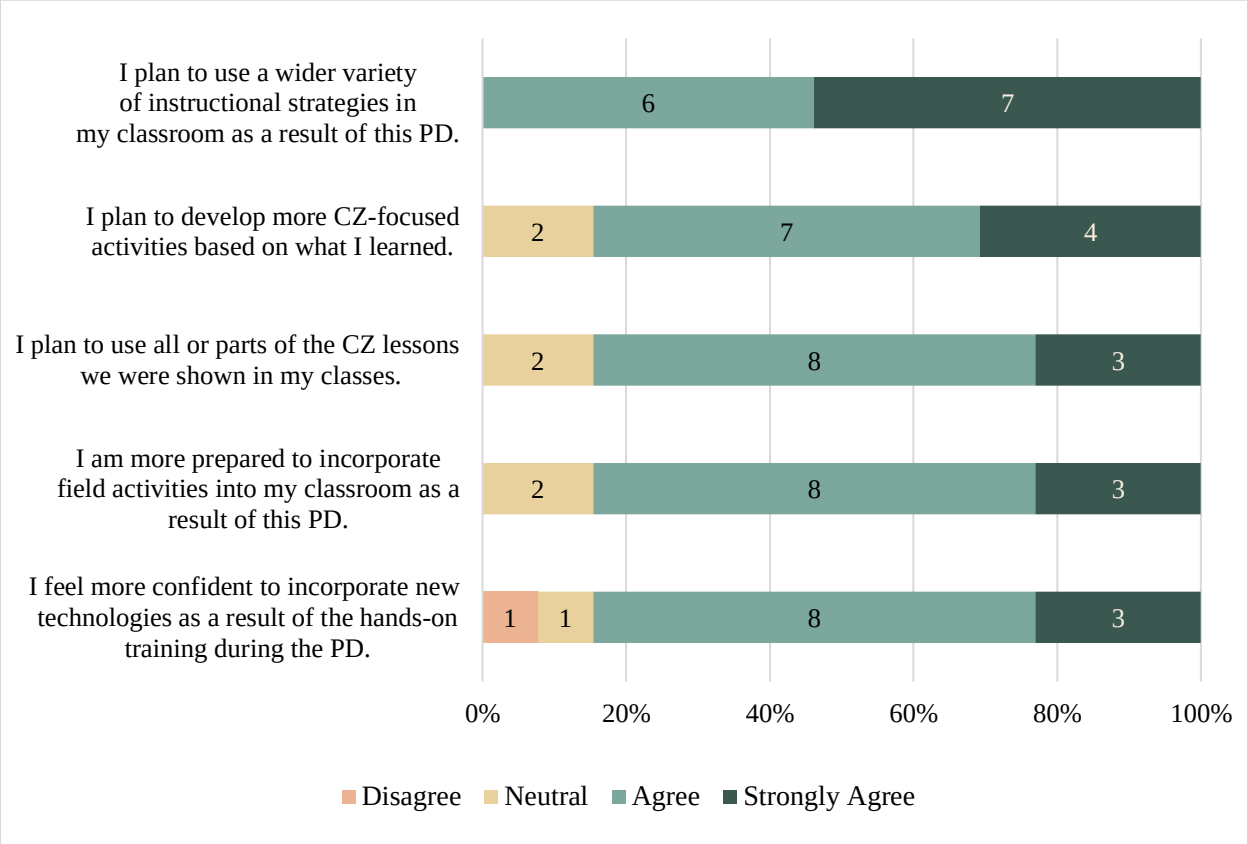

Figure 9. Teachers’ responses to confidence Likert-type questions, (*n*=13). Statements concern their confidence and plans.

Motivations of Teachers and Researchers

Both teachers (*N*=30) and researchers (*N*=9) were asked open-ended questions about their reasoning for participating in professional development/outreach and the benefits received from that participation. Researchers included co-principal investigators from the Critical Zone Dryland grant and a graduate student who assisted with developing and leading the field trip activities. Six researchers and 12 teachers responded to these specific questions. The responses

were analyzed and coded according to themes that emerged as similar answers. Teacher and researcher motivations are collected and shown in Figure 10.

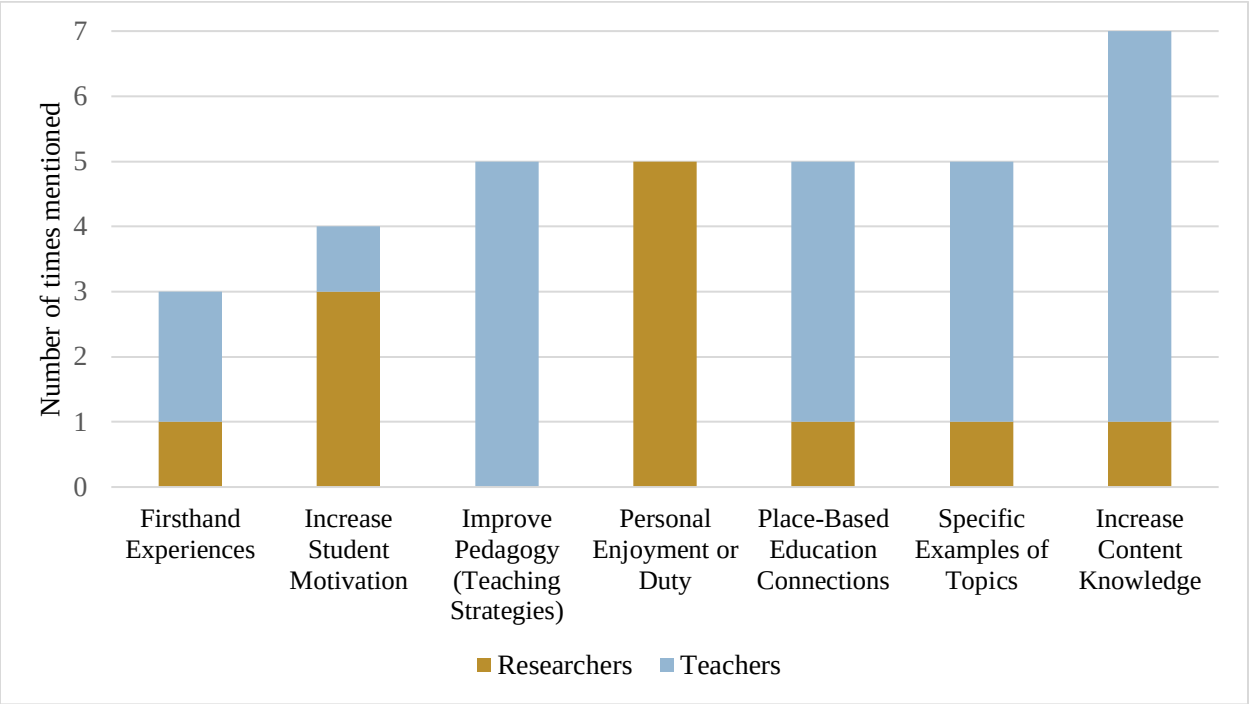

Figure 10. Reasons for participating in the professional development. Data are shown as reported by Teachers (*n*=11) and Researchers (*N*=6).

The teachers' most common reasons for attending the PD mentioned were to increase their content knowledge and improve their pedagogy by learning about new teaching strategies. Also mentioned was a desire to enhance their ability to connect content to the environment and community or to glean specific examples of topics that could be tied to their subject matter. One teacher reported: "I do not have background knowledge on the topic. I believe I can benefit from learning about this topic as I can incorporate it into my classes. I will be able to bring in concrete examples of topics I have personally experienced." Another teacher states, "I look for ways to make the content and the needs of the community relevant to my students." The researchers' responses varied. Most were motivated by personal reasons, either due to personally enjoying

participating in outreach or a sense of duty to share the knowledge from their research "…duty to the community as a research scientist using public funds". They also shared a desire to help teachers, believing that their efforts to improve student motivation. "Getting teachers and their students motivated to learn about their environment."

There were also some commonalities in the reported and perceived benefits of attending professional development; both groups had an equal amount of increasing content knowledge as a benefit from PD. When asked how PD improves their teaching, many participants reported finding things relevant to their subjects and students, with a desire for specific hands-on activities, resources, and lab experiments mentioned numerous times. One teacher wrote, "Engaging professional development has been very successful. Hands-on activities have been very helpful in incorporating in my classroom." The perceived benefits shared by the researchers also varied; many mentioned making connections between the university, other partners, and the schools, while only one teacher said networking explicitly with other teachers. Two researchers made connections from teacher to student, with one researcher explaining, "Hopefully they are inspired to include these activities in this class - and it makes their jobs a little easier."

CHAPTER FIVE

CLAIMS, EVIDENCE, AND REASONING

Claims From the Study

My focus question asked how participation in the professional development (PD) would affect teachers' mental models of the critical zone (CZ); this was measured by having them draw pictures of the CZ and identify academic disciplines related to studying the critical zone. I found that their ideas grew in complexity and accuracy by including the different components of the CZ and how they interact with one another. This conclusion is supported by comparing how many components of the CZ (air, water, rocks, and living things, including plants, animals, and people) were included in the before and after drawings, as seen in Figure 11 below. Before the PD, an average of about two out of four CZ components were included, with only 1 out of 14 including all parts. After the PD, this increased to an average of three out of four components included, with 14 out of 23 including all four.

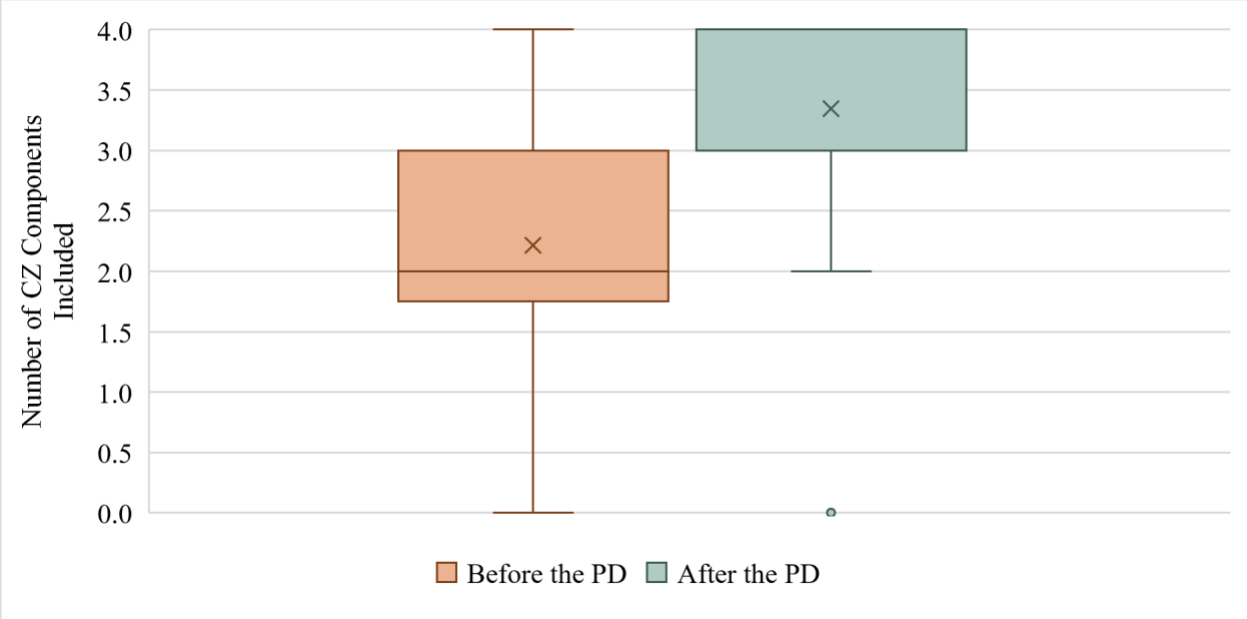

Figure 11. The range of the number of CZ components included in drawings. The data shown is from before the PD (*n*=14) to after the PD (*n*=23). After the PD, the median and mean (indicated with an X) were higher.

My first sub-question concerned how participation in the PD impacted teachers' knowledge of CZ concepts and how confident they felt about teaching it. From their perspective, teachers' felt that their knowledge and confidence increased, and the results from their assessments and drawings agreed with this assessment. The reflection, survey, and assessment results support this conclusion. While all teachers who took the post-survey agreed that they were unfamiliar with the critical zone before the PD (*n*=13), 12 out of 13 teachers agreed that they learned enough to feel comfortable incorporating related concepts into their classroom. Their reported comfort level also increased when asked an open-ended question about how comfortable they were teaching geology topics in their classroom; 67% replied with a comfortable response, compared to 42%. Their comfort level was supported by increased knowledge, with 12 out of 15 questions answered correctly after the PD.

My final sub-question was how teachers and researchers' motivations for attending the PD compared to each other. I found that both groups overlapped on the topics of improving teachers' knowledge and supporting student learning. This conclusion is supported by how teachers and researchers agreed on five of seven reasons for participating in a PD. At the same time, the two distinct motivations that were not shared are directly related to their professions. Teachers strove to improve their pedagogy, as required to keep their certification current, and researchers recognized that outreach is necessary for their grant. The teachers' valued the researchers' expertise, stating "the presenters were all knowledgeable in their specific field" and "they do have enough educational background to help you understand the information." In surveys, both groups expressed a desire for PD content to align more closely with the teachers' needs. One teacher stated that the "Lecture needs to be student-friendly." These sentiments were shared by the researchers who felt they could have been better prepared for their contribution, sharing, "I would have loved to know more about the teachers - what level do they teach, what classes, what is their context, what works for them" and "I would be interested in hearing a bit more from the teachers about what would be most beneficial to them."

Value of the Study and Considerations for Future Research

This study was valuable to many Critical Zone Hub partners and could have been improved in many ways. First, teachers could obtain continuing education hours and be exposed to contemporary research and connections; every survey respondent shared specific activities and content they would take back to their classroom. Secondly, the grant, in which Insights Science Discovery is a partner, requires education and outreach efforts for the public and educational community. Knowing where and how a PD is successful at affecting student learning helps all

groups that offer this type of service. The details of the professional development and some of its initial findings were shared at CZ Net Education & Outreach meetings with attendees from across the United States. Other members were inspired, and one group asked us more questions as they planned their professional development for teachers in their community.

The professional development itself went well; there were hiccups with technology, timing, and finding the correct parking area on a sprawling farm! The day of the field trip experienced a cold front, but the sun allowed everyone to withstand and stay engaged. Despite this, the staff at Insights (including myself) and the researchers worked well together, maintaining communication and thinking on our feet to address obstacles as they came up. While changes should be made, the people involved were the best part and proved that the partnership between the CZ Net Dryland Hub and Insights should endure and continue to be successful.

Several things could have been improved. Less than half of the teachers responded to the survey even though ample time was provided during the PD. While there was a stipend, receiving it was contingent on attendance and not on completing or submitting any of the instruments. There are several ways I could increase the response rate. First, the assessment, Likert-type items, and open-ended survey were combined in one online survey, making it quite long to complete. It is possible that several teachers started the survey but did not complete it. Also, while it was emphasized that the instruments were voluntary, I could have explained more about how important it was to my research and how they would be applied to future PD offerings by the CZ Net and Insights. Finally, teachers were not informed that their Mental Model and Discipline List handouts would be picked up at the end of the PD. As such, some teachers had taken detailed notes on their handouts and were reluctant to turn them in because they would be

lost- a headline at the top of the paper reading "DO NOT TAKE NOTES" would have deterred this. I took pictures of some of them, but it was not an efficient method for gathering data.

Impact of Action Research on the Author

I conducted this research study during a strange time in my life, a period of transition. I was stepping away from my position as Education Curator at Insights and starting a new job as an Instructional Designer at Arizona State University. I would not collaborate with research faculty to provide professional development for teachers anymore; I was now in a position of assisting research faculty with developing their pedagogy to improve student outcomes. Although the subject matter, the age range, and the target audience have changed, I still find myself applying what I have learned from this study to my new job. One major takeaway is how I try not to make assumptions about professors' experience with pedagogy, as many have not had any training in how to support active learning, metacognition, or student motivation. Instead, I could learn about the professor just like we learn about our students, by asking questions about their prior experiences, listening, and validating them and their efforts. Then, by presenting exemplary courses and data, I could reveal how these strategies are proven to positively affect student learning. Another impact is how learning outcomes can be determined in various ways; a multiple-choice assessment might not give enough opportunity for someone to show the depth of what they know in addition to revealing misconceptions. Finally, my big lesson was that educators are short on time but big on caring about students. They desire directed, actionable items that could be used immediately, and experiencing a teaching strategy or technology firsthand effectively influences change. Finally, getting to know an educator, their prior knowledge, goals, and context allow people in my position to support them better.

REFERENCES CITED

Almquist, H., Stanley, G., Blank, L., Hendrix, M., Rosenblatt, M., Hanfling, S., & Crews, J. (2011). An integrated field-based approach to building teachers' geoscience skills. *Journal of Geoscience Education*, *59*(1), 31–40. https://doi.org/10.5408/1.3543926

Bestelmeyer, S., Grace, E., Haan-Amato, S., Pemberton, R., & Havstad, K. (2018). Broadening the impact of K–12 science education collaborations in a shifting education landscape. *BioScience*, *68*(9), 706–714. https://doi.org/10.1093/biosci/biy088

Burrows, A. C., Borowczak, M., Myers, A., Schwortz, A. C., & McKim, C. (2021). Integrated Stem for teacher professional learning and development: "I need time for practice." *Education Sciences*, *11*(1), 21. https://doi.org/10.3390/educsci11010021

Capps, D. K., & Crawford, B. A. (2013). Inquiry-based professional development: What does it take to support teachers in learning about inquiry and nature of science? *International Journal of Science Education*, *35*(12), 1947–1978. https://doi.org/10.1080/09500693.2012.760209

Fore, G. A., Feldhaus, C. R., Sorge, B. H., Agarwal, M., & Varahramyan, K. (2015). Learning at the Nano-level: Accounting for complexity in the internalization of secondary STEM teacher professional development. *Teaching and Teacher Education, 51*, 101–112. https://doi.org/10.1016/j.tate.2015.06.008

Gray, K. (2017). Assessing gains in science teaching self-efficacy after completing an inquiry-based Earth science course. *Journal of Geoscience Education, 65*(1), 60–71. https://doi.org/10.5408/14-022.1

Huang, B., Siu-Yung Jong, M., Tu, Y.-F., Hwang, G.-J., Chai, C. S., & Yi-Chao Jiang, M. (2022). Trends and exemplary practices of STEM teacher professional development programs in K-12 contexts: A systematic review of empirical studies. *Computers & Education, 189*, 104577. https://doi.org/10.1016/j.compedu.2022.104577

Katz, P., McGinnis, J. R., Hestness, E., Riedinger, K., Marbach-Ad, G., Dai, A., & Pease, R. (2010). Professional identity development of teacher candidates participating in an informal science education internship: A focus on drawings as evidence. *International Journal of Science Education*, *33*(9), 1169–1197. https://doi.org/10.1080/09500693.2010.489928

Kohen, Z., & Dori, Y. J. (2018). Toward narrowing the gap between science communication and Science Education Disciplines. *Review of Education*, *7*(3), 525–566. https://doi.org/10.1002/rev3.3136

Landa, J. B. (2022). Employed teacher demographics 2015-16 through 2021-22. https://tea.texas.gov/sites/default/files/employed-teacher-demographics-2022.pdf.

Murphy, R., Daniel, A., Cai, M., & Lau, E. (2022). Texas public schools explorer. https://schools.texastribune.org/.

Passow, M. J. (2020). Earth2Class: An effective and easily duplicable model for providing a broad impact of cutting-edge science, teacher professional development, and inspiration for high school students. *Geosciences*, *10*(10), 407. https://doi.org/10.3390/geosciences10100407

Pompea, S., & Russo, P. (2021). Ten simple rules for scientists getting started in science education. *PLOS Computational Biology*, *17*(12). https://doi.org/10.1371/journal.pcbi.1009556

Rasmussen, C., Troch, P. A., Chorover, J., Brooks, P., Pelletier, J., & Huxman, T. E. (2010). An open system framework for integrating critical zone structure and function. *Biogeochemistry*, *102*(1-3), 15–29. https://doi.org/10.1007/s10533-010-9476-8

Subramaniam, K. (2020). Prospective teachers' prior knowledge of science instruction in informal settings: A place-based education analysis. *International Journal of Educational Research*, *99*. https://doi.org/10.1016/j.ijer.2019.101497.

Watermeyer, R. (2015). Science engagement at the Museum School: Teacher perspectives on the contribution of museum pedagogy to science teaching. *British Educational Research Journal*, *41*(5), 886–905. https://doi.org/10.1002/berj.3173

Weeks, F., & Oseto, C. (2018). Interest in insects: The role of entomology in environmental education. *Insects*, *9*(1), 26. https://doi.org/10.3390/insects9010026

APPENDICES

APPENDIX A

MONTANA STATE UNIVERSITY IRB EXEMPTION

Hello Huffman, Sue,

Your protocol was reviewed by the IRB and has been approved.

PI: Huffman, Sue
Approval Date: 11/2/2022
Title: Effect of Professional Development on Teachers' Mental Models of the Critical Zone

Protocol #: 2022-342-EXEMPT
Review Type: Exempt Review
Expiration Date: 11/2/2027

APPENDIX B

PRE AND POST ASSESSMENT

PRE- AND POST-ASSESSMENT

Grade level(s) currently teaching:
Subject(s) currently teaching:
Certification area(s):
Number of years teaching:

1. The most complete description of the water cycle refers to the processes by which water:
   a. freezes and melts.
   b. evaporates and condenses.
   c. sublimates and deposits.
   d. moves through the environment.
   e. is used by plants, animals and humans.
2. What is a major reason why ocean water is salty?
   a. Cargo from sunken ships dissolves in the ocean water.
   b. Rivers carry dissolved minerals to the ocean.
   c. Humans dump pollutants into the ocean.
   d. Animals that live in the ocean deposit their waste in the water.
   e. Sodium chloride forms most of the minerals in ocean floor rock.
3. In which of the following areas is it possible to find groundwater?
   a. Deserts.
   b. Rain Forests.
   c. Plains.
   d. Only b and c.
   e. a, b and c.
4. What could scientists expect to find at the center of the Earth if they could drill to it?
   a. Magma (molten rock).
   b. Solid rock, such as granite.
   c. Iron and other metals.
   d. A hollow chamber.
   e. Scientists have no idea what's at the center of Earth.
5. Which time sequence best shows how rock and soil are related?
   a. soil --> clay --> rock
   b. clay --> soil --> rock
   c. rock --> clay --> soil
   d. clay --> rock --> soil
   e. soil --> rock --> clay
6. Which of the following affects the breakdown of surface rock?
   a. Plants.
   b. Animals.
   c. Humans.
   d. Only two of the above.
   e. a, b and c.
7. Which of the following is not energy in a scientist's view?
   a. Light.
   b. Electricity.
   c. Weight.
   d. Sound.
   e. Heat.
8. Which of the following sources do you think contributes the most energy at the Earth's surface?
   a. Heat from the Earth's core.
   b. Energy from the Sun.
   c. Heat and light from human activities.

d. Heat from volcanic activity.
e. Energy of motion from ocean currents and tides.

9. Over time, oxygen atoms move between:
   a. the air only.
   b. the air and living things.
   c. the air, living things and oceans.
   d. the air, living things, the oceans, and crustal rocks.
   e. the air, living things, the oceans, crustal rocks, and the core.

10. The most important factor currently affecting Earth's climate is:
   a. the amount of the surface covered by oceans.
   b. the amount of energy transferred by the Sun.
   c. the amount of fossil fuels burned by humans.
   d. the number of asteroids that hit Earth.
   e. the position of the continents across Earth's surface.

11. Tree roots growing and breaking up rocks is an example of:
   a. erosion.
   b. weathering.
   c. deposition.
   d. contraction.
   e. deformation.

12. Which of the following happens when sound travels through air?
   a. The air molecules move at right angles to the sound's path.
   b. Air travels from the source and enters the listener's ear.
   c. Energy is transferred.
   d. Only two of the above happen.
   e. a, b and c all happen.

13. Jessica planted two seedlings in airtight containers, leaving one in the sun and another in a dark closet. The seedling in the sun grew rapidly but the one in the closet wilted and died because:
   a. it didn't get sunlight so it couldn't make food.
   b. it didn't get sunlight so it couldn't keep warm.
   c. it didn't get air so it couldn't respire.
   d. it got too much carbon dioxide so it died.
   e. it didn't get water so it dried up.

14. Which statement about the flow of matter and energy throughout our planet is correct:
   a. energy is recycled, but matter is not recycled.
   b. matter is recycled, but energy is not recycled.
   c. both matter and energy are recycled.
   d. neither matter nor energy is recycled.
   e. it depends on where you are on the planet.

15. Giant redwood trees can weigh more than a ton, even after all the water is removed. Where does most of the mass of a dried up tree come from?
   a. Carbon-based molecules that the tree took in from soil.
   b. Minerals that the tree took in from soil.
   c. Water that the tree took in from soil.
   d. Carbon dioxide gas from the air.
   e. Sunlight energy.

APPENDIX C

PRE-SURVEY QUESTIONS

PRE-SURVEY

The purpose of this 3-day PD is to expose science teachers to CZ concepts and its critical role in freshwater resources, soil quality, food production, and carbon emissions. We hope you leave this program with tools and resources that you can utilize in your classroom to stimulate students' interest in the CZ and STEAM. **Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. You do need to click "submit" at the end in order for your responses to be received.**

Grade level(s) currently teaching:
Subject(s) currently teaching:
Certification area(s):
Number of years teaching:

1. Do all scientists use the scientific method? Please explain your answer.
2. Are observations the same as or different from inferences? Please explain your answer using examples.
3. How comfortable do you feel with teaching or incorporating geology topics into your classroom? Do you have any major concerns?
4. Do you have any prior experience with geology training or scientific research? Please describe.
5. In your experience, how successful are professional development (PD) in improving your teaching? What are the most effective forms of professional development for you?
6. What is your motivation for attending this *CZ PD*? How did you believe you would benefit from participating in this *CZ PD*?

APPENDIX D

POST-SURVEY QUESTIONS

POST SURVEY

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. You do need to click "submit" at the end in order for your responses to be received.

Grade level(s) currently teaching:
Subject(s) currently teaching:
Certification area(s):
Number of years teaching:

Likert Scale Questions: (Strongly Agree to No Opinion to Strongly Disagree, 5-point scale)
Please indicate how you feel about each statement.

1. The *CZ PD* focused on very important subject matter.
2. The content in this program strengthened my own knowledge base which will help me be a better science teacher.
3. The *CZ PD* improved my knowledge and understanding of the following critical zone concepts:
    a. Carbon cycling
    b. Nutrient Cycling
    c. Anthropogenic interactions
4. I plan to use a wider variety of instructional strategies in my classroom as a result of this *CZ PD*.
5. I feel more confident to incorporate relevant technologies as a result of the hands-on training during the *CZ PD*.
6. I am more prepared to incorporate field activities into my classroom as a result of this *CZ PD*.
7. Please evaluate each content area in the list below using the following statement: The (insert A-B) content presented in the *CZ PD* was very valuable for my education and for addressing CZ concepts in my curriculum.
    d. Dryland Carbon Balance
    e. Hydrological Processes
    f. Playas as biological hotspots
    g. Biological soil crusts
    h. Phosphorus Cycling
8. My instructors used effective examples and illustrations in classes.
9. My instructors encouraged class participation and interaction.

Open-Ended Questions:

1. Do all scientists use the scientific method? Please explain your answer.
2. Are observations the same as or different from inferences? Please explain your answer using examples.
3. What concepts or experiments do you plan on inserting into your curriculum as a result of attending the *CZ PD*?
4. How did participation in the *CZ PD* result in increased understanding of science concepts, skills, and processes relating to CZ?
5. Do you feel that working with university faculty researchers is valuable for your professional development? Why or why not?
6. What do you think could have been done or done differently to better enable you to use the curriculum?
1. Do you plan to share ideas learned from this *CZ PD* with other teachers in your school?
2. Please share any further thoughts on the *CZ PD* and how that experience may have influenced your teaching.

APPENDIX E

MENTAL MODELS

Mental Model of the Critical Zone

In the box below, please draw the critical zone or what you picture when you imagine the "critical zone". You can use color and include as much detail as you would like.

Please write a few sentences describing what is happening in your drawing above:

_____

_____

_____

_____

_____

_____

Mental Model of the Critical Zone

In the box below, please draw the critical zone or what you picture when you imagine the "critical zone". You can use color and include as much detail as you would like.

Please write a few sentences describing what is happening in your drawing above:

_____

_____

_____

_____

_____

Compare the mental model you just drew to your first one. What did you change? Why did you choose to make those changes?

_____

_____

_____

_____

_____

APPENDIX F

RELATED DISCIPLINES LISTS

Academic Disciplines Related to the Critical Zone

A list of academic areas of study or disciplines is shown in the table below.

Circle, color, or highlight any academic disciplines that you think are related to studying the critical zone. In other words, which disciplines address topics that are also addressed or are influenced by the critical zone?

Agriculture	Gender Studies	Philosophy
Anthropology	Geography	Physics
Archaeology	History	Political science
Architecture	Journalism	Psychology
Business	Languages and Linguistics	Public Administration
Chemistry	Law	Religion
Computer Science	Life Sciences	Sociology
Earth Sciences	Literature	Space Sciences
Economics	Mathematics	Statistics
Education	Medicine and Health Sciences	Theology
Engineering	Performing arts	Visual arts

Please pick one of the disciplines that you think is NOT related and explain your reasoning:

_____

_____

_____

_____

Academic Disciplines Related to the Critical Zone

A list of academic areas of study or disciplines is shown in the table below.

Circle, color, or highlight any academic disciplines that you think are related to studying the critical zone. In other words, which disciplines address topics that are also addressed or are influenced by the critical zone?

Agriculture	Gender Studies	Philosophy
Anthropology	Geography	Physics
Archaeology	History	Political science
Architecture	Journalism	Psychology
Business	Languages and Linguistics	Public Administration
Chemistry	Law	Religion
Computer Science	Life Sciences	Sociology
Earth Sciences	Literature	Space Sciences
Economics	Mathematics	Statistics
Education	Medicine and Health Sciences	Theology
Engineering	Performing arts	Visual arts

Compare your selections on this page to the ones you selected on the first day. What changed? Why do you think your selections changed?

_____

_____

_____

_____

_____

APPENDIX G

SCIENTIST SURVEY

SCIENTIST SURVEY

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. You do need to click "submit" at the end in order for your responses to be received.

1. What motivated you to participate in this teacher professional development program?

2. Have you participated in other education and outreach efforts before? Can you describe them?

3. What benefits have you experienced from participating in education and outreach efforts?

4. What benefits do you think the recipients of your efforts get from the experience?

5. Please share any further thoughts on your experience with this PD.