Place-Based Principles in Primary Versus Secondary Education Lesson Plans

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Abstract

Place-based education is a pedagogical development that is largely based on the most primeval and fundamental aspects of education. In essence, PBE is a return to learning in the context of the local community and environment with a newfangled emphasis on global awareness and the best learning strategies for individuals. Place-based educational strategies have been studied in practice and in theory, but more research is needed to qualitatively compare our contemporary style of education to the place-based education pedagogy. This paper uses the six design principles of PBE designed by the Teton Science Schools (TSS) as a tool to uncover how frequently place-based practices are used in Earth science lesson plans from teachengineering.org, a database managed by CU Boulder and the National Science Foundation. All lessons align with the *Next Generation Science Standards* (NGSS), and none explicitly advertise place-based methods as part of the lesson plans. It goes on to compare lessons written for primary and secondary science classrooms. Three place-based principles were found frequently across lesson plans in both sample groups: Community as Classroom, Learner Centered, and Inquiry. Three principles were found less frequently: Local to Global, Design Thinking, and Interdisciplinary Approach. All principles were written in a way that could be strengthened by instructors who have a background in place based education.

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Chapter 1

Introduction

Background

Think back to your primary school education. Recall a lesson that was particularly memorable, one that made a positive, lasting impact on your education. How did your teacher approach the class? Did the content come from a textbook or was the lesson interactive and based in a real life context? Was the activity "fun" perhaps to the point you may have forgotten you were in school? Was the lesson worth learning and provide you with life skills applicable outside the classroom?

These are some of the goals of education reform and likely, this lesson was carefully crafted by a passionate teacher who had developed their teaching skills through a rigorous certification program followed by years of on-the-job experience and professional development.

The craft of teaching meaningful and memorable lessons is both an art and science (Dewey, 1916). It is constantly evolving through teacher creativity and research-based practices. Education is not science alone, nor is it purely art. Scientific knowledge helps develop formal pedagogy and inform best practice, while the artistic creativity of teachers makes for interesting, inspiring, and worthwhile lessons that are challenging yet accessible, and lasting in the memory of the student. This duality of education is summarized by Flake (2017) who engages the debate on whether education is art, science, or both. "The different approaches and ways to teach make teaching an art but the necessary knowledge of the material being taught also makes teaching a science" (Flake, 2017, p.83). Education today is a combination of the affective and the empirical.

In schools across the United States, research-based practices and data-based interventions have become the norm for the scientific component of education. This is especially true in special education. It is no longer sufficient to only say, ‘Sarah is doing above average work in science.’ Now teachers must quantify the quality of their instruction and quality of learning by all students and say, ‘Sarah is performing at an 80% aptitude.’ (Cook & Cook, 2013).

The creative component of education can be found in schools of all kinds - from lab schools to public schools - where innovative teaching methods are constantly being explored and implemented. One such pedagogy is Place-based education (PBE). PBE as a defined pedagogy has its origin in the 1990’s and early 2000’s. Accordingly, foundational works from those decades will be referenced in this paper.

PBE is a pedagogy which promotes academic achievement of core subjects through memorable and impactful lessons within the local environment (Green, 2016; Lowenstein et al., 2018; Theobald, 2018). By connecting classroom to community, it gives real-world context to a given subject. One of the most influential figures in the field, Sobel (2004), provides a comprehensive definition of PBE and the desired outcomes:

> Place-based education is the process of using the local community and environment as a starting point to teach concepts in language arts, mathematics, social studies, science and other subjects across the curriculum. Emphasizing hands-on, real-world learning experiences, this approach to education increases academic achievement, helps students develop stronger ties to their community, enhances students’ appreciation for the natural world, and creates a heightened commitment to serving as active, contributing citizens. Community vitality and environmental quality are improved through the active

engagement of local citizens, community organizations, and environmental resources in the life of the school. (Sobel, 2004, p.7)

A leader in the field of place-based curricula is the Teton Science Schools (TSS), whose curriculum is entirely place-based. In the 1990's and 2000's, the Teton Science School along with the Annenberg Rural Challenge developed six principles that make for a complete place-based curriculum. Their approach to PBE is based on these six design principles: a) local to global context, b) learner centered, c) inquiry-based, d) design thinking, e) community as classroom, and f) interdisciplinary approach. Not all place-based experiences include a complete manifestation of these principles, but by integrating some of these principles, a curriculum or lesson plan can be considered place-based (Teton Science Schools, n.d.; Vander Ark et al., 2020).

The researcher of this study has experience with PBE, outdoor education, and classroom education at both the primary and secondary levels. As a graduate student at the Teton Science School, they are experienced in Place-based education in an outdoor education setting and classroom outreach. The TSS experience was oriented towards connecting students to the natural and human history of the Teton region as well as building conservation and science literacy and relationships with each other.

Practical experience with PBE in the field for 11 months provided them with insight into qualitatively analyzing the pedagogy. Yet, this experience is limited compared to other experienced PBE scholars like Sobel, Demarest, Elfer, Gruenewald, and Theobald. Therefore, this study is correspondingly limited in its claims and insight.

As a formalized pedagogy, PBE is a relatively new approach, though the practice of some of its major principles have existed in education for centuries (Elfer, 2011). Also known as Place-based learning, PBE has gained significant traction and has been implemented to varying degrees in both private and public school curricula (Demarest, 2015; McCombs, 2003; Sobel, 2004; Vander Ark et al., 2020).

To determine if, and to what degree, place-based practices exist in current science education, the researcher designed a tool to measure the representation of the six principles of PBE articulated by the Teton Science School. This tool is presented in the results as a rubric with criteria based on what the researcher perceived as the most essential qualities of each principle based on the literature and examples from TSS and other place-based curricula. Lesson plans were scored based on the presence or absence of sub-themes and compared between major themes and also between sample groups.

Both qualitative and statistical findings are presented in the results. The significant differences are addressed, and their importance discussed in the conclusion. Based on these findings, the researcher believes that place-based practices do have a noticeable presence in current science education.

Statement of the Problem

Our society is shifting the focus of education beyond the four walls of the classroom (Best, 2017; Semken et al, 2017; Thomsen, 2016). This shift in learning seeks to lead students beyond the classroom both physically and intellectually. It seems that the time of place-based education has come.

To prepare new teachers to be effective place-based educators, the teacher education learning community must reflect place-based practices (Lowenstein et al., 2018). Place-based practices, such as a school partnering with outside educators, has increased pre-service teachers' professional engagement and increased student performance in two longitudinal studies by Green (2016) and Burrows et al. (2013) respectively.

Despite PBE's general popularity and acceptance, few teacher certification programs formally teach it (Elfer, 2011). Without the pedagogy of PBE in the teacher education curriculum, educators would need to gain a perception of PBE from other sources. They may develop ideas of PBE intuitively. Perhaps it can be sourced from experience, professional development, or from the influences of outside teaching resources like free publicly available online lesson plans.

Certain principles of PBE are not new conceptually, but the comprehensive definition and practice of PBE is young. This is followed by two assumptions. First, professional educators such as those writing public lesson plans may have not yet encountered PBE and thus have no knowledge of it. Second, educators may be intentionally using one or more of the PBE principles while writing lesson plans independently of any knowledge of PBE as a comprehensive pedagogy.

To reiterate, lacking formal instruction on PBE does not necessarily make anyone ignorant of any particular PBE principle, it is merely a lack of explicit, wholistic instruction on the pedagogy. Not being explicitly taught a concept does not exclude a person from independently learning that concept.

Veteran teachers are exposed to a broader spectrum of pedagogy and teaching philosophy simply because they have more time, experience, and incentive from the school to do so.

However, not all skills need to be taught, some develop naturally through creative innovation. Teachers with a creative open mind may call upon an intuitive design process to develop lessons on their own which may contain qualities of original or established pedagogy (Markauskaite & Goodyear, 2014). This organic creative process from the mind of a teacher could be responsible for formulating a place-based lesson.

According to Dewey's theory of experiential learning, experience influences beliefs (Dewey, 1916). With diverse backgrounds and life experiences, educators could very well possess the principles necessary to create a place-based lesson in their own way. However, since there is no explicit mention of PBE or place-based lessons of any kind anywhere in the *Next Generation Science Standards* (NGSS) curriculum (www.nextgenscience.org) or online teaching resource teachengineering.org is, there is no way to know if these principles are being implemented without a focused investigation into these sources.

In order to find the best quality of place-based practices in science, the researcher chose to use the field of Earth science. It is apparent that studying Earth systems can be applied anywhere on Earth whether it be a rural, urban, or suburban setting. Therefore, it may prove easier to find hidden place-based practices and if found, those practices could be readily implemented in the most places.

To investigate the hidden qualities of NGSS lesson plans, this study used a database of lesson plans managed by the University of Colorado Boulder and the National Science Foundation. Their open-access website teachengineering.org contains curricula for all fields of STEM including Earth science which was the focus for this study. As a reputable source of NGSS curricula with no advertisement of PBE it fits the parameters of this study.

Since place-based education is not explicitly taught in many places, the authors of lesson plans from the source teachengineering.org might have either gained an understanding of PBE through diligently staying updated with new pedagogies or have done so organically through the intuitive design process of teaching. Since PBE is not intentionally included in the data, then if the principles of PBE show up in their lesson plans it suggests that those principles may be inherent to education and an educators' thought process. This curiosity is the focus of this study which investigates the potential place-based influences from publicly available online lesson plans.

As popularity and acceptance grow, PBE shows great promise in elevating the art of teaching. And thus, there is also a need for research on the subject. Research into the use of PBE in a given curricula is ongoing and the need for further evaluation exists (Zandvliet, 2012). Semken et al. (2017) recognizes the importance of "place" in Earth science and calls for comparative studies to measure how PBE can apply to Earth science in the future.

From what the literature reveals, the use of place-based practices has not been quantified for primary versus secondary education. Therefore, this paper will serve as a preliminary cross-sectional study attempting to reveal elements of PBE which already exist in contemporary primary and secondary science education.

This paper attempts to combine a priori knowledge about ideal PBE practices while also using grounded theory to evoke those practices from lesson plans of contemporary education where it was not known to exist before (Heath & Cowley, 2004). Ultimately, this was an attempt to pull a sample of existing place-based qualities out of K-12 public science education based in the NGSS standards.

Purpose and Research Question

This paper seeks to uncover how frequently the principles of PBE are used in public online lesson plans. Considering a limited timeframe and capacity to read, code, and analyze data, the researcher chose to compare the top 10 most popular primary school Earth science lessons with 10 secondary Earth science lessons acquired from teachengineering.org. None of which explicitly advertised place-based methods as part of the lesson plans.

This research is driven by the following questions:

1. How do the six principles of PBE manifest in open-source lesson plans written for contemporary NGSS Earth science?
2. How frequently are the six principles of PBE used in primary education lesson plans compared to secondary education lesson plans?

To be considered place-based in the TSS curriculum, a lesson plan should contain at least some of the design principles but does not require a perfect application of all six (Teton Science Schools, n.d.; Vander Ark, 2020). Professional educators who wrote these lesson plans may develop place-based ideas organically, unconsciously, or independently from their formal training. Discovering design principles of PBE in these lesson plans provides a measure for whether the principles are implicit in science education, as well as which ideas of PBE are most frequently presented to educators.

This product acts like a window into what might be influencing new teachers when planning lessons. What pedagogies come to their mind, what methods do they think are best, and what ideas they consider important to teach. Through this window, it is possible to see if there are concepts of PBE that come out on paper.

Significance

The question then arises: What makes place-based learning so important in today's classroom? The simple answer is to make education relevant and true to life, remedying a disconnect between institutional education and the lived experience of students and community life (Smith, 2007). This was first recognized by Dewey (1916) who made great contributions to education by explaining the disconnect which has been recognized by others including Smith (2007).

PBE is a pedagogy based on some of the oldest, most fundamental forms of education. Teaching with a sense of place has always existed. In fact, it is the original form of teaching in the grand scheme of humanity. Socrates, for example, discussed the nature of justice on the steps of the Athens courthouse (Grube, 2002).

Schoolroom teaching as a society-wide practice is only a couple centuries old (Oreopoulos, 2006). Before compulsory school attendance laws, communities sustained themselves by passing down knowledge of place to younger generations who became acculturated and developed expertise in what is relevant and useful to their communities (Smith, 2016; Theobald, 2018).

Since its inception, the methods of place-based learning have gained praise among educators for community revitalization, as well as increased student engagement, satisfaction, and learning performance (Kplolovie et al., 2014; Larson, 2006; Sobel, 2004). PBE is also an attractive and cutting edge pedagogy for environmental education and curricular reform that revitalizes schools and communities together (Gruenewald, 2003a; Smith, 2007; Theobald, 2018). It contains principles which have been advocated for decades including learner centeredness, inquiry-based and interdisciplinary learning, engaging the community, and a focus on local context which connects and expands to global issues.

Research from the inception of PBE also shows that the practice has significant positive effects on the academic and social success of school children (Lawson, & Lawson, 2013). A good quality of life in an academic setting, especially in these formative years, will set young people up for success later in life.

A forerunner to PBE is Environmental Education (EE) which is characterized by learning about the environment while applying value to the treatment of the environment both locally and globally (Locke et al., 2013). Learning outdoors with EE benefits the overall quality of the environment while learning in that setting also increases student engagement and rates of college enrollment (Johnson et al., 2012; Smith, 2007).

ACS (Application, Career opportunities, Societal impact) is a STEM based teaching strategy composed of similar qualities as PBE. It is similar in that this strategy considers intentionally writing real-world applications societal and career applications into lessons. Burrows et al. (2013) quantitatively showed that this teaching method improved high school science students scores. The sample group of 43 high school students increased their correct answers by 17% between pre/post-questionnaires.

Recognizing the qualities of PBE and its historical roots leads to the hypothesis that PBE principles have been present in the minds of educators long before the method was formally defined as a contemporary teaching pedagogy. In essence, PBE is a return to learning in the context of the local community and environment, with a newfangled emphasis on global awareness and an individual’s learning strategies. Discovering hidden elements of PBE being practiced within popular lessons will increase its relevance. This could help advance PBE as a comprehensive pedagogy.

In the context of special education, for example, the element of “place” is highly significant. In order to teach special education effectively, students should be given the same opportunities as their peers. This is called the least restrictive environment (LRE). Whenever a student with special needs is taken away from their peers, out of the classroom, they are being removed from the LRE. It is the goal of special education professionals to minimize this disruption from their regular educational delivery (Friend & Bursuck, 2019, p.23). PBE and EE are thus helpful for engaging students with special needs because they may participate in stimulating lessons while staying in the LRE (Anaby et al., 2014; Peterson, 2011). Acknowledging the importance of “place” in special education yields greater awareness of the overall PBE pedagogy and a broader context in which to situate the role of place.

Research on preservice teachers engaging with the community shows that initially preservice teachers are intimidated by teaching outside the classroom, but after a workshop often show brimming confidence. A Living Classroom is characterized by outdoor grounds with both “built” and “natural” features including native plants and a shelter for the class. After experiencing a Living Classroom, the pre-service teachers recognize the merits of teaching various topics in an authentic setting outside the classroom and using ‘local expert’ knowledge (Green, 2016). Both are concepts of PBE. These pre-service teachers show great interest in the ideas of PBE after their experience, so what if others were exposed to PBE principles in their pre-service training? Would raising awareness of elements of PBE in pre-service curricula serve to stimulate lesson plans which breach the four walls of the classroom and increase measurable academic achievement?

As a first step in answering these questions, the literature review section will address the historical relationship between PBE, existing pedagogies, and standardized testing, and then provide a thorough definition of each of the six PBE principles. The researcher will outline examples of how PBE is practically implemented in real schools using the information collected by Demarest (2015), Sobel (2004), and Theobald (2018). The researcher will then attempt to qualitatively analyze how "place-based" public lesson plans are and quantitatively compare instances of place-based practices in primary Earth science lesson plans to secondary Earth science lesson plans.

Chapter 2

Literature Review

A Brief History of Standardized Education in the United States

Beginning in the mid-19th century, education in the United States gradually became compulsory and standardized. By 1918, all children were required to attend at least elementary school. This benefits all students in all parts of the nation who receive a relatively good quality of education (Elfer, 2011; Oreopoulos, 2006).

Late in the 20th century, standardized testing became increasingly common as a means to assess the rapidly growing number of college applications. At the same time, two world wars and a cold war prioritized professional selection for the army and heralded the need for heightened standards in STEM (science, technology, engineering, mathematics) fields (Himelfarb, 2019). A well-regulated education system was important to the survival and success of the nation. Standardized testing was the best way to achieve that.

Standardized education is synonymous with the American education system. It assures that students across the country receive a similarly good quality of education, but meeting the standard often limits teachers' opportunity to teach other topics in a school year.

In the 21st century, modern standards such as NGSS were developed in order to "create a set of research-based, up-to-date K-12 science standards. These standards give local educators the flexibility to design classroom learning experiences that stimulate students' interests in science and prepare them for college, careers, and citizenship" (NGSS, n.d.). Modern standards like NGSS allow teachers to explore more diverse, interdisciplinary instructional methods and teach "how" science is done, not simply delivering scientific information and facts (Drew & Thomas, 2018).

Place-Based Education

Place-based education is compatible with the NGSS framework of scientific inquiry, authentic science and engineering practices, and cross cutting concepts which blur the lines between disciplines (Drew & Thomas, 2018; NGSS, n.d.). More traditional curricula are oriented to meeting classroom test performance standards while PBE seeks to help student performance by delivering more impactful learning experiences while acknowledging the need to meet standards.

The educational philosophy of PBE achieves these benefits by teaching the important, standard-fulfilling content while using meaningful experiences and authentic settings to facilitate learning (McInerney et al., 2011; Sobel, 2004). Using the community or the environment as an integrating context are examples of authentic setting (Gruenewald, 2005).

"Environment" in this case refers to the natural environment. "In nine studies comparing students in the environment as an integrating context (EIC) to students in traditional programs in the same school, EIC students demonstrate better behavior, attendance, and attitudes than traditional students" (Sobel, 2014, p.62). By extension, better behavior, attendance, and attitudes redound to better test scores and overall academic performance (Kplolovie et al., 2014).

If the aforementioned benefits are true, then the merits of PBE should also benefit an active-service teacher's performance evaluations which are based on student reviews and academic performance indicated by test scores. Furthermore, there are also potential to benefits for pre-service teachers.

Pre-service training gives teachers the essential tools for success in the classroom but cannot possibly provide the full scope of teaching methodologies which currently leaves out practices such as PBE. Therefore, as a developing pedagogy, it would also be beneficial for pre-service teacher training to provide the tools necessary for teachers to succeed in PBE the moment they enter the workforce. Yet, for a new teacher much of the skill and nuance needed to be successful must be learned on the job.

When a pre-service teacher is finally hired into active-service they assume the same responsibilities for their classroom as the veteran teachers. Standards must be met, classroom culture must be positive and emotionally safe, assessments must be valid and fair, and individualized learning plans (IEP) must be accommodated. Yet, the reality is most new teachers are not fully prepared the moment they enter (Corcoran & Tormey, 2012; DeLuca & Bellara, 2013).

Despite general popularity and growing acceptance, few teacher certification programs formally teach PBE (Elfer, 2011). Yet, many principles of PBE exist somewhere in the established methodology of education. This literature review will examine the established teaching methods and pedagogies which are in common with PBE.

Six Principles of PBE

To thoroughly define what qualifies as a place-based lesson, leading practitioners of place-based education have defined several principles. According to the Teton Science School, a place-based institution, the following principles constitute a place-based curriculum. The principles as written by the Teton Science Schools are a) community as classroom, b) learner centered, c) inquiry based, d) local to global, e) design thinking, and f) interdisciplinary approach (Teton Science Schools, n.d.; Vander Ark et al., 2020). These principles strongly overlap with the "elements of place-based curriculum design" defined by Demarest (2015) and the "models for place based learning" defined by Gruenewald & Smith (2014).

Some items in the PLACES (Place-Based Learning and Constructivist Theory) instrument by Zandvliet (2012) can be used to measure TSS' principles (Vander Ark et al., 2020). Zandvliet's description of relevance/integration overlaps with TSS and Vander Ark's local to global, student negotiation and shared control both overlap with learner centeredness, and environmental interaction overlaps with community as classroom (Vander Ark et al., 2020; Zandvliet, 2012).

For clarity and simplicity's sake, the six principles defined by the Teton Science School will serve as the primary qualities of PBE and will be used for measuring lesson plans for their inclusion of place-based practices. Many common pedagogical elements contained within the six principles of PBE will be explored in the following sections.

Principle 1: Community as Classroom

Education is not limited to the state mandated education people receive. Only 5 percent of our lives are spent in school, the other 95 percent is spent outside of the classroom (Falk & Dierking, 2010). Falk and Dierking argue that the majority of our learning happens outside of school. When using the community to teach, the instructor is planting seeds for students to seek knowledge outside of school.

Not only does the community create lifelong learners, but engaging the community is necessary to maintain a school. Sobel (2004) illustrates how schools are like a three-legged stool that only stands when supported by academic achievement, community vitality, and environmental preservation. A different metaphor which expresses similar ideas is the "place triangle" (see Figure 1) by the Teton Science School which includes ecology, economy, and culture (TSS, n.d.; Vander Ark et al., 2020). In either case, it is the intersection of these three aspects that describe a place. Using the community as a classroom contributes to all three legs of the stool and all three sides of the triangle to maximize the impact on the common good.

For smaller communities, a reciprocal relationship between the school and the community is integral to the longevity of that community (Theobald, 2010). Environmental Education and knowledge of one's community is shown to increase investment in the health and welfare of the community as well (Locke et al., 2010).

Littleton, New Hampshire is a rural town of 6,000 people that embraced a place-based curriculum. Littleton merged the town and school budgeting procedures in an effort to increase the vitality of their town. "The town and school boards realized that their futures are intertwined: without more resources in the schools, Littleton could not develop a strong labor force and attract investments" (Sobel, 2004, p.70). School programs that engage the class with the community and save the community some money are very attractive and will create more opportunities (Sobel, 2004).

Consider another small town example of community-as-classroom. A middle school in Guilford, Vermont. Rather than a school publication, the school partners student journalists to publish articles in the local newspaper and publishes the local newspaper. Student journalism meets Vermont state curriculum standards plus the local population expresses satisfaction and a greater sense of community connectedness as a result (Sobel, 2004, p53).

Equity increases as the classroom expands outside the walls of the school. Social capital is the currency of PBE and investing in museums and other cultural facilities narrows the achievement gap (Vander Ark et al., 2020).

Educational researchers agree that out-of-school learning experiences can anchor, supplement, expand, and deepen students' in-school learning experiences (Clarke-Vivier & Lee, 2018). It makes sense for classroom education to make connections outside the traditional class "room" in order to inspire students.

Use of the community as a classroom is hard to measure in a discrete lesson plan because the relationship exists most prominently between the school and the community not necessarily in a single lesson plan. Accounting for this, the rubric will look for any evidence of lessons calling upon resources outside of school. When assessing a lesson for its use of community as classroom, ask the following questions.

- Is the community used to create authentic lessons or does the lesson explicitly call for the class to leave the classroom?
- Does the lesson bring up critical issues about the environmental and natural resources?
- Are real-world connections made or external resources brought into the classroom?
- Are real professions brought up for the purpose of showing students opportunities beyond school?

Principle 2: Learner Centered Approach

The learner centered approach is characterized by a shift from "what teachers teach" to "what students learn" (McCombs, 2003). The idea of learner centeredness is an educational philosophy which was first developed in 1993. Since then, it has been widely adopted (Smart et al., 2012).

The following quote provides a description and rationale for the shift to learner centered teaching.

> The perspective that couples a focus on individual learners (their heredity, experiences, perspectives, backgrounds, talents, interests, capacities, and needs) with a focus on learning (the best available knowledge about learning and how it occurs and about teaching practices that are most effective in promoting the highest levels of motivation, learning, and achievement for all learners). (McCombs & Whisler, 1997, p. 9).

A learner centered approach is an important principle of PBE because it prioritizes the student's personal life experiences and builds on their strengths and interests. Allowing choices within homework and classroom tasks has been shown to increase student motivation and performance (Patall et al., 2010). The same is true for underprivileged and minority students (Salinas & Garr, 2009).

Differentiated instruction is a kind of learner-centered instruction as well. These philosophies share the idea that a variety of teaching and learning strategies are necessary to meet the range of needs evident in any given classroom. Differentiation is based on the belief that students differ in interests, experiences, and readiness to learn; therefore, instruction should differ enough to reach the various needs of students (Brown, 2003).

Differentiation is achieved by providing materials and tasks at varied levels of difficulty, and with varying levels of instructional support, through the use of multiple grouping arrangements, student choice, and varied evaluation strategies (Rock et al., 2008; Tomlinson, 2014). When a teacher allows their students to engage in various content that matches their interest and proficiency level, they are practicing the learner centered approach.

Students' diverse needs are met by differentiating the content being taught, the process by which it is taught, and the ways students demonstrate what they have learned and their level of knowledge through varied products (Huebner, 2010; Tomlinson, 2014). Differentiation enables learner agency.

Personal agency is the capacity of a person to be self-determining. A learner centered approach gives power and choice to the student. Power and choice are shown to increase a student's initiative and desire to participate (Fay & Funk, 1995; Larson, 2006). Enabling learner agency is a key factor in PBE.

Knowing the benefits, it should come as no surprise that learner-centered approaches are becoming more mainstream since the year 2000 (Smart et al., 2012). This is the new norm preferred over the teacher-centered approach to learning which is an outdated practice where teachers focus more on the content than on the student tasked with consuming the content (Brown, 2003).

Though PBE is a classroom pedagogy, it has space for activities that resemble extracurricular activity. Semi-structured, voluntary learning and extracurricular activities have a positive effect on youth development. Larson (2006) found that these learner-centered activities are associated with reduced delinquency, and increased initiative, achievement, self-control, and self-efficacy. A learner centered approach is allowing children to become active agents in their own lives when given a range of choices.

Becoming an active agent is especially true when dealing with behavior and delinquency problems. Students may reject discipline when given an imposed punishment but when given the choice between two or three remedies, they will more likely choose one and follow through knowing they took control of their own fate (Fay & Funk, 1995).

In any lesson, especially inquiry-based lessons, there are levels of student autonomy that may be implemented. Broadly, those levels are teacher directed, where students explore a concept explained by the teacher, and student directed, where students spearhead the project with minimal teacher facilitation (Power, 2012). A teacher directed lesson has little autonomy, thus is not learner centered. However, a student directed lesson is highly learner centered.

When assessing a lesson using the learner centered approach, ask the following questions based on the literature on diversification and student directed learning.

- Is there evidence of instructional diversification or enrichment opportunities?
- Does the lesson make connections to students' lived experiences? Are there creative, student friendly, and age-appropriate scaffolding events?
- Is there an element of student directed learning or student choice?
- Does the lesson call for open, student-led discussions?

Principle 3: Inquiry-Based Approach

According to the National Research Council (NRC) "students at all grade levels and all domains of science should have the opportunity to use scientific inquiry..." (NRC, 1996, p.105). The NRC goes on to list the skills associated with inquiry. There are six fundamental abilities associated with inquiry: a) the identification of a question and hypothesis; b) design and conduction of an experiment or research; c) use of technologies such as data analysis tools; d) revision of scientific explanations using evidence; e) recognizing and analyzing alternative explanations; and f) communication and defense of a scientific argument (NRC, 1996; NRC, 2000). These fundamental abilities have been the standard for inquiry since the publishing of the *National Science Education Standards*: A Guide for Teaching and Learning and remains the standard today (NRC, 2000; Wu et al., 2014). Much of this remains true today according to the NGSS Science and Engineering Practices (SEP). The SEPs are a) asking questions and defining problems; b) developing and using models; c) planning and carrying out investigations; d) analyzing and interpreting data; e) using mathematics and computational thinking; f) constructing explanations and designing solutions; g) engaging in argument from evidence h) obtaining, evaluating, and communicating information (NGSS, n.d.). The NRC used the term skills in 1996, but these ideas have evolved into the new verbiage for NGSS.

> We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice. (NRC Framework, 2012, p. 30)

A thoroughly conducted inquiry lesson should give students experience with all these skills and practices within one of the Disciplinary Core Ideas (DCI) of NGSS which are the main concepts of the major fields of science including life science, earth science, physical science, and engineering. Therefore, the rubric for scoring a lesson's level of inquiry will look for use of these skills in a condensed form consistent with the rubric created in the methods section.

Juxtaposing the scientific process and the inquiry process reveals their remarkable similarity. Another example is Pedaste's phases of inquiry (orientation, conceptualization, investigation, conclusion, discussion) mirror the fundamental skills of inquiry found in the scientific process and the NRC's fundamental abilities (Pedaste et al., 2015). All these ideas of inquiry have been refined over time but have one main commonality. Scientists investigate the natural world through inquiry; therefore, inquiry is a primary instructional model for teaching scientific investigation in K-12 education (NGSS, n.d.; NRC, 2000).

At a place-based institution like the Teton Science School for example, students almost always have an environmental inquiry experience. Visiting school groups that sign up for a week-long class will experience between two and three days dedicated to an inquiry-based research project related to the “place” which is the Greater Yellowstone Ecosystem.

Place and inquiry go hand in hand, especially in an environmental context. Furthermore, place-based inquiry is just as effective as traditional instruction on student achievement and test scores (Gautreau, & Binns, 2014). This makes sense considering that inquiry is a common instructional model in science classrooms, but it is also an essential part of science itself.

The level of freedom students have in an inquiry lesson depends on the chosen level of guidance. These levels can be summarized as follows: a) teacher directed, where students explore a concept explained by the teacher; b) teacher guided, where students generate an explanation for a given concept with scaffolding; or c) student guided, where students develop their own methods to explore and explain a chosen topic (Power, 2012). The chosen guidance level depends on the student’s foundation of knowledge and autonomy.

Inquiry may be done in several ways, the 5E model being one of the most common and generalizable (Bybee et al., 2006). The 5E’s stand for engage, explore, explain, elaborate, and evaluate (Lynn, 2012). Whatever the level of guidance, there is always an investigation or exploration phase where students must discover information on their own. This phase is crucial to characterizing an inquiry lesson. After research is conducted, students must make sense of their findings and explain them. This requires critical thinking and listening, and evidence based reasoning. During this phase, the teacher can assess a student’s understanding by listening to explanations. Definitions of new concepts can then be introduced which lead to the next phase, the elaboration phase. For students, the elaboration phase of the 5E model applies new understanding by sharing refined findings with the class. For the teacher, elaboration means reminding students to use the newly learned concepts and serving as a consultant like in the exploration phase. Once the findings have been shared, questions from peers or instructors moves the inquiry into the evaluation phase. Here the presenter has the opportunity to defend their findings or to reevaluate them after being questioned. Science is cyclical after all. The thinking process should not end when the lesson is completed: re-evaluating and posing new questions should come naturally.

When assessing a lesson for its use of inquiry, ask the following questions based partly on the current NGSS standards and the NRC fundamental abilities of inquiry (NGSS, n.d.; NRC, 1996; NRC, 2000).

- Does it call for students to produce a question or hypothesis?
- Do students get to explore/research a topic, or design and conduct an experiment?
- Does the lesson require data collection, analysis, and possibly use technology/tools?
- Is there a chance for revision and communicate or defense of their scientific argument?

Principle 4: Local to Global

A core concept of place-based education is learning about the near before learning about the far away (Gruenewald & Smith, 2014). Learning about what is in the immediate community and connecting it to global issues is more relevant to the young learner than simply learning that which is in a distant land. An example of the local to global principle would be a school in San Francisco which uses plants growing on campus and the forest adjacent to the school to teach biology and the life cycle of plants (Sobel, 2004). This idea asserts that learning in a local context serves as a foundation for understanding larger issues and global challenges.

Learning experiences connected to real-life places and issues increase engagement, agency, and academic outcomes (Parsons & Taylor, 2011). Furthermore, those life experiences at the high school level and corresponding achievements then predict post-secondary achievement as well (Martin et. al., 2013). This means that if a local to global framework provides real-world experiences, it also prepares students for college and to be active participants in society.

The idea of a Local to Global progression can be visualized as concentric rings (see Figure 2). At its center is learning about the individual self, which then expands out to the classroom, the school, communities, larger regions, and finally the globe (Getting Smart, n.d.). A local-to-global framework is made when the context of an inner ring is connected to an outer ring.

A local to global framework does not necessarily need to begin near the center of the model. At the secondary science level, this model may begin at a middle ring and connect to larger global issues because secondary level learners are closer to participating full time in the greater community. Becoming young adults therefore calls for connecting local issues to larger issues.

Gaining experience in the inner rings prepares the individual to make stronger impacts on the outer rings. Understanding of “place” begins with understanding and exploring the individual’s role in the community (Green, 2016). In this way, a place-based program advocates for students and teachers at all levels to treat their classroom and school like a community of its own. An example of this would be engaging in common-good activities like building and cultivating a garden which will serve the school for years to come.

Students connect learning experiences in the community to their personal lives and prior knowledge (Bamberger & Tal, 2007). Natural curiosity and gaining experiences in the local community is a step towards being active citizens in that community at any scale. "It is the local experience that grounds students in an understanding of what is important or why they might want to care." (Vander Ark et al., 2020, p.65). Students can gain experiences and expertise through engaging partnerships with the community and service projects that build professional relationships and benefit the community all at the same time.

When assessing a lesson for its use of the local to global principle, ask the following questions.

- Does the lesson make use of nearby resources like people, businesses, cultures, natural resources, or other familiar local aspects?
- Are connections made between local issues or phenomena and greater global issues or phenomena?
- Is the classroom treated like a community of its own?
- Is prior knowledge used as a foundation to expand to larger issues or current events?

Principle 5: Design Thinking

Design thinking is a problem solving approach to learning which drives students to build solutions and create innovations to make differences in the present and in future careers (Vander

Ark et al., 2020). Similar to other principles of PBE, design thinking is a philosophical shift in education towards student generated learning and practical skills.

The Engineering Practices of the Next Generation Science Standards are an example of design thinking used in curricula (NGSS, n.d.). Design thinking and the Engineering Practices are also a form of problem-based learning (PBL) and, in the context of PBE, tries to be as real-world oriented and impactful as possible.

Academically, PBL has its origins in medical education. Over 30 years ago it was used as a tool for practicing diagnosis and deductive reasoning (Savery, 2015). Rapidly growing medical information and the constant changing demands made traditional lecture-then-practice teaching less effective. The same can be said for secondary science education.

Since its inception, PBL has expanded into all age levels and disciplines of education and is largely treated the same as it is in the medical field. In problem-based learning (PBL) students are given a problem or a scenario that guides their learning. Students set their own learning objectives aimed at resolving the posed scenario. PBL is largely a student-led and self-directed learning strategy (Wood, 2003).

Whereas traditional learning would teach the necessary skills to solve problems, PBL often presents a problem first and the skills are learned on the way to a solution (Nilson, 2016). It may refer to any kind of open-ended, student-led exercise that tackles a real-world problem or simulated version of a real-world problem.

This is another principle of PBE which can positively impact communities by producing an artifact that benefits someone else in some way. Products can have a direct and recognizable benefit to the community or give students the skills needed to benefit their community later on.

Key for a PBL project is that there is a "changing of existing conditions into preferred ones" (Simon, 1996, p.111).

An example of recognizable benefit could be surveying the species and pollutants in a waterway then restoring the riparian ecosystem. On the other hand, a non-recognizable benefit would be conducting the survey for the sake of practice but taking no action with that information. Another example of a recognizable benefit would be to engage with local government through attending public hearings or writing letters to government officials, administrators, or incumbents. A non-recognizable benefit would be to simulate a government session in the classroom where the end-product of the legislative exercise is unimpactful. It is important to note that a non-recognizable benefit does not disqualify design thinking if the lesson is intentionally geared to prepare students for a beneficial application of their knowledge.

To include design thinking in a lesson means to intentionally structure the lesson so that students must construct, design, or direct their learning objectives to solve a problem. Design thinking includes connotations of original, proactive design as well as designs oriented as retroactive to an existing problem.

When assessing a lesson for its use of design thinking, ask the following questions.

- Is a problem posed before students learn the tools needed to solve it?
- Is there an emphasis on creative problem solving over getting the "right" answer?
- Do students tackle a real-world problem and possibly improve it?
- Is the lesson hands-on or part of a multi-class project?

Principle 6: Interdisciplinary Approach

Secondary education in the US is done by dividing learning subjects into distinct classes. This is less true in primary school where most subjects are taught in home-room, but it is especially true in secondary school where classes of different subjects are detached from each other in almost every way. A secondary student will move from their history class to their physics class and very little will relate between the two.

The Next Generation Science Standards call for more overlap in their Cross Cutting Concepts (NGSS, n.d.). These concepts include a) patterns, b) cause and effect, c) scale, proportion, and quantity, d) systems and system models, e) energy and matter, f) structure and function, and g) stability and change. Similarly, a place-based course would call for more crossover with other areas of learning. This is called the Interdisciplinary Approach to education.

Getting Smart and TSS define an interdisciplinary approach as when "the curriculum matches the real world where the traditional subject area content, skills and dispositions are taught through an integrated, interdisciplinary and frequently project-based approach where all learners are accountable and challenged." (Getting Smart, n.d.). PBE attempts to make learning as close to the real world as possible. An interdisciplinary approach to learning does exactly this. It calls upon a variety of skills and disciplines to complete a single cohesive project or activity (Jones, 2010).

Here is a hypothetical example of an interdisciplinary project in a physics classroom learning about electrical properties. Students might take electricity for granted as if it were always accessible but reading about Thomas Edison and Nikola Tesla might be a good engagement tool by the instructor which incorporates reading and English skills and even provides a short history lesson.

Our hypothetical electrical lesson might also incorporate an artistic assessment where students build or illustrate a circuit. This is an example of STEAM (Science, Technology, Engineering, Art, and Math) which integrates the creative expression of art with the empirical data driven findings of traditional STEM (Harris & De Bruin, 2018).

To observe an interdisciplinary approach is simpler than for the other principles. Any skills that are not traditionally included in the subject of that class can be considered interdisciplinary. When assessing a lesson for being interdisciplinary, ask the following questions.

- Is there crossover with science and other disciplines? (e.g., English, literature, history, art, engineering, etc.)
- Is this lesson part of a complex multi-dimensional class project?
- Do students call upon multiple schools of thought?
- Are instructors from other disciplines invited to teach or does the class visit them?

Summary of Principles

Not all six principles are required to be implemented perfectly for a lesson to be considered "place-based" (Vander Ark, 2020). The consensus among the primary scholars of PBE is that perfect implementation if each and every place-based practice is too high of an expectation (TSS, n.d.; Vander Ark et al.; Sobel, 2004). This is especially true for this study which uses one lesson as a data point. Therefore, the principles described above will be measured on a spectrum to measure a place-based lesson.

It is important to note for later on that in this research that these six principles are not represented equally in the literature to begin with. There are standard teaching methods such as learner centered and inquiry based teaching, there are common teaching methods such as design thinking and the interdisciplinary approach, and there are rarer methods which don't have a strong research base including community as classroom and the local to global context. This disparity may have a strong influence on the results of this paper.

How Does PBE Look in Primary and Secondary Education?

Two fundamental differences are apparent when comparing primary and secondary education. First, students in primary school have most core subjects taught by a single classroom teacher while at the secondary level each subject will be taught by a different teacher in a different room. Second is the obvious difference in age and developmental stage of the students.

Books which exemplify how PBE is done in schools across the nation make it apparent that primary and secondary classrooms alike can feasibly implement a place-based curriculum in small or profound ways (Demarest, 2015; Sobel, 2004; Vander Ark et al., 2020). Excerpts within the abovementioned principle summaries show this.

One of the goals of this paper is to explore the difference between PBE in primary and secondary education. Semken et al. (2017) calls for the development of instruments to comparatively study place-based practices. From what the literature reveals, the use of place-based practices has not been quantified for primary versus secondary education.

Why Earth-science and PBE?

When looking for a glimpse of PBE in general education, Earth science seems to be a good object to examine. No matter where you are, Earth science draws the learner outdoors to learn about what is around in the environment. Whether it is the stars, the atmosphere, watersheds, or the carbon cycle, it all exists wherever there are humans on Earth. Therefore, irrespective of the setting, every classroom can potentially take advantage of place-based practices when learning about Earth science. This aspect makes Earth-science a relatively expandable topic for the analysis of PBE in science.

Geoscience is highly dependent on place (Semken et al., 2017). Whether it is an urban, suburban, or rural setting, the landscape of that place is ripe with geological history and phenomena. In Earth and space science there is great potential to make a lesson place-based. This study anticipates that Earth science lesson plans may acknowledge this potential and make strong connections to place while also being the most generalizable of the science practices.

Chapter 3

Methodology

Design

This chapter explains the type of study that took place. It describes the sampling groups, the methods of sampling, the coding procedure, and the analytical methods used to compare the sample groups. The research is driven by the following questions:

1. How do the six principles of PBE manifest in open-source lesson plans written for contemporary NGSS Earth science?
2. How frequently are the six principles of PBE used in primary education lesson plans compared to secondary education lesson plans?

Koro-Ljungberg et al., (2009) make a strong case for the essentiality of epistemological awareness. In qualitative studies it is essential to not appear random, uninformed, or unjustified from a lack of an epistemological basis of knowledge. This is especially true in educational research which can be epistemologically diverse in its methods. After reading the decision junctures offered in this article, the researchers determined the theoretical framework of this research project is most aligned with the idea of hermeneutics.

Hermeneutics is a constructivists epistemology which builds knowledge from interpretive and subjective analysis of a phenomenon. In this study the phenomenon is the unintentional formulations of place-based practices in non-place-based lesson plans. The researcher here has the task of finding descriptive data in a place where it’s not meant to exist, and therefore, must be flexible and interpretive. The data used here is archival and narrative based, following the story of a structured lesson.

Braun and Clarke (2006) acknowledge that researcher conducting a thematic analysis must be flexible and that this freedom comes with many assumptions. It is also the job of the researcher to be transparent with the assumptions being made and which liberties are taken. Assumptions and decisions made for this study are addressed in this design section and throughout the methods.

This was a qualitative study which examined themes of PBE within Earth science lesson plans gathered from teachengineering.org, the STEM curriculum database managed by the University of Colorado Boulder and the National Science Foundation. A thematic analysis was done to pull out the place based contents of those lesson plans. The frequency of those themes was compared between sample groups and finally a thorough analysis of qualitative findings as well as numerical frequency was done.

There were two purposes for this research. The first was to measure the use of PBE principles which may exist in standard contemporary curricula. The second was to compare the frequency of these principles between primary and secondary education. It was important to do this because little empirical research has been done on the teaching of PBE (Zandvliet, 2012).

Moreover, the researcher believes that elements of PBE exist in common and contemporary forms of education but since they are not donned with the label of "place-based" they go unnoticed. It was practical and worth examining whether those elements do in fact reside in contemporary education.

Since PBE is still relatively in the background of modern educational pedagogies, this study seeks to reveal the qualities of place-based practice in lesson plans by scoring science lesson plans against the rubric developed by the researcher to measure TSS's six principles of PBE (Vander-Ark et al. 2020). The qualitative nature of written artifacts such as the six principles and schoolroom lesson plans cannot be quantified in their original state. Themes must be pulled out in a qualitative analysis before being scored or compared in a numerical way.

The two sample groups consisted of lesson plans written for primary school and secondary school. These lesson plans were scored using the same codebook containing the six principles of PBE written by this author in Table 3. Without a thoroughly established and standard curriculum for PBE in secondary science education, the researcher used the best and most current frameworks for place-based class design to define the six principles from the literature review (Gruenewald, 2003b; McInerney et al., 2011). They also pulled from the accounts of real schools which have implemented their own place-based curriculum (Sobel, 2004). Ultimately, the researcher combined examples from real life and theory from current PBE curricula to write codes to describe what makes a lesson place-based (Demarest, 2015; Gruenewald & Smith, 2014; Gruenewald, 2003b; Sobel, 2004; Theobald, 2018; Vander-Ark et al., 2020, Zandvliet, 2012).

This was a qualitative study because the data pool consists of written artifacts containing themes which needed to be extracted. Written data have meaning in the context of its language therefore, to know whether themes can be found in the data, the place-based principles in each written artifact must be characterized qualitatively (Xu & Zammit, 2020). Once these qualitative themes were analyzed and highlighted in the data a simple descriptive statistical analysis was done to support the qualitative findings.

The most crucial and controversial assumption made by the researcher of this study is that qualitative data can be compared in a numerical fashion. The researcher created a thematic framework and subsequently used it to construct a rubric to score lesson plans based on its representation of the six principles of PBE. Here, the terms "thematic framework" and "rubric" are distinct processes but work together to make meaning of the data. Since this study looked for particular and desired qualities in lesson plans created for public use by teachers, it makes sense to use the same method as an instructor would to score these items as written by using a rubric. If rubrics are traditionally used to measure the quality and desired content of a product, then this study uses a rubric in the same way to measure the place-based content of these written lessons.

Saldana, as cited by Xu & Zammit (2020), explains how a code "symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldana, 2016, as cited by Xu & Zammit, 2020, p.4). The researcher took the nature of language and coding into consideration when establishing the codes used to capture the attributes within the lesson plan.

A digital coding instrument was not used for the sake of time and complexity. Electronic coding programs demand considerable time to be spent learning the program. Time which was not available in this study. This also came down to a personal choice on the part of the researcher who determined it was not warranted with the small sample (n=20) and short timeframe of research. Regardless, if coding is done by hand or electronically, the need to for critical thought and deliberation is not eliminated (Basit, 2003).

A decision was also made to do template coding as opposed to open coding (aka line-by-line coding). Template coding is a tool consistent with the use of a rubric. It is used for framing data into a coherent construct through the application of an established 'language.' Using this language, codes are defined by the researcher prior to reading the data set as opposed to open coding where descriptive labels are created while reading the data (Blair, 2015).

Ultimately, neither of these decisions will not negatively impact the study. Influence by the researcher is inevitable whether it is digital or coding by hand and a template coding method allows for the data to speak through the researcher (Basit, 2003; Blair, 2015).

In this case, a template code was the most appropriate since specific aspects of PBE were pre-established in the literature review. Open coding is meant to be a more objective way of coding that suspends the researcher's bias and judgement to a degree. However, it is a far more intensive, time consuming process and it is difficult to entirely remove the personal bias of the researcher (Blair, 2015). Therefore, template coding was chosen instead of open coding. Bias in template coding was limited by using only what is established in the codebook.

Our literature review categorized principles of PBE to make up a hierarchical set of themes that allow for a thematic framework analysis.

Pedagogical Content Knowledge

A tool to measure lesson plans was a necessary starting point to build upon. Various tools for measuring different sources of teacher knowledge were developed based on Shulman's (1987) famous assessment of teacher knowledge.

Shulman sought to conceptualize the sources of teacher knowledge as it related to pedagogy, content, and action (Shulman, 1987). This idea is the foundation for evaluating teacher knowledge and professional performance. The researcher applied this idea to evaluate the "knowledge" of PBE contained in each data item.

After Shulman, more teacher evaluation ideas were developed. Studies similar to this one have developed and validated tools that can measure certain elements of a teacher's lesson. The content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) frameworks are such tools (Juttner et al., 2013; Park et al., 2018).

Place-based education is considered a pedagogy (Gruenewald, 2003a; Stevenson, 2008), so the PCK framework was used as the guiding point for the thematic framework of this study. These ideas helped inspire this research design because they similarly looked for teachers' pedagogical knowledge while this study looked for knowledge of PBE. This study's rubric was adapted to apply to the online lesson plans without needing to observe an active lesson.

Sampling Methods / Data Collection

In these methods, the terms "lesson plan" "transcript" and "data item" are used interchangeably. The researcher selected 20 Earth-science lesson plans from an accredited online resource to use in this study. This online resource (teachengineering.org) was chosen for two reasons. First, because it is acceptably up-to-date with science curricula and comes from an accredited university. Second, because of the high profile and reputation of the resource, the researcher believes it will be used by, and have influence reaching, many educators; new and pre-service teachers especially.

The sampling methods herein are non-probabilistic. To select these lesson plans the researcher used the search feature on-site at teachengineering.org to filter specifically for Earth and space science lesson plans that were at least 30 minutes in length and fit into the two age groups. A buffer was placed between the primary and secondary level groups to avoid overlap in hopes of making a treatment effect clearer. Lessons on the site have a three year range for appropriate grade levels. For example, a lesson written for 6th grade is flagged as appropriate for 5th through 7th grade. Lessons written for 6th and 7th grade were excluded to establish this buffer.

To avoid selection bias and to select for the most prevalent lessons for each sample group, the results were simply sorted by popularity and the top 10 lessons which fit the criteria were selected. Sorting by popularity means choosing the lessons with the most influence. The researcher noticed a significant number of redundant lessons in the top 10 list, so it was decided to only include up to two lessons that cover the same topic in each sample group. For example, there were four secondary level lessons based on navigation techniques, so two were skipped and supplanted by the next two lessons about seismic activity and space travel.

Transcripts for each lesson plan were copied in their entirety to Microsoft Word documents, given a code number, then edited for readability. The ten primary level lessons were labeled P1 through P10 while the secondary level lessons were labeled S1 through S10. These are shown in Table 2 lists of lesson titles and labels for each lesson. Superfluous information was redacted from the transcripts for the sake of clarity and readability. Redacted information includes vocabulary lists, links to external lesson plans, and redundant passages. These details took up space and had no bearing on the lesson's content, so they were removed. Relevant content for each lesson within itself was maintained entirely.

Every lesson from teachengineering.org included one or more associated activity meant to follow the lesson. Some were strongly recommended while some were only suggested. The way the lessons were written they were incomplete without the inclusion of at least one associated activity. Therefore, for consistency and completeness, every lesson was combined with one activity if available and treated as a single sampling point. Inclusion of these extension activities served to lengthen the timeframe of the connected lesson and thus increase the probability of detecting themes which require a longer timeframe such as principle 5 design thinking. Due to the limited timeframe of the study, the researcher did not use entire unit plans, instead the lesson plans plus extensions lengthened the data items while allowing this research to be feasible with a higher sample size of 20.

In the case of multiple potential activities, the researcher selected the one most strongly recommended by the authors or if all is equal, then the first one listed. Examples of lessons followed by their associated activity were paired as one transcript, such as the “Chernobyl Empathy” lesson paired with “Nuclear Energy Virtual Field Trip” activity, or “Solar Power: When and Where” paired with “Solar Water: Heat it Up.”

Coding & Analytical Procedures

When coding raw data for a qualitative study the researcher has freedom to construct the coding methodology. “It is a dynamic, intuitive, and creative process of inductive reasoning, thinking, and theorizing.” (Basit, 2003, p.143). Much of coding is based on the researcher’s firsthand experience, and the methods within are unique to the research question.

For this study, a thematic analysis (TA) was done to extract themes of PBE. The data analysis process generally followed these six steps based upon Braun and Clarke’s (2006) approach to TA:

1. familiarizing yourself with your data
2. generating initial codes
3. searching for themes
4. reviewing themes
5. defining and naming themes
6. producing the report.

A major difference between the six phases by Braun & Clarke (2006) and this study was that phases 5 & 2 were done first, prior to the analysis. Key themes were established ahead of the analysis in the literature review when the six principles of PBE were defined and sub-themes were created by the researcher to describe how the principles might be practiced in a lesson plan. The actual order of steps for this particular study was 5, 2, 1, 3, 4, 6.

First, the thematic framework was made based on the six principles of a place-based teaching approach which were defined in the literature review. The six place-based principles make up the six key themes of the framework. a) Community as Classroom; b) Learner Centered; c) Inquiry Based; d) Local to Global; e) Design Thinking; f) Interdisciplinary Approach.

The rubric used four sub-themes under each major theme to score lesson plans. In line with hermeneutics, the sub-themes were interpretations by the researcher who distilled the major practices that make the major theme what it is. They were made up of the questions articulated at the end of each principle in the literature review as sub-themes to the major themes. For example, in Community as Classroom, a critical question would be "do they leave the classroom?" This question was transformed in the rubric to read "Leaving the Classroom."

Four sub-themes were used to describe each principle because the researcher believed it would be best to compare these scores if the scoring system was kept consistent. Admittedly, this is an unorthodox technique of mixing methods. This novice researcher needed a way of giving qualitative data a numerical score to compare the major themes.

Coding procedures looked for instances of the sub-themes. Once the data sets were collected, the researcher became familiar with the data by reading through every data item once and applying the code book/rubric shown in Table 3.

Coding Round 1

Two rounds of coding were done on each data item. The first was a thorough readthrough of the lesson plan while applying established a-priori codes for the six key themes.

During this round, the researcher was generous with applying codes, noting if codes were uncertain or not-explicit. Color codes for the six major themes of place-based education is shown in Table 1. These colors correspond to all respective sub-themes in the dataset. See appendices A & B, for detailed coded data.

Table 1: Key to Color Coding

Codes within the data are color coded to indicate the six themes of PBE using the colors in this table (see appendices A & B).

Place-Based Principles (Major Themes) Color Coding Key	
	Community as Classroom
	Learner Centered Approach
	Inquiry-Based
	Local-to-Global Context
	Design Thinking
	Interdisciplinary Approach

Code words written for the principles of PBE were made broad to get away from the jargon of PBE and encompass more common verbiage than that of PBE scholars. This was a judgement call by the researcher who acknowledges that some commonalities between contemporary education and PBE are excruciatingly plain and clear. For example, science and math go hand-in-hand. This is obvious yet counts as an interdisciplinary approach whenever mathematics are detected in the lesson plans.

Since the sample size is small, a coding software like NVivo was not used. Instead, the (n=20) lesson plans were coded by hand in Microsoft Word. The methods of coding were simple. Two columns were created with the transcript on the left and wherever a sub-theme was found, it would be noted in the right column in-line with the highlighted excerpt.

Qualitative analysis is a recursive process (Braun & Clarke, 2006). Part of the freedom and flexibility that comes with qualitative study is that the researcher can develop codes and language simultaneously while reading the data, allowing themes to be found which are unique to the data sets. This includes writing and jotting down ideas throughout the coding process. Before, during, and after each round of reading and coding, notes were taken to deepen the analysis. Some of the important notes and ideas led to emergent codes being added to the a-priori codes for the second round.

Coding Round 2

After the first round the researcher understood the writing style for each lesson plan better which allowed for better descriptive codes to be used in the rubric. They also noted word choice and implied meanings within the text without going too far into the latent or interpretive. A revised codebook was created with the addition of some emergent codes.

Synonymous terms were also combined from their original draft. One example is within the learner centered principle where the sub-themes “diversified instruction” and “enrichment opportunities” describe a similar teaching concept of allowing student choice and thus were combined. Other concepts combined into one sub-theme were leaving the classroom and using the community as a setting for lessons.

The second round of coding applied the revised codebook shown in Table 2 to look for themes that were missed in the first round. Codes that were initially flagged as not-explicit or uncertain were reviewed. “Re-coding from the data set is to be expected, as coding is an ongoing organic process” (Braun & Clarke, 2006, p.91).

Limitations to this coding method include the researcher’s interpretation of excerpts from the data, stylistic differences if the lesson plan authors, and missing implied meanings in the text.

When the coding was complete, a thematic analysis (TA) of the qualitative data and a descriptive statistical analysis took place which are discussed in the next sections.

Thematic Analysis

For each of the six themes, the researcher conducted a thorough written analysis known as a thick description. Nuances and qualitative features of the data are only visible through an analysis of this type (Blair, 2015; Braul & Clarke, 2006).

It is important as researchers to acknowledge limitations to a qualitative study. "A weak analysis does not appear to consider other obvious alternative readings of the data or fails to consider variation (and even contradiction) in the account that is produced." (Braun & Clarke, 2006, p.95). For this reason, the analysis tried to include every perceivable variable and interpretation reasonably within the scope of this study considering the sample size.

Bearing in mind that none of these lesson plans were designed to intentionally feature PBE, every instance of a place-based principle is interpreted on the part of the researcher.

Descriptive Statistics

Descriptive statistics were used primarily to aid in the qualitative analysis with the help of some inferential statistics. Descriptive statistics include frequency or counts of themes and sub-themes. The only inferential statistic used is a paired t-test attempting to find statistically significant differences in the representation of themes in the two groups. Both are discussed in this section.

Similar to French & Burrows (2018), qualitative data was scored using a rubric. The French & Burrows (2018) method used a 3-point scale to indicate if a component was described (2), partially described (1), or not described in a data item (0).

This study uses a 5-point scale of zero to four (0-4) to determine whether a theme was "described" in a data item. Each of the sub-themes found counts for one point and all four sub themes equate to a complete score. A score of 4 means that all sub-themes were present while a score of 0 means none of them were present.

It is important to acknowledge that a score of 4 is considered complete only for the purposes of this study and it does not necessarily indicate a perfect application of that principle in the lesson. The quantitative analysis simply serves as a quick visualization of the trends in the data while the qualitative analysis makes a judgement on to what degree the lesson was truly place-based.

With the 5-point scale, lessons with a score of four (4) are noted as having complete representation, while lessons scoring a three (3) are noted as having strong representation, scores of two (2) are noted as having moderate representation, scores of one (1) have weak representation, and a score of zero (0) is marked as absent. In Table 4 of the results, perfect and strong representations are noted in shades of green while weak and absent representations are noted in shades of orange.

Next, an inferential statistical analysis was done to compare the use of each principle of PBE across the primary and secondary level sample groups. A simple paired t-test was run to compare the use of each theme where each of the sub-themes were paired. Paired sample t-tests were done with a 95% confidence interval. A significant P-value in social science is less than 0.05 ($P<0.05$) which indicated there is a less than 5% chance of making a type one error.

Table 2: List of Lesson Titles from The Dataset. Includes ID numbers.

Titles and ID numbers for lesson plans written for the primary grades K-5 and secondary grades 8-12. Each data item can be identified by a simple code on its left side made up of the group letter followed by its number in the list.

Primary Group (K-5)		Secondary Group (8-12)	
PP1	Renewable Energy	SS1	Solar Power: When & Where Is Best
PP2	Earthquakes Rock!	SS2	Nuclear Energy through a Virtual Field Trip
PP3	Earthquake Formation: Crust, Plates, Currents, Drift and Faults	SS3	Rock Solid
PP4	Lunar Learning: Moon Phases Always on the Move	SS4	Topo Map Mania!
PP5	Tornado!	SS5	Get Me Off This Planet
PP6	Greenhouse Atmosphere: Let's Heat Things Up!	SS6	An Introduction to Air Quality Research
PP7	Volcanic Panic!	SS7	Seismic Waves: How Earthquakes Move Through the Earth
PP8	All About Water!	SS8	Where Is Here?
PP9	Newton Gets Me Moving	SS9	Not So Lost in Space
PP10	Using Thrust, Weight & Control: Rocket Me into Space	SS10	Watershed Balance

Chapter 4

Results

This section uses qualitative excerpts from the data as well as descriptive statistics to help answer the research questions. Herein, two types of results are shared: thick descriptions of the sub-themes, and descriptive statistics. Descriptive statistics are shared and shown in tables while the qualitative findings are shared as excerpts from the dataset with their meaning and significance described at length.

Two rounds of qualitative coding were done to establish usable data in these results. Coding sought out sub-themes of the six place-based principles. A codebook was created in two iterative revisions. The codebook was also used as a rubric to score and record the specific place-based qualities of the dataset. The finalized codebook / rubric is shown in Table 4 depicting the six major themes and the key descriptions of the four sub-themes. Coding results provided useful data to answer the qualitative and statistical questions of this study.

A pattern was discovered while coding the data. Sometimes, there would be a line from a transcript that describes multiple sub-themes. When such a description was appropriate, both sub-themes were coded for the same line. An example would be this excerpt from appendix C.

> We are going to start exploring engineering applications for a sustainable world by using the engineering design process to design, build and test our own solar water heaters! – Lesson S1 in Appendix C.

This part of the lesson describes the sub-themes "complex multi-dimensional project" and "extensive multi-class project." Both were appropriate, so both were coded as being present. Similar overlap was found for the following pairs of sub-themes: real-world connections & use nearby resources; showcase profession & crossover with other disciplines; student directed learning & opportunity for communication and revision.

Table 3: Codebook / Rubric for Lesson Plans

Final codebook/ rubric including each sub-theme used in the final round of coding.

PBE Principle	Community as Classroom	Learner Centered	Inquiry Based	Local to Global	Design Thinking	Interdisciplinary Approach
Subtheme 1	Based in the community / Leave the classroom	Diversified instruction or enrichment	Students question or hypothesize	Use nearby resources (business, culture, nature, etc.)	Pose a problem before learning the tools.	Crossover (English, history, art, etc.)
Subtheme 2	Consider natural resources	Connect to lived experience	Explore/research topic	Compares local and global phenomena	Emphasis on creative problem solving	Complex multi-dimensional project
Subtheme 3	Real-world connections	Student-directed / choice in learning	Data collection & analysis	Classroom treated like a community	Tackle a real-world problem	Multiple modes of thought
Subtheme 4	Showcase professions or experts speak	Open, student-led discussions	Opportunity for communication and revision	Knowledge is expanded to larger issues or events	Hands-on activity or multi class project	Visit another classroom / invite another teacher

Statistical Results

To answer the second research question, a descriptive statistical summary was necessary. The researcher asked how frequently any of the six principles of PBE are used in primary education lesson plans compared to secondary education lesson plans?

All six of the principles of PBE were scored based on the presence or absence of sub-themes. Each theme was scored on a 5-point scale ranging from zero (0) to four (4) based on the count of these sub-themes. A few sub-themes were totally absent, but all six major themes were discovered to some degree in the data pool for this study.

A simple paired t-test was run to find potential differences in representation between themes in the primary and secondary education sample groups. Each of the sub-themes were paired across sample groups to find if the larger theme was used more frequently within the sample grades.

Only one of the six principles was found to be significantly different between the groups. Secondary lesson plans used a Local-to-Global Framework significantly more often than the primary lesson plans ($P=0.005$). All other paired t-tests between primary and secondary groups resulted in non-significant differences ($P>0.05$). The only other test that came close to significance was Community as Classroom being more frequent in the secondary group ($P=0.069$). It is speculative to say that this score may have been significant under more strict circumstances.

Table 4. Scores For Lesson Plans in Both Sample Groups

Total counts of sub-themes per-lesson for each major theme. Lesson ID numbers in the top row correspond with the (P) primary or (S) secondary group. Strength is color coded, dark orange *indicates a score of zero (0), light orange indicates one (1), white is two (2) which indicates the mid-point of the scale, light green is three (3), and dark green is a perfect score of four (4).*

Principles of PBE (Group P or S)		1	2	3	4	5	6	7	8	9	10
Community As Classroom	P	3	2	0	0	2	3	0	2	3	2
	S	4	4	2	3	3	4	3	2	1	3
Learner Centered Approach	P	3	4	3	2	2	3	3	1	3	2
	S	2	3	3	3	2	2	3	3	1	2
Inquiry Based	P	3	3	1	4	2	2	4	1	2	2
	S	3	2	3	0	3	4	4	2	0	4
Local to Global	P	0	1	0	0	1	1	0	0	1	0
	S	2	2	2	2	0	2	1	2	1	2
Design Thinking	P	1	1	0	1	2	1	2	2	0	1
	S	3	1	1	3	1	2	3	1	0	2
Interdisciplinary Approach	P	2	2	1	1	2	2	2	0	1	2
	S	3	2	2	0	1	2	1	1	1	2

Qualitative Results

Qualitative coding discovered many sub-themes of the six place-based principles within the dataset. The significance and frequency of themes in both sample groups are examined herein using support from the preceding statistical results.

Important sub-themes of the six principles of PBE were established using a combination of a priori knowledge of place-based practices later combined with emergent grounded theory from reading the data closely. These were the primary lenses to examine the data for the two rounds of coding, respectively.

For the first round, a precursory list of codes was written based solely on the broader literature and a priori ideas of PBE. Precursory codes did not always pick up place-based themes but accomplished its purpose of starting to establish a path to navigate the hidden meanings within the lessons. Therefore, the researcher made note of nuances, novelties, and other trends in the language of the data. Whenever the researcher was faced with an uncertainty or a novel concept in the text, an interim code was written to be reviewed later. Codes such as “Is KWL learner centered?” (Lesson P5) or “Using real costs makes the project true to life” (Lesson S1) served as notes-to-self when reviewing the data for concrete themes and sub-themes (see appendix A & B).

Word choice and implied meanings were noted in the text. Underlying meanings had to be taken into account cautiously without going so far into latent or interpretive meanings that the researcher loses sight of the probable meaning written by the lesson’s author. An obvious implied meaning would be “students then use their compasses to shoot a bearing at a tree or mountain” implying that the class has gone outside for the lesson (Lesson S4, see appendix B).

Synonymous terms were also combined in the revised codebook. One example is within the theme of Learner Centered where the sub-themes “diversified instruction” and “enrichment opportunities” describe a synonymous teaching concept and thus were combined.

A revised codebook was made from a synthesis of this information. Table 3 represents the final codebook used for round two of coding.

After the second round of coding, the researcher found a wide range of results. Some themes were nearly absent while others were found in almost every data item. The most common and thoroughly described themes were community as classroom, learner centered, and inquiry based. On the other hand, the less frequent themes were local to global, design thinking, and interdisciplinary approach which were either infrequent, not explicit, absent, or missed by the researcher in much of the data.

This pattern is both rational and surprising. For example, learner centered teaching is a common and effective practice and thus would be expected frequently in this study, but so is design thinking which was not found frequently (NGSS, n.d.; Salinas & Garr, 2009). Local to global is a place-based practice which that has not come up in the literature, so it was not expected to be frequent. It was in fact the least frequent of all principles. All six of the place-based principles and their sub-themes are examined more closely below.

Community as Classroom

This principle is characterized by using the local community as the setting or subject of lessons and treating the classroom/school itself as a small community. Aspects of community-as-classroom were found frequently in both groups. There was no statistically significant difference between groups (P=0.069). Both groups contained the principle more than half the time.

In the primary group, community-as-classroom was not commonly represented. Only three of ten (3/10) lessons had a strong representation. On the other hand, in three of ten (3/10) lessons the theme was absent.

In the secondary group, this is the most commonly found principle. Three out of ten (3/10) lesson plans had a perfect representation, matched only by the three perfect scores in principle 3: inquiry-based. Seven out of ten (7/10) had at least a strong representation. Furthermore, all sub-themes were more frequently represented in the secondary group than the primary group as shown in Figure 3.

Despite the statistical non-significance, the researcher believes that principle 1: community as classroom is more strongly represented at the secondary level because each sub-theme was found more strongly in the secondary group. The strength of representation is stronger in both number and depth of description. Each of the sub-themes are addressed below.

Sub-theme “leaving the classroom / community as setting for lessons” represented any instance where the class either physically moved locations or used the local context as the basis for their lesson. Few times did the lessons call for physical travel which would be the most place-based action.

Sub-theme “consider natural resources” represents any instance where a lesson takes into account environmental issues or the stewardship of natural resources. Some lessons such as S4 and S8 were based in technical skills and did not have much potential to consider natural resources. However, many lessons in the primary group had this opportunity and did not take it. Some examples of missed opportunity where in lessons P2, 3, and 5 which were all based on natural phenomena such as earthquakes and tornadoes.

Sub-theme “real-world connections” represents lesson content which enables students to be active citizens in their community outside of school. Every lesson in the secondary group made this type of connection. It seems to be the natural progression that as students mature into young adults, they will take on more real-world responsibilities. Youth are empowered when given useful roles in the community (Hamilton et al., 2004). The secondary lessons studied here show there is a concerted effort for educators to make this connection.

Sub-theme “showcase professions” represents the depiction of jobs or careers built into a lesson for the purpose of giving students an idea of what they could pursue after school. Since the lessons from teachengineering.org are all tailored to feature some aspect of engineering, However, a deeper description of a profession was necessary to score in this category. This sub-theme was featured in both groups, but few professions were featured in primary school. Why? Perhaps this is of lesser concern for younger students compared to the older age group.

Community as classroom sub-themes were found to be the most frequent of all principles at the secondary level, with a compiled score of 29 out of the possible 40. Although many sub-themes were found to describe community as classroom, few lessons would constitute a thorough practice of this principle. Perfect scores were awarded to lessons S1, S2, and S6. Yet it is difficult to equate these with a lesson tailored intentionally to engage the community in the classroom. These lessons check all the quantitative requirements, but only scratch the surface of what is possible when applying those sub-themes in-depth. For example, leaving the classroom for an outside activity is one level, while taking a trip to a local business as part of a class project is another level. Breaking the four walls of the classroom is one objective of PBE (Smith, 2007). A simple example of leaving the classroom is shown in the excerpt below.

> Go outside or into a gymnasium space to demonstrate S waves with a [gentle] game of snap the whip. Have students line up and hold hands. The first person in line runs first in one direction and then back to make the line look and move like a long snake -Lesson P2: Earthquake's rock.

When looking at lessons through the lens of "community as classroom", there were frequent instances where the lessons could be easily adapted into truly place-based lessons. Simple actions like doing this lesson outside, visiting a location or institution related to the topic or calling an expert to speak on the topic would make these lessons much more community centered. The Rock Solid lesson (S3) could have made use of an outdoor location to teach about rock types in an immersive way in addition to bringing rock samples into the classroom. Topo Mania (S4) is another example where practicing navigation outside or using a local map would be far more community centered than staying inside using prescribed maps of irrelevant places (see appendix B).

Learner Centered

The learner centered approach was described frequently in both sample groups; 26 times in the primary group and 24 times in the secondary group. There is statistically no significant difference between the two groups. Six out of ten (6/10) primary lessons had at least a strong representation (score of 3) of the theme and one perfect representation. Similarly, half (5/10) of the secondary lessons had a strong representation. At least one learner-centered sub-theme was present in every single lesson in the dataset (see Table 4).

What both groups did best was cater to the student's lived experience and make complex content student friendly eight out of ten (8/10) times in both groups. This is important in helping student motivation, when the content of the lesson is relatable (McCombs & Whisler, 1997). Refer to the following excerpt where the connection is made to a student's home address. This is more relevant to the student, to locate home coordinates than some ambiguous location.

> Have each student bring in his/her address and look up his/her own — or alternatively, the school's — latitude and longitude (as close as possible with available maps). -Lesson S8: Where is Here?

Learner centered teaching is an expected part of public education at this point in the United States (Smart et al., 2012). The fact that learner centered sub-themes are described in every single data item reflects this standard of practice. Moreover, nine out of ten (9/10) lessons in both groups had multiple sub-themes. See Figure 4 for a comparison of all learner-centered sub-themes between groups.

Sub-theme “diversification” represents any instance where alternate lesson approaches are explained for the purpose of reaching a broad classroom audience. This also includes enrichment opportunities or alternative options for IEP students. Diversification is common, being found more than half the time in both groups.

Sub-theme “connected to lived experience” represents a variety of possible instances. These include lessons using relatable content which would help a specific age group understand through their own knowledge and experiences. This was found eight out of ten times in both groups. Many lessons used multiple connections to help ground complex learning themes.

Sub-theme “student choice” looked for instances where an activity is left open ended where the student chooses how to tackle a problem or research a topic. One example includes lesson P7 which let students choose the object of their research within the larger lesson topic of volcanoes. Choice was more frequent at the secondary level, perhaps because of the age and maturity difference.

Sub-theme “open discussion” represents any class discussion that is not limited to specific teacher-generated questions and is not primarily teacher-led. Many lesson plans contained an open and student-led discussion similar to this excerpt from P2.

> As a class, have the students engage in open discussion. Solicit, integrate and summarize student responses. Give clues if necessary. Remind students that in brainstorming, no

idea or suggestion is "silly." All ideas should be respectfully heard. -P2: Earthquakes Rock!

Learner centered excerpts from the data tended to be written more in-depth at the primary level, perhaps to cater to a young audience. Nevertheless, it was still present in a comparable way at the secondary level but described more simply in the text. Learner centered is one principle that yielded almost no noteworthy differences between sample groups. It is safe to say that the use of learner centered methods are thoroughly represented and consistently used throughout K-12 education.

Inquiry Based

As anticipated, inquiry-based teaching strategies were abundantly described in the data. Both sample groups had a similar representation of the theme; primary scoring 24 and secondary scoring 25 overall.

Inquiry had more perfect scores than any of the other principles tested. Five lessons had a perfect score representing a complete inquiry process. Since inquiry based teaching is systematic and has many interlocking steps, it was observed to be intentionally written as a complete process in the sampled lesson plans. This makes it easier to interpret a thorough description of inquiry as being genuine. A lesson with all phases of inquiry would not happen by accident, rather it would be a great example of inquiry-based teaching. These sub-themes represent those phases accordingly. See Figure 5 for a comparison of all inquiry based sub-themes between groups.

Sub-theme “question / hypothesize” indicates where students are prompted to generate a question or hypothesis of their own before conducting an investigation. This is a simple quality to measure, the key for this is that the students and not the teacher are the ones formulating the question. One reason this sub theme was less frequent in the data was that some lessons had a question already in place which the students then explore. Four lessons in the data pool lacked questioning / hypothesizing but otherwise contained a complete inquiry process. By missing the first step of inquiry, these were incomplete, low-level usages the inquiry process.

Sub-theme “explore / research” indicated any act of students engaging in the research process ranging from simply investigating a topic for a report to the intensive design and execution of an experiment. Largely, the primary group either had prescribed exploration instructions for students or the exploration was not part of a true inquiry process. This was observed in lessons P1, 2, 3, 5, 6, and 7. More often the secondary group had complete research designs, observed in lessons S6 and S10.

Sub-theme “data collection & analysis” can refer to the collection and synthesis of information online or the physical collection of data in an experiment that may use data collection instruments. Some lessons either provided data or substantial data was not called for. Only lessons which explicitly instructed students to gather their own information were counted here.

Sub-theme “opportunity for revision and communication” refers broadly to the later phases of inquiry where information is shared, debated, revised, and possibly restarted with a new research question. The data shows almost every time a lesson calls for students to “explore / research” they are also called to communicate their findings.

Local to Global

A local to global framework was found least frequently out of the six principles in the primary group and second to least frequently in the secondary group. This is also the only time in the data when one group was statistically more frequent than the other. Secondary education features a local to global context more frequently than in primary education with a P-value of (P=0.005).

Of all the principles of PBE this is perhaps the least established as a pre-existing pedagogy. Two factors lead to this understanding. First, there is a lack of literature to support the specific idea of a local to global framework outside of place-based texts. Second, this study found little to reveal local-to-global practices being used in earth science lesson plans. See Figure 6 for a comparison of all local to global sub-themes between groups.

Sub-theme “use local resources” indicates when anything from the local community was made use of for the lesson. Local resources included professional speakers, local laws and policies, and local institutions such as a power plant. This also overlaps somewhat with the community as classroom theme but is far more specific.

Sub-theme “compare local to global phenomena” refers to any connection made between a small and large scale phenomena which is relatable to the students in the community. A good use of this sub-theme was in lesson S6 which made a point about complex atmosphere science by connected local air quality to air quality in China. This sub-theme was expected to appear more often but was absent in the primary group and found four times in the secondary group.

Sub-theme “classroom as community” refers to the classroom operating less like a traditional classroom and more like the greater environment or society. This could include simulations that mimic nature or human elements of natural resource management. It could also include community projects such as a school garden or environmental project. However, these were not found in the data. In the dataset only two lessons treated the classroom like a community, and they were both navigation and map making lessons S4 and S8 which used the school itself to teach map reading.

Sub-theme “knowledge expanded to global issues / events” refers to making a connection between the lesson and real events where one helps students understand the other. This connection could be between the same phenomena at different scales, such as the solar water heaters in S1 compared to large scale solar energy or experimenting with a seismograph in P2 compared to data from major earthquakes.

Design Thinking

Design thinking was a surprising case. Literature shows it is a common teaching tool (Savery, 2015; Wood, 2003), yet it was largely undetected in the data. In hindsight it makes sense that the elements which require several sequential classes would go undetected. Few lessons in this dataset indicated they were part of a larger project. Regardless, a few sub-themes were detected and discussed below. See Figure 7 for a comparison between both sample groups.

Sub-theme “problem posed before the tools to solve it” is somewhat self-explanatory. It indicates any time students are made to wrestle with a problem and discover the skills needed to solve it along the way. Only two lessons had this sub-theme, one in each group. Lesson S4 on reading topographic maps is a good example. An objective is posed initially; students need to travel to a known location. The problem is deciding on the navigational methods which are learned throughout the lesson. Lesson P8 on water quality is the other example. Here students are made to design a water filtration system with only a bucket of dirty water and the tools needed to create it.

Sub theme “emphasis on creative problem solving” is an attitude that emphasizes a student’s thought process over following a teacher-directed pipeline to the right answer. It would be easy for a teacher to imply this attitude or add-in without it written in the lesson plan. Therefore, this needed to be found explicitly to count.

Sub-theme "tackle real-world problems" could be any instance where the students are made to design a solution to a. To be considered genuinely place-based it should contain the intention of genuinely improving an issue, but this is also not required. A low level example would be testing earthquake resistant popsicle stick structures in lesson P2. A high level example with potential for real positive action would be the air quality and emissions testing in lesson S6. Generally, the secondary group contained more high level problem solving scenarios.

Sub-theme "hands-on / multi-class project" refers to any project where students create a functional device, model, or a novel idea or system to solve a problem. A true place-based design project would ideally be extensive covering multiple class periods and contain moments of revision and ample opportunity for creativity. One noteworthy pattern is that the primary group only had one multi-class project while the secondary group had six. Two lessons were part of an extensive multi-class project (S1 & P4) where both required designing an instrument and multi-day observations.

Interdisciplinary Approach

An interdisciplinary approach is characterized by breaking out of the single-subject style of teaching to overlap with other disciplines or other schools of thought. The NGSS standards call for more emphasis on Crosscutting concepts which have applications across all domains of science (NGSS, n.d.). Beyond this, other non-science disciplines in school can be crossed over with science including the arts (Harris & De Bruin, 2018). This study detected crossover with many other disciplines, including history, literature, art, civics, and other disciplines of science

Sub-theme “crossover with other disciplines” is the most general parameter which indicates if there is any overlap at all. The website has a focus on engineering practices and every lesson featured engineering practices. For a fair assessment “crossover with other disciplines” the assessment needed to exclude engineering and look for other examples such as language arts or history. Including engineering in this would skew the data to suggest that general lesson plans crossover with other disciplines 100% of the time.

Nevertheless, Earth science itself uses a wide variety of sciences including biology, chemistry, physics, math, hydrology, and ecology. Therefore, it seems natural that these would show up frequently. See Figure 8 for a comparison of the sub-themes between sample groups.

Sub-theme “complex multi-dimensional project” is characterized by a high level of complexity. Similar to the design thinking, the key difference is this creative process must include multiple disciplines.

Sub-theme “multiple modes of thought” can include interdisciplinary crossover, but more generally could be any kind of out-of-the-box thinking that is explicitly called for in the lesson.

Sub-them “visit another classroom” is self-explanatory. It would be an interdisciplinary act to take an earth science class and meet up with a biology class to engage in a project. However, this type of action was never mentioned anywhere in the data.

Chapter 5

General Conclusions

Place-based education has great potential to benefit the Earth and geo-sciences. Place in the context of PBE is not simply a location, but it is an explicit focus on the attributes and meanings of a place. It promotes authentic experiences and enriches the student's sense of that place (Semken et al., 2017). While Earth science is self-evidently based on the place where people all live, it could stand to be enriched by the principles of PBE.

This study is a first step in explaining and measuring the use and potential use of PBE in contemporary Earth science education. Coding and scoring lesson plans against a rubric for place-based principles provided evidence to help answer the primary questions of this study. The questions of this study were:

1. How do the six principles of PBE manifest in open-source lesson plans written for contemporary NGSS Earth science?
2. How frequently are the six principles of PBE used in primary education lesson plans compared to secondary education lesson plans?

Both research questions overlap in their findings and significance, thus both are discussed together with each principle in the sections below. After covering the six primary principles, additional insights from observations beyond the original research questions were discussed. To conclude, limitations to the claims and generalizability of this research as well as ideas for future research are discussed.

Research Question #1

Representation of place-based principles in the data varied greatly from weak to strong representations. Principles represented more than half the time across both sample groups include principle 1 – community as classroom, principle 2 – learner centered, and principle 3 – inquiry based. Principles represented less than half the time across both sample groups include principle 4 – local to global, principle 5 – design thinking, and principle 6 – interdisciplinary approach. The quantitative split between strong and weak representation is supported qualitatively and is discussed in a principle specific basis in the sections below.

All of the principles were found to a certain degree somewhere in the data, although some sub-themes were missing. indicating that none of them are completely untenable.

Research Question #2

To add depth to these findings the researcher asked this quantitative comparative question. How frequently are any of the six principles of PBE used in primary Earth science lesson plans compared to secondary Earth science lesson plans? A simple paired t-test between sample groups is used to answer this research question. Furthermore, both inferential and descriptive statistics are used to function as a quantitative support mechanism for the qualitative findings in the data. The statistical findings are presented alongside the qualitative findings according to each place-based principle in the sections below.

Principle 1 – Community as Classroom

This principle is characterized by using the local community as the setting or subject of lessons and treating the classroom/school itself as a small community. Aspects of community-as-classroom were found frequently in both groups. There was no significant difference between groups and both groups contained the principle more than half the time.

Community as classroom was the most frequently discovered principle which appeared in every lesson in the secondary group. It was also discovered in the primary group more than half the time. There was strong representation of the principle but at varying levels. A true place-based lesson would break the four walls of the classroom more intensely and intentionally than many of these lessons did. See the quote from lesson P2 on page 49.

This basic level of breaking the four walls of the classroom constitutes one limitation of this specific data pool. Field trips and intensive community engagement would not be reasonably expected in these short lesson plans. Therefore, the easier to implement and surface level qualities of the six principles are what was available for the purpose of this study.

One striking trend is that a "real-world connection" is made in every single secondary lesson compared to only four in the primary group. This is aligned with the idea that secondary level classrooms put more effort into preparing students for life beyond the classrooms. As stated by place-based scholars ad-nauseum, PBE is meant to prepare students to be active citizens on their communities and in the world (Gruenewald, 2003a; Sobel, 2004). It is because of this that, despite no statistically significant difference (P=0.069), the researcher posits that community as classroom is more strongly represented at the secondary level.

Principle 2 – Learner Centered

The learner centered approach is characterized by a shift from "what teachers teach" to "what students learn" (McCombs, 2003). Teaching with a learner centered focus is mainstream and highly encouraged across public school education today (Smart et al., 2012). Accordingly, learner centered practices were frequently found in the data. There was no significant difference between groups (P=0.637) and both groups contained the principle more than half the time.

Every single lesson had a learner centered sub-theme. Implications for special education include a high frequency of diversified instruction and student choice. A wide range of diversification may help allow students to remain in the least restrictive environment more often.

It is apparent based on this data that a learner centered approach is a mainstream educational approach. Therefore, it is fair to say that the second principle of PBE is thoroughly represented in contemporary education.

Principle 3 – Inquiry Based

An inquiry based approach is one of the most essential aspects of science and science education (NRC, 1996 & 2000). It is expected to find this principle commonly in science lesson plans and according to the data it was commonly represented. Inquiry was commonly and consistently represented across both groups and there was no statistically significant difference between groups.

Five lessons had perfect scores for inquiry across both groups which shows a complete inquiry process in those lessons. Inquiry also resulted in more perfect scores than any other place-based principle across both groups. Notwithstanding, the only weak or absent scores came from low detail and rudimentary lessons which produced little data for this study overall (S4, S9).

It is no surprise that inquiry based teaching was thoroughly represented in the data as it is fundamental to the sciences (NRC, 2000). This study can conclude that the third principle of PBE is commonly represented in contemporary science education.

Principle 4 – Local to Global

This dataset often lacked evidence of a local to global context. In the primary group it was completely absent from six of the ten lessons, and in the secondary group it was never strongly represented. Yet, local to global context is significantly more represented in secondary education compared to primary education (P=0.005). This was the only statistically significant difference from the six tested groups.

Local to global is an odd case because although the secondary group is significantly more frequent than the primary, both groups are poorly represented compared to the other themes and weakly detailed in the lessons overall. This paper concludes that the fourth principle of PBE is not commonly represented in contemporary science education.

The researcher surmises from what is available in this dataset that the idea of connecting school topics to larger global issues is not a priority in early education. They also claim that even with greater representation at the secondary level, there should still be more connections made between the student's immediate surroundings and the larger globe and society.

Principle 5 – Design Thinking

This principle was surprisingly infrequent. Since design thinking is a useful tool for practicing diagnosis and deductive reasoning, the researcher expected it would appear more strongly (Savery, 2015). Nevertheless, a strong representation was found in a few secondary level lessons (see Figure 7).

Hands on and multi-class projects occurred in the majority of secondary lessons, but only once in the primary group. This may be another example of academic rigor increasing with maturity, or the older age group receiving more true-to-life work in the form of extended projects. Regardless of the reason, it shows that class projects are frequent.

The idea of delivering instruction in an open ended fashion was frequent in the data. Lessons that have sub themes "tackling real-world problems" and "emphasis on creative problem solving over 'getting it right'" have a strong influence on students, calling upon their own creative problem solving skills. When combined, it shows that the majority of lessons are open-ended and design-driven which is important to the academic goals of PBE which includes student-led and self-directed learning (Wood, 2003), and preparing students for careers. In an ever changing economy, it is the adaptable problem solvers that will succeed. This fact makes the design thinking approach an important aspect for future education.

Beyond the detected data, defining and searching for elements of design thinking was trickier than most other themes. It was difficult to identify design thinking and interdisciplinary approach because of the time scale. Methods like these seem to need multiple classes to come to fruition. Occasionally these were explicitly written into the lesson plan, but more often it would be necessary to look at a sequence of several lessons to identify the complete design thinking process.

It is also possible that aspects of design thinking were missed because of the way this rubric was written. Other particular traits of this principle may not have been considered by the researcher while being present in the data and thus left undetected. This could be said of the other themes/principles as well but especially of this theme, design thinking.

Principle 6 – Interdisciplinary Approach

An interdisciplinary approach to teaching in the form of problem-based learning has expanded into K-12 schools at the turn of the century (Savery, 2015). The STEM sciences have also become integrated as a powerful and unified learning tool (Burrows, 2018). The place-based principle of an interdisciplinary approach is another principle that is already established in education, but this study produced mixed results.

Secondary education often divides the learning disciplines into classes. Primary education has a home room, but still has partitions between learning disciplines. However, in the real world nearly every endeavor is an interdisciplinary one. Place-based education prepares students for life by giving them critical thinking practice with interdisciplinary teaching.

Interdisciplinary teaching was not detected at a high rate in this study, potentially because the coding rubric used was not adequate to detect it (see Figure 8). The sub-theme of "visiting another classroom" was absent and not a practical item of measurement for the nature of this data while other sub-themes were also infrequent or absent. Yet, both primary and secondary groups had a strong representation of science "crossing over" with other disciplines. This is aligned with the aforementioned trends in interdisciplinary teaching (Burrows, 2018; Savery, 2015).

There was no statistical difference in the representation of interdisciplinary teaching between primary and secondary education (P=1).

This paper suggests that teaching the sciences does and should take an interdisciplinary approach. Not only in integrating the four disciplines of STEM, but it can and should use a wide variety of schools of thought. History and literature crossover was found frequently in the data and were used to create context which may benefit science learning in both primary and secondary education.

Overall Trends in Data

Place-based principles were found throughout the data in one way or another. Some of the six principles were found much more frequently than others. Expectedly, a couple more common, vetted, and established pedagogical principles which were found most frequently in both groups. These include the learner centered approach and inquiry-based teaching. Learner centered and inquiry-based lessons appear more than half the time in both sample groups. Both pedagogical principles are firmly synonymous with the objectives of PBE. However, two other established pedagogies, design thinking and interdisciplinary approach, were not commonly detected. As discussed above, the data does not make a strong enough case to dismiss these two principles as indicators of place-based teaching.

The two principles relatively unique to PBE, local to global and community as classroom, also had split results. Most lessons used several community aspects in their lessons, but there were few connections made between the near and the far.

Use of age appropriate content is the most apparent qualitative trend between the primary and secondary sample groups. As students graduate from primary to secondary level school, they approach adulthood and thus are exposed to more scholastic aspects which relate to citizenship and careers. Some of the largest differences in this trend were found in real world connections, showcasing professions, comparing local to global phenomenon, hands-on multi-class projects.

Limitations

This section addresses limitations specific to this research. It is important to be transparent with limitations, especially with the interpretive nature of qualitative research and the accompanying thick descriptions which come from the perspective of the researcher.

The most important limitation to acknowledge is the unavoidable perspective of the researcher combined with the small sample size. Small sample sizes are appropriate to produce usable findings in qualitative study (Braun & Clarke, 2006). Nonetheless, this study should be acknowledged as a small representation of a population with limited generalizability.

Moreover, these relatively unspecific lesson plans make sense in context because their purpose is to be a template easily integrated into any teacher's curriculum, which means that much of the technique is up to the teacher. It is harder to identify explicit examples of PBE or any other pedagogy in this case. The researcher must then recognize that this is not a complete indicator of how place-based common contemporary education is.

The second most significant limitation is that it has proven difficult to identify a single thoroughly place-based lesson. Deeply intentional connections to place were not detected simply because there was no intent written into these lesson plans. Since there is no explicit intent to be place-based, there is no authentic place-based characteristics (Semken et al., 2017). This fact was known at the beginning of the study, yet it still limits what can be interpreted as place-based.

Undetectable traits also have partly to do with the temporal scale of a place-based curriculum. Typically, place-based education is done over longer periods, over multiple classes, or weeks of activity. Although these lesson plans provide a neat snapshot into current education, they literally fall short in capturing the entire complexity of PBE. This had an impact on what was detected in the design thinking principle. Perhaps the analysis of an entire unit or curriculum would elicit more holistic descriptions of PBE in a future study.

Another significant limitation is that these lessons leave some details ambiguous. Details that come down to teacher choice are left open ended and do not always make explicit statements which could be detected by the instrument of this study. Often these lesson details are on the cusp of being place-based but lack sufficiently explicit instruction or detail to be objectively PBE. Such indeterminate writing includes whether to go outside or to use local features as illustrative examples.

Recommendations and Future Research

Regardless of the results, the data in this study can be made useful for the advancement of PBE. Areas of commonality make a strong case for the feasibility to tweak lessons for a more place-based style. Likewise, areas of scarcity can be taken as a sign to bolster those efforts. Trends like these can provide useful insight to the implementation of PBE in future Earth science classrooms. Furthermore, this study also serves as a generalizable pilot study for future research into the use of place-based principles in other educational disciplines. Such ideas are discussed below to conclude this paper.

First, there are several themes found which educators are already using commonly. Second, there are differences in the implementation of some themes between the primary and secondary groups. Third, some place-based principles which are not present would be easy to implement with some intentional adaptation by the teacher. Considering the limitations of the data pool and research design, these factors will be discussed with appropriate judgment on generalizability.

Within these lessons there are instances where a place-based approach would be easily adapted or implemented. For example, using a local watershed as the subject of analysis in "Watershed Balance" is just as feasible as the San Francisco example from Sobel (2004) and uses the local environment.

Pre-service teachers are trained in fundamental and state-of-the-art pedagogies which prepare them for the classroom setting. However, due to a great volume of teaching methods and a limited time-frame to be trained in them, pre-service teachers come out of the certification program with an adequate yet limited set of skills. Successful teachers, of course, continue to develop skills through many years of experience and professional development beyond the short pre-service certification program (DeMonte, 2013). At many universities, PBE does not yet exist in the pre-service teacher education curriculum (Elfer, 2011).

Similar to the methods and objectives of this study, future research can be done on the implicit existence of place-based teaching methods in non-explicit place-based settings. A question for a future study may be whether or not pre-service teachers enter the teaching profession with any preconceptions about the implementation of PBE without any prior training in PBE.

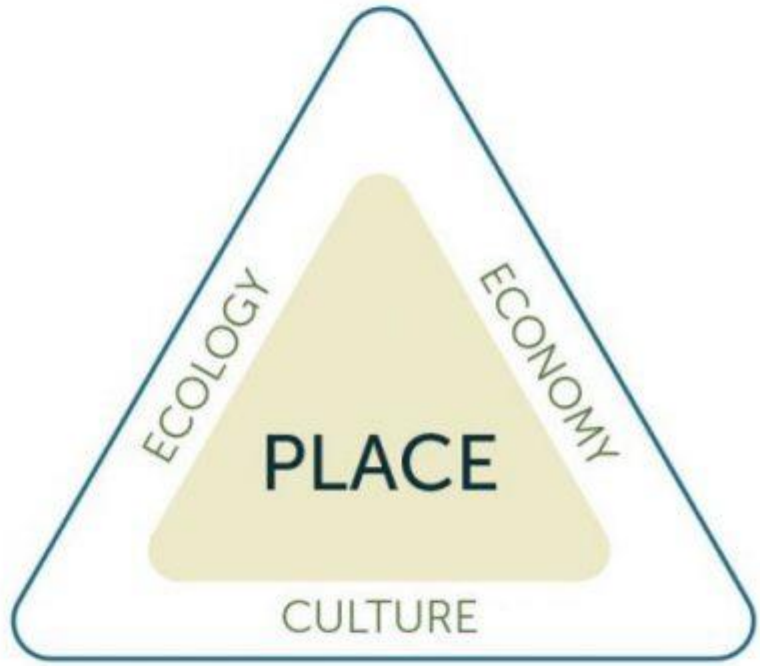

Figure 1: TSS Place Triangle

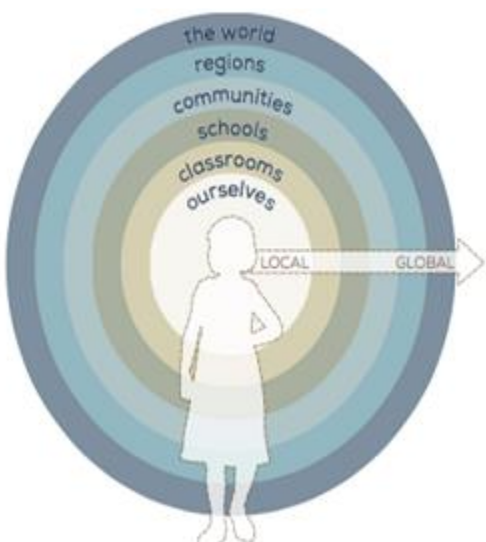

Figure 2: TSS Local to Global Context

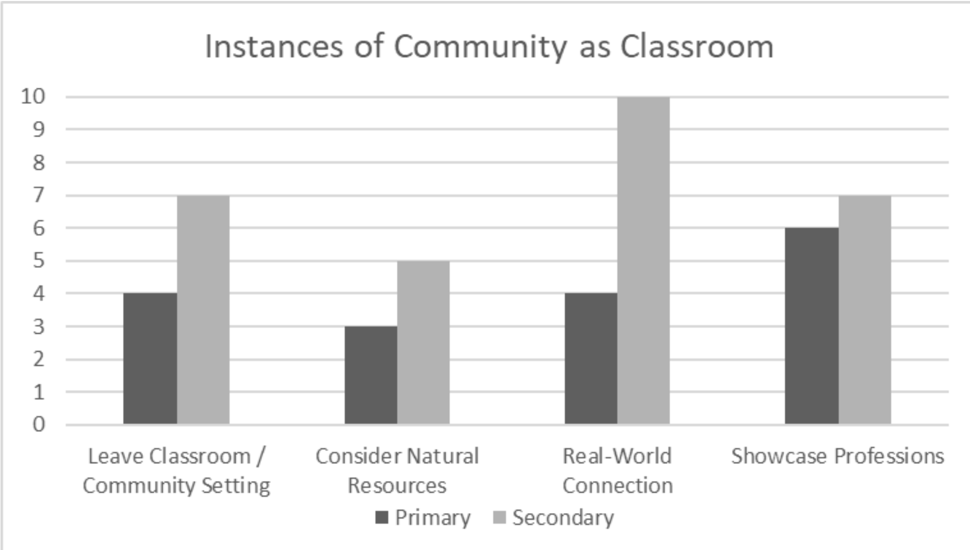

Figure 3: Instances of Principle 1: Community as Classroom sub themes

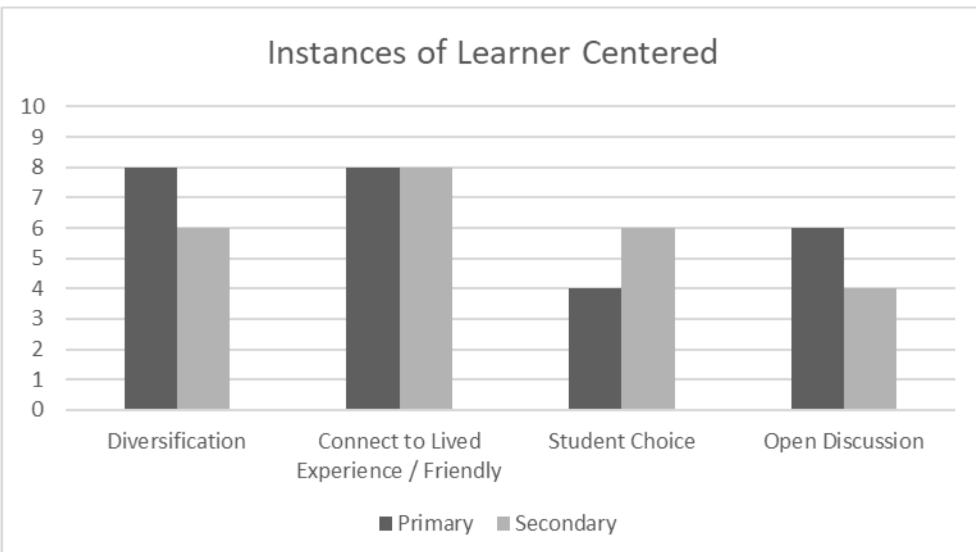

Figure 4: Instances of Learner Centered sub-themes.

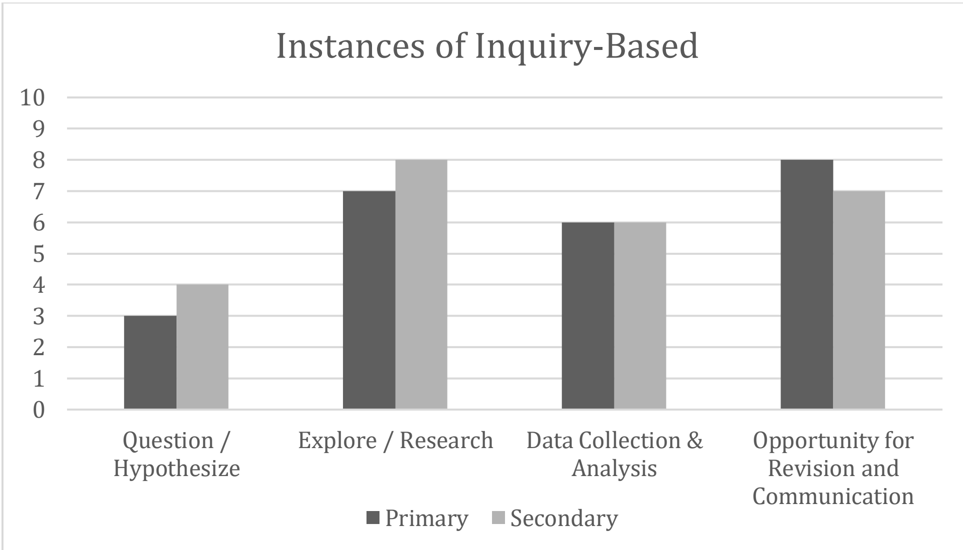

Figure 5: Instances of Inquiry-Based sub-themes

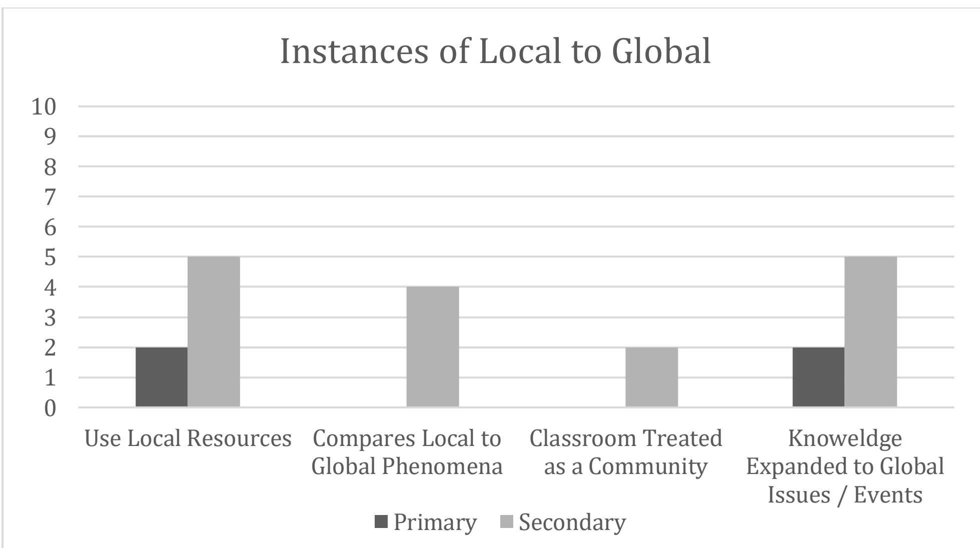

Figure 6: Instances of Local to Global sub-themes.

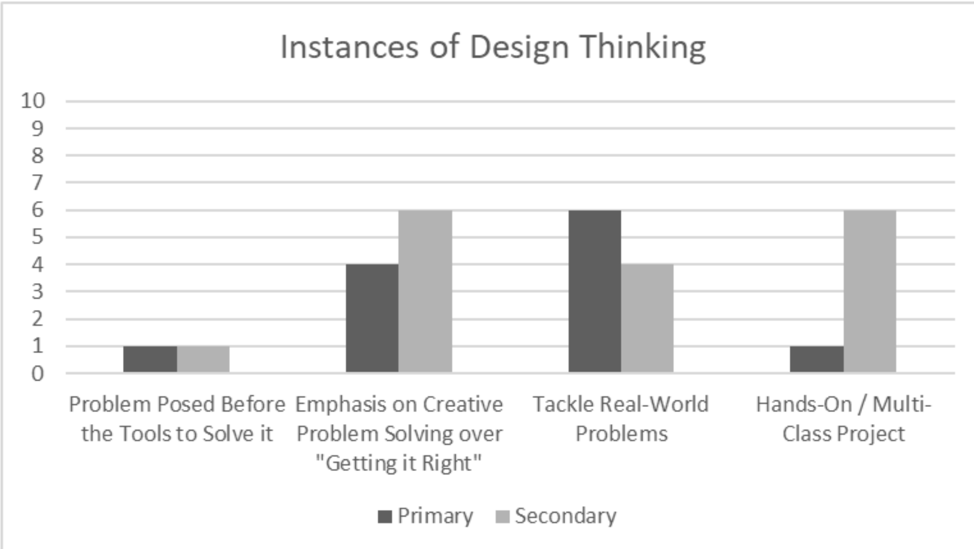

Figure 7: Instances of Design Thinking sub-themes.

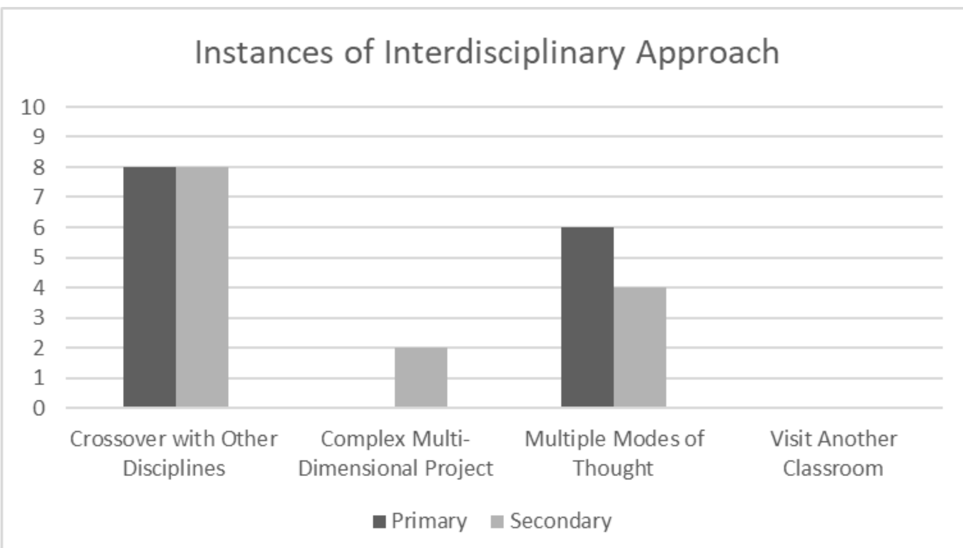

Figure 8: Instances of Interdisciplinary Approach sub-themes.

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Appendix A

Compiled codes and select excerpts from the K-5th group.

Renewable Energy (P1)	Earthquakes Rock (P2)	Earthquake Formation (P3)	Lunar Learning (P4)	Tornado (P5)
Consider natural resources Real-world Connection Connection to lived experience Open discussion Explore / research Communicate and defend findings NGSS Crossover history Data collection Tackle real-world problem Opportunity for revision Showcase professions Multiple modes of thought Diversified instruction ---	NGSS Crossover with history, Diversified instruction Leaving the classroom Relatable content and demo **Knowledge expanded to current events Multiple modes of thought Tackle real-world problem Consider a client / sell a brand Explore / research Opportunity for revision Showcase professions (engineering) Data analysis using technology Communicate and defend (Peer-review) Student Choice Open discussion	NGSS Relatable content Explore / research a topic Connect to lived experience Student Choice in Learning Crossover with language arts Diversified instruction ---	Multi-dimensional project NGSS Students explore/ research Communicate observations Hands-on project Question / hypothesize Open discussion Diversified instruction Data collection ---	NGSS Relatable content (pop culture) Connect to lived experience (minor) Tackle Real-world problem Showcase professions hands-on Multiple modes of thought KWL Student centered? Explore/research Communicate and defend findings Diversified instruction Emphasis on creative problem solving Uses local resources (speaker) Community is setting for lesson ---
Energy is everywhere! Although sometimes you can hear energy (sound), feel energy (wind), taste energy (food), and see energy (light), most often it	Go outside or into a gymnasium space to demonstrate S waves with a [gentle] game of snap the whip. Have students line up and hold hands. The first person in line runs first in one direction and	Activity Extensions Math Extension (for advanced math students): Print out the attached Scaling Down the Earth – Math Extension Worksheet.	Students create Moon Logs to record and sketch how the Moon looks each night in the sky. With these first-hand observations, they are ready to figure out how the continuously changing relative positions of the	Using what we have learned to describe some of the characteristics of tornados, and we will create a flyer to educate people about the warning signs of a tornado and help describe what to do

is hard to figure out exactly where energy is. Save a Watt: Ask students to engage in two energy saving activities before the next class period. Ask them to describe in detail the impact these actions had during the next class. You can have the students list the activities or write a paragraph and turn the assignment in. As a generic test, pour a fixed amount of water over the waterwheel and count the number of turns it makes. Have a student time this test by using a stopwatch to record the elapsed time. Have a few groups present their designs to the rest of the class indicating what elements worked well and what they could improve on. Engineering Design project: Divide students into groups and tell them that they are working for H2O Solutions, an engineering design firm that works mostly with waterwheels and water	then back to make the line look and move like a long snake.) Engineering Poster: Using the skills they learned in the three lesson activities and the lesson on how earthquakes form, have students create a poster of a best design for a building that would withstand an earthquake. Have them title their posters with an engineering firm name that they make up. (Example: Shaky Engineering Firm). Have the students work in teams of four if possible? Discussion/Brainstorming: As a class, have the students engage in open discussion. Solicit, integrate, and summarize student responses. Give clues if necessary. Remind students that in brainstorming, no idea or suggestion is "silly." All ideas should be respectfully heard. Town meeting: Tell the students that each group is an engineering firm. Each group should choose a name for their firm. Tell them that the town found a seismograph and does not know how it works. The town has asked their	Pass out calculators. Read the worksheet instructions aloud to the class. Help students by going over the "Inner Core" as a class. Have them finish the rest of the worksheet independently. Have students complete the table by calculating the actual diameters of the Earth's layers.	Moon, Earth and Sun result in the different shapes and sizes.	if you live in an area with tornado activity. The students can be as creative as they want; there are no wrong answers. Invite a structural or civil engineer to discuss building designs that help prevent loss during windstorms.

energy. The city has asked them to design a more efficient watermill. The firm has been split into several engineering teams (student groups). Tell the teams that they must design a functioning waterwheel that turns, and their constraint is to use only the materials provided for their designs. Have students conduct research: How much water do Americans use daily? For what purposes? Do people in other countries use as much water? What are some ways to conserve water?	engineering firm to test the seismograph and figure out how it works. At a local town meeting, have the different engineering firms report back to the community on what they have discovered. Have the students make a short presentation or create an informative flyer for distribution to the community.			

Greenhouse (P6)	Volcanic (P7)	Water (P8)	Newton (P9)	Using Thrust (P10)
Crossover with civics and law biology/chemistry Language Arts NGSS Connect to lived experience Multiple modes of thought (poetry) Potential for PBE (real climate action) Consider natural resources Open discussion	NGSS Connect to lived experience (minor) Crossover (Historical references) Relatable content Tackle real-world problem Communicate findings Explore / Research a topic Student choice Question / Hypothesize	NGSS Consider natural resources Problem before tools Showcase profession Connected to lived experience (minor) Tackle real-world problem Communicate and defend Opportunity for revision ---	NGSS Relatable content Crossover with math and physics Real-world Connections Open Discussion Leaving the Classroom Knowledge Expanded Showcase professions Data collection Question / hypothesize	NGSS Multiple modes of thought Crossover (history) Real-world connection Student choice Showcase profession (engineering) Opportunity for revision Data collection Emphasis on Creative Diversified instruction

Relatable content Real-world connection Tackle problem (write bill) Explore / research Use local resources Community is setting for lesson Communicate and defend (minor) Diversified instruction ---	Data Collection Open discussion Multiple modes of thought Emphasis on creative ---		Diversified instruction ---	---
Create a Poem: Have the students write a short poem that expresses what they understand about global warming and how it may affect our environment in the next 50 years. Explain how a bill becomes law in the U.S. Congress and research legislation related to global warming. Activity Scaling Depending on the abilities of the students, adjust the written summary of proposed legislation to be an individual, team, or class project.	The crust is much thinner than the other two layers. If you think of the Earth as an egg, the crust would be the shell, the mantle would be the egg white, and the core would be the yolk. Have them sketch or design an instrument that could help detect an eruption and present their designs to the class. Have students each research a specific volcano, finding out its location, the last time it erupted, what type it is, and whether or not it currently threatens any population centers.	By building houses and roads near streams and rivers, humans can increase DOM content in water. However, humans can help reduce erosion! By planting ground cover on hills and stream banks, roots systems help to maintain the natural structure of the soil, and therefore helps limit erosion. Have students brainstorm and then sketch filter designs on their worksheets. Their sketches should show the various layers of materials they are going to use. Have students show their designs to the teacher and explain why they think their designs will work.	Engineers who design rockets might even experiment with a small wooden car to understand Newton's third law of motion. Such a car must obey the laws of motion, just as a rocket must. Observing how a toy wooden car moves forward when a small block is launched off its back is analogous to a rocket moving forward when hot gases are expelled from the back of the rocket. Why would engineers need to build small-sized model cars like ours? Well, engineers often build models to demonstrate and study how science concepts affect the objects and vehicles they are designing before they	Sylvia Earl: In 1970, Sylvia Earl and four other women dove 50 feet below the ocean's surface and lived in a small structure for two weeks. In 1979, she walked untethered on the sea floor at a lower depth than any living human being before or since. She wore a "Jim" suit—a pressurized one-atmosphere garment, and was carried by a submersible down to a depth of 1,250 feet below the ocean's surface

			build the real things. By studying the similarities and differences between small models and real-size rockets, engineers can build more successful rockets. Prediction: Have students predict the outcome of the activity before the activity is performed. Ask students to predict which will move farther: the Newton rocket car or the small, weighted block. Data Recording: As directed in the Procedure section, each time another rubber band or small weight is added to the setup, have students measure the distance the model car travels from the masking tape starting line. Have them record this data on the data sheet.	

Appendix B

Compiled codes and select excerpts from the 8-12th group

Solar (S1)	Nuclear (S2)	Rock Solid (S3)	Topo (S4)	Off Planet (S5)
Showcase professions PowerPoint presentation is not PBE Consider natural resources Knowledge expanded to current events Compares local and global aspects Real-world example Community is setting for lesson Crossover with math Tackle Real-world problem Consider client / Cost calculations Multiple modes of thought Relatable content Complex multi-dimensional class project Student choice in learning Opportunity for revision Explore / research Using real costs make activity true-to-life Hands-on construction Emphasis on creative Cost analysis Communicate and defend findings Data analysis	Emphasis on creative problem solving Showcase profession Consider natural resources Real-world Connection Multiple modes of thought Narrative format Connection to lived-experience Relatable Discussion Explore / research a topic Opportunity for revision / alternatives Communicate and defend findings Leaving the classroom virtually Use Nearby Resources (powerplant) Compare Local to Global phenomenon Crossover with physics Student choice --	NGSS Crossover (biology, physics, chemistry) Potential to go outside. Real-world connection Relatable content Potential to crossover with chemistry, biology Showcase profession Potential for more local examples Hands-on Open discussion Multiple modes of thought Explore Communicate and Defend findings Data for analysis ***Knowledge expanded to larger global geo Potential to use real location geology and be student-directed Diversified instruction (options) Use nearby resources (maps) Community is setting for lesson ---	Hands-on Potential for PBE (do this outside) Showcase profession ***Problem posed before the tools Potential for PBE (use local map) Potential for PBE (go outside) Potential for PBE (local examples) Knowledge expanded too global Leaving the classroom (implied) Design thinking (map of classroom) Student choice Relatable content Treat the Classroom as community Diversified instruction ---	NGSS Showcase Profession Connected / Student Friendly Crossover Math Real-world Connection Research Diversification Leaving the classroom Hands-on Data Collection Students Hypothesize ---

Many other communities that do have access to coal, natural gas, oil, and wood have decided to use renewable energies such as solar power instead. Why? This is because the reliance on fossil fuels and wood is believed to lead to climate change, which has intensified severe weather events such as floods and storms. Sea levels could rise dramatically in the 21st century if a different course of action is not taken to supply our energy needs. When people use wood for cooking and heating water and homes, many trees must be harvested. If more trees are cut down than are planted and allowed to grow, this energy source is unsustainable. For example, the government of Haiti did not regulate the number of trees that its citizens were permitted to cut down. As a result, the forests in the country have been destroyed. Conversely, the government of the Dominican Republic monitored its country's	Look at the finished photograph sequences and check to see if the correct order was achieved. Does every student have an understanding of the potential impact of nuclear disasters? Have students share their feelings, prompted by the following questions. Expect responses to vary, based on personal experiences and classroom climate. It is important for engineers—as well as students pursuing engineering career paths—to be able to research complicated systems and then synthesize that information to gain a thorough understanding in order to resolve problems within the systems. Determine the nuclear power plant closest to where you live and find out how far away it is [or look it up online as a class]; see the interactive map at Nuclear	Press your hands together again. You can feel that the inner parts of your hands are being smashed by compressional stress from the muscles in your hands pushing inward. Drawing: Have students draw a picture of each of the different types of stress. Ask them to draw arrows that show which way the pressure is acting and identify each type of stress. Have them draw another picture illustrating their choice of any example of weathering. Have students find geology maps for their state and determine the most common rock types present in their state or region. Applying their findings in this activity, have them determine the best locations to build caverns in their state.	What if you were not traveling to another city but taking a trip in the wilderness? What kind of information do you think that you would need to know? (Possible answers: locations and names of trails, rivers, and mountains.) What if there was a mountain right in the middle of where you wanted to go? Most of us would think to go around the mountain instead of up and over it. How is a map helpful? A state like Nebraska, known for its flatness, would barely even have contour lines. This is illustrated in Figure 2. On the left side, the 10-ft. contour line is far away from the 20-ft. contour line. Looking at the same point on the elevation plot, you can see that the slope is pretty shallow. It would be easy to walk up this slope. But, looking at the right hill, the distance between the 40-ft. contour line and the 50-ft. contour line is small. The corresponding elevation plot shows a steep slope. Walking	

forests. The border between the two countries shows this difference in forest management. Solar Water: Heat it Up! - Students learn about the engineering design process as they design, build and test flat-plate solar water heaters. Working in groups, they apply their knowledge of heat transfer forms and calculate the efficiency of their solar water heater designs. They consider the trade-offs between efficiency and cost. We are going to start exploring engineering applications for a sustainable world by using the engineering design process to design, build and test our own solar water heaters! **Multi-Dimensional** Give students time to make design modifications. Tell students to focus on improving the efficiency of their devices. They should list any additional materials they are using in their	Energy Institute's *Map of US Nuclear Plants* website at		that part of the line would be much more difficult. Have students draw a map of their classroom. How would they draw topographic lines for a desk or chair?	

budget. Consider passing out a new budget sheet for students to use.				

Air Quality (S6)	Seismic Waves (S7)	Where is Here? (S8)	Space (S9)	Watershed (S10)
Complex multi-dimensional activity Crossover with chemistry and civics Data collection Explore / research projects Connection to lived-experience Question / Hypothesize Real-world connections Leaving Classroom Use local resources Compares local to larger global aspects Accessibility for schools and public Student choice learning Communicate and defend findings Hands-on multi class project Tackle Real-world problem NGSS Design Test Consider Natural Resources Relatable Very strong and detailed lesson based in real-life, relatable phenomena.	NGSS Crossover with History Connect local to global phenomena?? Showcase Profession (eng) Real-world Connection Relatable / Connect to Lived ex Diversified Instruction Design thinking? Explore / Research Student Choice Hands-on Design Consider Natural Resources Tackle real-world problem Opportunity for Revision Data Collection Consider a client Communicate and Defend Explore / Research --	NGSS Potential for PBE (go outside) Classroom as community Use nearby Resources (coordinates) Real-World Connection Community is setting for lesson Connection to lived experience Creative problem solving Student-choice in learning Diversified instruction Consider a client to sell the solution Leaving the Classroom!!! Explore / research a topic Communicate and defend findings ---	NGSS Crossover with history and math Real-world connections Knowledge expanded to current events Relatable Open Discussion ---	NGSS Showcase professions Relatable Potential for PBE (local watersheds) Multiple modes of thought Consider the community (runoff) Consider Natural Resources Knowledge expanded Use nearby resources (drainage) Community is setting for lesson Crossover with engineering Explore Data collection (models) Question / hypothesize Communicate and defend findings Open Discussion Creative problem solving Tackle Real-world problem Opportunity for Revision Diversified instruction --

Showcase profession Uses nearby resources				
The very common example of smoke from a tailpipe illustrates how air quality intersects your everyday life. Today, we will cover an introduction to air quality research, measurements, and control technologies to provide you with a foundation from which to undertake your own air quality projects later in the term. Due to the complexity of our atmosphere and the possibility of transport over long distances, we can also think of air quality in terms of scale—that is, pollution may cause local or global problems. For example, pollution in China can make its way over North America and add to existing pollutants there. If possible, take 10 minutes at the beginning of the next class period to discuss their answers. The questions are open-ended and intended to	The information, animations, photos, and videos in its 16 slides cover wave basics, including a definition of a wave, which can be difficult for students to understand. Hand out the attached Engineering & Waves: Seismic Waves PPT Worksheet to aid in note-taking and help students be accountable for the information provided in the presentation. Students, like engineers, use shake tables that simulate the movement of seismic waves to test the resistance of their model building structures to earthquake shaking. Success: If the building survives for a full minute and is still one-foot tall, consider it a success—the group has engineered a solution to the challenge and is "hired" to design real buildings for their community.	In this unit on navigation, you will learn more about navigating with the stars. Today, you will start by learning to navigate in your own classroom. Have each student bring in his/her address and look up his/her own — or alternatively, the school's — latitude and longitude (as close as possible with available maps). Design Thinking Challenge! Have students think about a problem that could be solved using GPS technology. It is okay to leave it open-ended like this. For students that may need a little more guidance, you can assign them a problem such as: State the problem you will attempt to solve through the creation of your unique design.	The Galileo spacecraft recently ended a 14-year mission to the planet Jupiter and its moons by crashing into the planet on Sept 21, 2003. The 2003 Mars Exploration Rovers are currently enroute to Mars, expecting to arrive in January 2004. More recently, the Mars Curiosity Rover was launched in 2011 and is currently sending us information and pictures about Mars. You can find detailed information on NASA ***Use ^this^ or the Kepler example*** In this activity, you will learn how to predict and track the ISS' path using special computer software and how the paths of spacecraft and satellites can be calculated and accurately predicted.	Engineers must be able to understand, calculate and graph water runoff for many reasons, including flood control and management, water pumping, designing, and building dams, recreational planning, and probability and statistics concerning future flood scenarios. These skills are particularly useful for civil engineers involved in modeling hydrological processes and studying water resource management for the benefit of human communities and natural ecosystems. Let's spend five minutes and do a think-pair-share. (Think-pair-share activities pose a question to students that they must consider alone and then discuss with a neighbor or two before settling on a final answer. Assuming our watershed is a closed system, we can apply the principle of conservation of mass to our watershed to come up with an equation that tracks how much water is in each of

prompt students to reflect on connections between what they are learning and everyday life. If your students are completing the entire AQ-IQ curriculum, these questions are recommended to help them begin to think about topics they may wish to focus on for their projects. Let's take a look at some real-world examples of how science, technology and society intersect around the transportation industry. (Show students the suggested video listed below. As an alternative, have students read the Current Event Article and answer/discuss its questions.)		State the constraints of the problem (i.e., does it need to be portable/stationary? Does it need to be waterproof/durable? What materials should it be made out of? What are the size and weight limits? Encourage students to consider their "client" in the problem when stating constraints. Design your device. How does your design differ from existing devices or technologies? How will you test the success of your solution? Take students outside the classroom, to a playground, for instance. Have them use compasses at several directional locations to find magnetic north.		these storages. What is conservation of mass? (Answer: A fundamental theory stating that for any closed system, mass is conserved over time.) According to the conservation of mass: Scientists and engineers do these same types of experiments with small-scale models, as well as computer simulations, to understand how real-life floods behave. Using models to make observations and collect data allows engineers to develop effective designs. Prediction: Have students predict the outcome for each trial and record predictions on the board. Will the river flood or not? Will the houses be affected? Have students look up a map for a floodplain in their area. Can they make recommendations for development (or building houses) on the floodplain,

				based on the riverbeds modeled in this activity?

Appendix C

Example of a Coded Lesson Plan Transcript

Solar Power: When & Where

Summary Students learn about solar energy and how to calculate the amount of solar energy available at a given location and time of day on Earth. The importance of determining incoming solar energy for solar devices is discussed. This engineering curriculum aligns to Next Generation Science Standards (NGSS). Engineering Connection	
As the market for solar power technologies grows, determining the amount solar energy available at a given location is important for maximizing energy efficiency of solar technologies and determining if solar power is even a possibility for a specific	**Crossover engineering**
region. Engineers must understand the basics of solar energy and the Earth in order to incorporate solar energy into their designs.	**Showcase professions**
Learning Objectives After this lesson, students should be able to: Describe solar energy and why it changes with time and location. Calculate the amount of solar energy on Earth at a given time and location. Explain how solar energy is used in sustainable engineering applications. Explain why solar energy is becoming more prevalent. Educational Standards NGSS: Next Generation Science Standards - Science International Technology and Engineering Educators Association - Technology State Standards Introduction/Motivation Did you know that the sun can help us heat and light our homes, cook our food, and heat our water? In fact, many communities do not have access to fossil fuels or wood, which are typically used to supply our energy needs, and so people rely on the Sun to do all of these things! Many other communities that do have access to coal, natural gas, oil and wood have decided to use renewable energies such as solar power instead. Why? This is because	
the reliance on fossil fuels and wood is believed to lead to climate change, which has intensified severe weather events such as floods and storms. Sea levels could rise dramatically in the 21st century if a different course of action is not taken to supply our energy needs. But just how much energy can we capture from the sun? What do you think it depends on? Today's lesson will give us an idea of how we can use the Sun's energy and how to determine how much solar energy is available to us. Following the lesson, consider conducting the associated activity Solar Water: Heat it Up! where students learn about the engineering design process as they design, build and test flat-plate solar water heaters! Lesson Background and Concepts for Teachers Use the following script as you show the class the Solar Power Presentation. Then have students complete the Solar Power Energy Estimation Worksheet.	**Environmental aspect**

This lesson is a modified version of the more complicated method of determining solar radiation at a given location and time to introduce students to the concept of solar energy experienced on Earth. For a more detailed explanation of solar angles, refer to the Solar Angles and Tracking Systems lesson for photovoltaic modules.	
Slide 1 [Solar Power] – Title slide.	**PowerPoint presentation is not PBE**
Slide 2 [Why do we need solar power?] – In many locations of the world, like the Pacific Islands, natural resources such as fossil fuels are not available. Often, fossil fuels, such as coal and oil, are shipped to these areas to provide heat and electricity. Rather than transporting these fuels, we can generate both heat (for cooking and water heating) and electricity (with photovoltaic panels) with energy from the sun.	
Slide 3 [Problems with fossil fuels] – Unfortunately, when we burn fossil fuels to provide heat and electricity, greenhouse gases such as carbon dioxide are released into the atmosphere. This intensifies the greenhouse effect, whereby more of the sun's heat is trapped in our atmosphere. The abundance of greenhouse gases in our atmosphere is responsible for many of the current changes we are seeing in our weather.	**Consider natural resources**
Slide 4 [Climate change consequences] – Climate change can cause many undesirable weather events such as more frequent severe storms (such as Superstorm Sandy), more frequent flooding (also caused by deforestation), and rising sea levels (due to more melting of the polar ice caps).	
Slide 5 [Lack of natural resources] – When people use wood for cooking and heating water and homes, many trees must be harvested. If more trees are cut down than are planted and allowed to grow, this energy source is unsustainable. For example, the government of Haiti did not regulate the number of trees that its citizens were permitted to cut down. As a result, the forests in the country have been destroyed. Conversely, the government of the Dominican Republic monitored its country's forests. The border between the two countries shows this difference in forest management.	**Relate class to current events**
Slide 6 [Potential dangers of deforestation] – We need our forests to protect our soils; otherwise, erosion can occur. Erosion harms our natural habitats and deteriorates the soil to the point that it is no longer suitable for farming. The roots of trees also prevent rain from pouring down the surfaces of hills and mountains in vast quantities. When too many trees have been removed from hillsides, flash floods can occur, causing mudslides.	
Slide 7 [Solar energy around the world] – Communities around the world use solar energy to heat homes and cook food when electricity is not available. In Peru, solar water heaters heat water for taking showers, and Trombe walls work like greenhouses to heat homes by absorbing the Sun's energy. In Mexico, this solar dish kitchen was designed to heat water and cook food by concentrating the Sun's energy using mirrors. This same concept is used with solar ovens for cooking food.	
Slide 8 [Solar energy close to home] – We can get our electricity from solar energy using photovoltaic panels. The National Renewable Energy Lab (NREL) in Colorado researches methods for efficient electricity production from solar energy. Many U.S. homes use solar water heaters. The top, middle image shows how a solar water heater might be set up on someone's roof. The solar water heater faces south and is connected to a water storage tank. Cold water is pumped to the solar module while the water heated	**Compares local and global aspects** **Real-world example**

by the Sun is used in the home. Batch water heaters and flat-plate collectors are two popular types of solar water heaters. Slide 9 [About half...] – Only about one-half of all incoming solar energy reaches the Earth's surface. The other half of the Sun's energy is reflected back into space by the planet's atmosphere or clouds, or it is absorbed by atmospheric gases, clouds and the Earth's surface. Solar energy is measured as solar power per unit area. Common units are Watts per meter squared. This is called irradiance. When we think about solar energy used in solar modules such as solar water heaters or photovoltaic (PV) panels, we use energy units of Watt-hours per square meter (called insolation) or just Watt hours (heat energy). Slide 10 [The amount of...] – The amount of solar energy found on Earth changes with location. One indication of the amount of solar energy present is the temperature at the Earth's surface. So, the hotter it is, the more radiation we expect to find. This image shows different temperatures around the world, where the blue and purple colors indicate cold temperatures (and low solar radiation) and the red and orange colors indicate hotter temperatures (and more solar radiation). Notice that most of the Sun's energy is focused around the equator and it decreases as we approach the North and South Poles. Where are we on this map? What is the color? How does the amount of solar energy we get here compare with what is found on the equator or either pole? Slide 11 [...and time] – The amount of solar energy we have access to not only depends on location, but it also depends on the time of day and the time of year. The angle of the sun relative to us relates to the amount of solar energy we experience. During the day, the Sun moves in the east-west direction. Throughout the year, the Sun also moves in the north-south direction. So, the amount of solar energy present in the middle of the day in the summer is quite different than the amount of solar energy we get in the afternoon during winter. Slide 12 [How much...] – In the Northern Hemisphere, regardless of location, all solar modules needs to be set up to face south because that is the direction that captures the most sunshine at any time of the year. If you were located in the Southern Hemisphere, you would set up your solar module to face north. A tilt angle is the angle the solar module (in this case a solar water heater) needs to be set up from the ground (the horizon) in order to capture the most amount of solar energy. The tilt angle is the same angle as the latitude of the solar module's location. For example, if we were located in Boulder, Colorado, the latitude is 40.1o so the solar water heater (or PV panel) would need to be tilted 40.1o from the ground facing south. Slide 13 [How much...] – NOAA, the National Oceanic and Atmospheric Administration, has a website where we can find the exact coordinates of our location. When you open the website, place the red balloon on our location on the map and the output will give you the location in terms of latitude and longitude. Slide 14 [How much...] – We also need to take note of the time of year and the time of day for which we want to find the solar energy potential. Slide 15 [How much...] – This map illustrates the U.S. solar resource. In other words, it tells us how much solar energy we have access to at any location in the U.S. As previously mentioned, the amount of solar energy available changes throughout the year. This map presents the average amount of solar energy available over the course	**Connection to home** **Community is setting for lesson**

of an entire year. We will use maps that show the solar energy available during different months to find out how much is available where we live. The solar energy units are in kilowatt hours per meter squared per day (kWh/m2/day). We will see how to work with these units in a few minutes. Photo shows a red hot Sun. The Sun. copyright Slide 16 [How much...] – We can access these solar maps from the National Renewable Energy Laboratory (NREL) website and find our month. (Note: If you do not have internet access to show the online maps, print out the attached Solar Energy Maps in color and hand them out to students.) Slide 17 [How much...] – When we find our corresponding month, say for example "May," we find our location on the map and use the color to determine how much solar energy we have in terms of kilowatt hours per meter squared per day (kWh/m2/day).	**Crossover with math and engineering**
Slide 18 [How much...] – Now let's work with our worksheets to determine how much solar energy potential we have where we live. For worksheet answer explanations, refer to the Solar Power Energy Estimation Worksheet Answers. To find the latitude of your location (which is needed in order to determine the tilt angle of a solar module), visit the NOAA Solar Calculator web page or use any internet browser to search for the latitude of your location (latitude is measured in degrees). Access the solar energy maps at the NREL website (https://www.nrel.gov/gis/solar.html) or print out the Solar Energy Maps in color as a student handout. Associated Activities	**Community is setting for lesson**
Solar Water: Heat it Up! - Students learn about the engineering design process as they design, build and test flat-plate solar water heaters. Working in groups, they apply their knowledge of heat transfer forms and calculate the efficiency of their solar water heater designs. They consider the trade-offs between efficiency and cost. Watch this activity on YouTube Lesson Closure As the demand for solar energy increases, engineers strive to make more efficient solar devices by capturing the most energy possible using the least amount of resources. Determining the available solar energy in a given location is essential for determining the efficiency of a solar device or establishing if solar power devices are even possible options. Today, you determined how much solar energy is available at our location, and this information can help you determine the efficiency and output of solar devices. Assessment Worksheet: Assign students to complete the Solar Power Energy Estimation Worksheet as an in-class worksheet or homework. Review their answers to gauge their depth of understanding of the lesson content.	**Design process (significant and extensive)**
Summary Students explore energy efficiency, focusing on renewable energy, by designing and building flat-plate solar water heaters. They apply their understanding of the three forms of heat transfer (conduction, convection and radiation), as well as how they	**← Associated Activity: Heat it Up**

relate to energy efficiency. They calculate the efficiency of the solar water heaters during initial and final tests and compare the efficiencies to those of models currently sold on the market (requiring some additional investigation by students). After comparing efficiencies, students explain how they would further improve their devices. Students learn about the trade-offs between efficiency and cost by calculating the total cost of their devices and evaluating cost per percent efficiency and per degree change of the water.	**Real-world problem** **Consider client / Cost calculations**
Engineering Connection With a growing need to reduce our nation's dependency on fossil fuels, improved energy efficiency is the key to the successful design of renewable energy options, but at what cost? Engineers spend a great deal of time and effort in improving efficiency of their designs, and the trade-off between cost and efficiency is an important concept to understand in the engineering world. To engineers, efficiency often means maximizing the amount of work done or energy produced from a given design while also minimizing the resources used. In the developing world, minimizing the use of resources and keeping costs low are two important factors that must be considered when deciding on the suitability of a given technology and its ability to improve a community's quality of life. Engineers use the engineering design process to help strike this balance between cost and efficiency.	**Natural resource consideration** **Multiple modes of thought**
Learning Objectives After this activity, students should be able to: Identify heat transfer properties of different materials. Explain the concept of efficiency and how it relates to energy. Calculate the efficiency of a solar water heater given heat input and output of a system. Compare the efficiency of built solar water heaters to those achieved by commercial models and explain why they might differ. Explain the engineering design process.	
Introduction/Motivation Can you imagine waking up and not having access to hot water to take a morning shower? Imagine this scenario in the middle of winter! Or not having hot water for cleaning? Well, for billions of people around the world, this is a reality. Communities that lack access to clean water, electricity and/or a way to get rid of waste (such as a sewage system) are considered developing communities or countries. As engineers we can help improve the quality of life for communities like these around the world. We are going to start exploring engineering applications for a sustainable world by using the engineering design process to design, build and test our own solar water heaters!	**Relatable content** **Complex multi-dimensional class project** **Extensive multi-class project**
Procedure Background In this 14-day activity, student groups design, build and test their own solar water heaters while experiencing the entire cycle of the engineering design process. This activity goes beyond building a "model" solar water heater by reducing the number of constraints on materials and encouraging students to explore how different variables, such as material selection and device shape and volume, affect the overall efficiency of the devices.	
Students design their solar water heaters based on the materials needed, cost per material, and an overall cost of their devices. They use a detailed worksheet to help	**Student-directed learning**

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<td>them calculate the efficiency of their solar water heaters during the initial and final tests. Then, they compare the efficiencies and costs from their initial and final designs. Exploratory questions are posed to groups to get them thinking about additional changes they would make to their designs if they did this project again with access to more materials. Students also think about how their efficiencies compare to commercial solar water heater models (requiring them to do some online research).

Before the Activity

Make copies of the attached Materials Budget Worksheet, two per group (students need one copy for the initial design and one for the final design). Before printing them, fill in appropriate price estimates for each of the materials provided (example prices are included). Try to use the actual material costs to make the activity more realistic.
Make copies of the attached Solar Water Heater Efficiency Analysis Worksheet, two per student (students need one copy for the initial design and one for the final design).
Make copies of the attached Final Budget and Efficiency Worksheet, one per student.
Prepare to project the attached SWH Project Introduction and Outline Presentation, a PowerPoint file.
Make sure students are trained to knowledgeably and safely use the tools provided. Depending on their designs, students may need to use drills, hammers and hand saws.
Divide the class into groups of three students each.
With the Students

Day 1: Introduction and brainstorming.

Show students the PowerPoint presentation slides using the following script:
Slide 1 [Title slide]

Slides 2-3 [Appropriate technologies can improve...] - Engineers design appropriate technologies to help improve the quality of life for communities around the world. Examples of appropriate technologies include the Q Drum, a container that is easy to roll so that water can be easily carried long distances, say from a river to a village. Another example of an appropriate technology is the Big Boda Load-Carrying Bicycle, a low-cost design that can transport hundreds of pounds of cargo. And this solar dish kitchen is used in rural communities throughout Mexico. The solar dish concentrates solar energy for cooking.

Slide 4 [Alternative energy...] - Appropriate technologies for developing communities might also use alternative energies. What are some examples of alternative energies that you can think of?

Slide 5 [Alternative energy...] - How about wind energy and solar energy? In Malawi, 14-year-old William Kamkwamba figured out how to build a windmill to produce electricity for his family's home. In a rural Peruvian home, engineers helped design and build a Trombe wall that absorbs solar energy and directs the heat to the inside of the home. They also built a solar water heater to heat water for bathing in the small bathroom outside.

Slide 6 [Solar water heaters...] – Here are a few examples of solar water heaters that you can currently buy for home use.

Slide 7 [Energy Efficiency] – To engineers, efficiency usually means maximizing the amount of work done or energy produced from a design while also minimizing</td>
<td>Opportunity for revision
Explore and research

Actual costs make activity realistic

Hands-on construction</td>
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resources used. For solar water heaters, efficiency is measured as the amount of heat transferred to water divided by the amount of heat used by the solar water heater (from the Sun or a heat lamp). This equation shows this in terms of heat energy out (or heat absorbed by water) divided by heat energy in (or heat put into the solar water heater by the heat lamp). Improving efficiency is an important aspect of engineers' work. Engineers strive to get the most work done or energy produced using the least amount of input work or energy possible. In the developing world, reducing resources used and cost are important factors to consider in deciding on appropriate technologies. This is why we care about efficiency! Slide 8 [Heat Transfer Basics] – Heat can be transferred in three ways. Through conduction, heat travels through matter because of a gradient in temperature (hot to cold), like a metal poker heating up near a fire. Another method of heat transfer is thermal radiation, which occurs when a warm object gives off energy that can be absorbed by another object. An example of thermal radiation is the Earth getting heated from the Sun's energy. The final method of heat transfer is convection, which occurs when the molecules in a fluid, such as air, heat up and circulate to cooler areas. An example of convection is the hot air coming off of a campfire. Can you think of some heat transfer properties of different materials? For instance, think about wearing a black vs. white t-shirt outside on a sunny day. Which absorbs more heat? Can you think of certain materials that heat up faster than others, say metal vs. Styrofoam? Do some materials reflect energy better than others, such as shiny materials vs. dull materials? Material properties are really important to consider designing devices that use solar energy to heat up water. Slide 9 [Solar Water Heaters!] – Students at the University of Colorado in Boulder designed, built, and installed a solar water heating system for a school in the rural highlands of Peru. Students at this Peruvian school do not have access to warm water at home, so this system helps kids in the village take baths and wash their hands with warm water. We are going to design and build flat-plate solar water heaters of our own! Slide 10 [Constraints for the design...] – You will work in groups to design, build and test solar water heaters. The overall volume of your water heater must be between four to six cubic feet. You will need to cycle one gallon of water through the water heater two times in 45 minutes. You will be able to place two 250 Watt heating lamps wherever you want, but they cannot be closer than 12 inches from any point on your design. Lastly, your designs should be waterproof! Slide 11 [Testing Set-up] – This is the testing set-up. We are using heating lamps to simulate the sun so that everything is as consistent as possible for determining and comparing the efficiencies of your solar water heaters. We will connect the testing station tubing to the inlet and outlet of your water heater. The water pump will be turned on in the collection reservoir and you will measure the initial water temperature and the water temperature every minute for the first 10 minutes, then every five minutes after that until the 45 minutes is up. You will then graph the water temperature vs. time to see how well you heated up the water. Then you will calculate the efficiency of your water heater, or how well you heated up the water given the amount of heat you had to put into the water heater. Finally, you will compare efficiencies between groups and with commercial models. Slide 12 [Project Timeline] – Now, I will explain how this project will work over the next couple of weeks. Today we are covering the details of this project and you will start to	**Design, build, and test**

brainstorm ideas for your solar water heaters. On day 2, your group will need to submit detailed design drawings (to scale) that include two views, materials labels and dimensions. Also, be sure to note the purpose of each material on your drawings. For example, the insulation traps the heat in the water heater, or the foil reflects the light to the pipes to concentrate the heat. You will also need to fill out your budget worksheet to let me know how much of each material you need and the overall cost of your initial design. On days 3 through 5, you will build your solar water heaters. On day 6 you will conduct an initial leak test in order to seal up any leaks before you finalize your initial design. On day 7 you will have time to make any final modifications to your water heater before doing your initial test.	**Detailed design, blueprint** **Cost analysis** **Modification / Revision**
Slide 13 [Project Timeline] – On day 8, you will conduct your initial solar water heater test. You will connect your device to the inlet and outlet hose at a testing station, take the initial water temperature, and turn on the water pump. You will record your results and make a graph that displays water temperature vs. time. Day 9 will be set aside for you to make any design modifications to improve efficiency or fix any problems. You will also need to calculate the overall efficiency of your water heater using a detailed worksheet that guides you through the process. The final testing will take place on day 10. For your final solar water heater test, you will conduct the test and make temperature graphs the same way you did on the initial test day.	
Slide 14 [Project Timeline] – On days 11 and 12 you will calculate final design efficiencies and compile your results. You will need to make a six-minute presentation using PowerPoint on day 12. This presentation will need to include all of your data (graphs, efficiencies, final costs and efficiency/cost) and compare your efficiency to commercial model efficiencies, so you may need to do some internet research. Be sure to include pictures and drawings in your presentation. Everyone should contribute equally in making and giving the presentation. On day 13, all groups will give a six-minute presentation to the class.	**Communicate and defend findings**
Slide 15 [Materials List] – Here is the list of materials you can use. You will be given a budget worksheet that lists the cost of each material to help you make the budget for your heater. You can use as much of any material as you want— just keep in mind the overall cost of your device!	**Consider client to sell to**
Slide 16 [Brainstorm Pointers] - Let's split up into groups and start the 3rd step of the engineering design process: imagine possible solutions by brainstorming ideas for the solar water heater designs. Keep in mind the materials you have access to and their heat transfer properties. You will have 15 minutes to come up with at least 10 ideas. While you brainstorm, write down as many ideas as possible. You can sort through all the ideas later. Encourage wild ideas. This is only brainstorming, so do not get critical yet and do not put down your teammates. Piggyback on each other's ideas; no one owns them during brainstorming. Write down or draw all of your ideas.	**Tackle real-world problem**
Slide 17 [Brainstorm Pointers] - After brainstorming, your group will go into the 4th step of the engineering design process: plan: select the most promising idea and create a detailed drawing that includes labeled materials and dimensions. Your group will also need to fill out an initial budget sheet with the cost and quantity of materials you need to start building. Questions?	
Divide the class into groups of three students each. Give each group a Materials Budget Worksheet.	

Direct students to start brainstorming designs for their solar water heaters. Remind students to consider the properties they know about the materials listed. (What color materials absorb more heat? How fast do we want the water to flow through the device? How would we control the flow of water?) Require students to submit a list of 10 ideas for their project, then decide on the most promising design. Day 2: Scaled Drawings and Materials List Have teams decide on their most promising design, create scaled design drawings and fill out a budget sheet before they begin building. Drawings can be done by hand or created using computer aided design software such as Google SketchUp (available for free with free online tutorial at: http://sketchup.google.com/). Require the design drawings to have two views (such as top and side) with material labels and dimensions. On their drawings, students should note why each of the major materials was chosen. For example: "we chose tar paper for the bottom to absorb more heat" or "we are sealing the solar water heater with Plexiglas to keep the heat inside the device, but still let the light in." When filling out the budget sheet, ask students to put down specific quantities (such as 30 ft of 1/4" plastic tubing or 2' x 3' piece of tar paper). Use group budget worksheets to inform material purchases. Days 3 – 5: Build Days Remind students that they are going into the 5th step of the engineering design process: create a prototype. Give students time to build the first iteration of their solar water heater designs based on their submitted drawings. Day 6: Leak Test The 6th and 7th steps of the engineering design process are testing/evaluating and improving the prototype. This is a crucial step that you will repeat several times to improve your design. The intention of the leak test is to check that no leaks exist inside the solar water heaters before the groups conduct their initial and final tests. Advise students to do their leak tests before they seal up their devices. Set up the testing stations as shown in the Figure 1 testing schematic with the exception of the heat lamps, which are not yet needed. Day 7: Build Day Give students time to fix leaks and finalize their designs before initial testing begins. Day 8: Initial Test Set up testing stations. Because the testing time for each group is 45 minutes, each group should have their own testing station. See Figure 1 for an idea of how to arrange everything. Testing station materials are listed in the Materials List. Have students attach the hosing to their devices using adapters. Make sure they do not leak! Fill a container with 1 gallon of water and check to see that the fountain pump is completely submerged before turning it on. Students can arrange the heat lamps however they choose, as long as they remain at least 12 inches from any point on the device. Have students take an initial water temperature reading before turning on the pump and lights. Have students attach the fountain pumps to their devices with tubing and connectors. Turn on heat lamps and fountain pumps. Have students record the temperature of the water every minute for the first 10 minutes, then every five minutes thereafter until the 45 minute testing time is up. Instruct students to graph the temperature change each minute to see where the highest change in temperature occurred.	**Computer aided design software** **Data analysis**

Day 9-10: Modifications & Efficiency Calculations Give students time to make design modifications. Tell students to focus on improving the efficiency of their devices. They should list any additional materials they are using in their budget. Consider passing out a new budget sheet for students to use. Have each group complete the Solar Water Heater Efficiency Analysis Worksheet to determine the efficiency for their initial test. Day 11: Final Test Set up testing stations (one per group if supplies permit) and have students attach the fountain pumps to their devices with tubing and connectors. Turn on heat lamps and fountain pumps (making sure the pumps are fully submerged in water). Have students record the temperature of the water every minute for the first 10 minutes, then every five minutes thereafter until the 45 minute testing time is up. Instruct students to graph the temperature change each minute to see where the highest change in temperature occurred. Day 12-13: Compile Results and Prepare Presentations Hand out the Final Budget and Efficiency Worksheet for the groups to complete. Have groups compile the results for both tests from days 8 and 11, including temperature graphs, efficiencies, total costs, cost/degree change, and cost/percent efficiency. For cost/degree change, have students divide the total device cost by the change in water temperature. For the cost/percent efficiency, have them divide total device cost by the overall efficiency. Also, have students do some research on costs and efficiencies of commercial solar water heaters and compare their devices. Ask them how they would change their designs if they could rebuild their devices over again with the materials provided (specifically, ask students if they would change the volume or use different materials). If students could rebuild their devices to improve efficiencies using an unlimited budget and choice of materials, what would they do differently? (For example, would they use real glass or copper tubing or stick to the materials they were offered in this activity?) Instruct groups to prepare six-minute PowerPoint presentations (during which each group member must talk for an equal amount of time). Encourage groups to include pictures and drawings of their designs and testing. The groups should also include the temperature vs. time graphs from the initial and final testing, as well as the information from the Final Budget and Efficiency Worksheet. Day 14: Presentations Have groups present to the class for six minutes using their prepared PowerPoint slides. Encourage peer review, with constructive criticism. Constructing the Solar Water Heater Testing Stations Assessment Pre-Activity Assessment Discussion Questions: Ask students what they know about renewable energy and the different types of renewable energy available. Ask them where in the country they think the most solar energy might be available? (Possible answers: Arizona, California, Colorado, New Mexico, Nevada.) What about the least? (Possible answers: Alaska, Maine, Washington.) Prompt students to think about locations where engineers would be most needed for solar power applications in the U.S.	**Opportunity for revision** **Communicate and defend findings**

Activity Embedded Assessment Worksheets: During the activity, have students complete the Solar Water Heater Efficiency Analysis Worksheet and the Materials Budget Worksheet. Post-Activity Assessment Final Worksheet: Following the final test, have students complete the Final Budget and Efficiency Worksheet, and present their findings to the class in a six-minute PowerPoint presentation. Safety Issues Practice safe workshop techniques when using saws, drills, box cutters and hammers. Students are typically required to complete a tool safety overview along with a consent form signed by their parents before they are allowed to use any tools. Troubleshooting Tips The connections between the different tubing used in the solar water heaters and the tubing used to pump and drain the water for testing can be difficult to coordinate. Make sure that connections for each type of combination are available. These connectors can be purchased at hardware stores, such as Home Depot. Activity Scaling To challenge students more, provide additional options for tubing, including 1/2" PVC and ¼" clear tubing. These additional options help students learn about trade-offs in flow rate of water through the device and the amount of time the water is exposed to solar energy for heating. Keep in mind that if students use varied tubing sizes, you need multiple hosing adapters in order to connect the hosing to the solar water heaters and garden fountain pumps.	-