Building Together: Problem Solving for Sustainability Consciousness

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Building Together: Problem Solving for Sustainability Consciousness

A Dissertation Presented

by

PAUL M. BOCKO

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

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Building Together: Problem Solving for Sustainability Consciousness

A Dissertation Presented

By

PAUL M. BOCKO

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DEDICATION

To my wife, Stephanie.
Your love and support energized this doctoral journey.
In addition to being a loving wife and mother, you are
the most exceptional sustainability advocate I know.
I aspire to live up to the level of love you put
into our family and your profession.
ACKNOWLEDGEMENTS

Thank you to my strong daughters, Nina and Bailey. I was thinking of you throughout this work. Sustainability education, by definition, has a future focus. You are the future and deserve a sustainable world. You are following in the footsteps of your mother, creating a better world through love, joy, good food, and advocacy for earth.

To my mother, Ruth Eleanor (Boyce) Bocko: Thank you for always being proud of me. To my dad, Edward Francis Bocko: You gave up pursuit of your doctorate to raise your eight children. I hope I honor you with this work. I miss you both. I admire and look up to my five brothers and sister. Thanks for being excellent role models.

Thanks to all of my Antioch University colleagues for your support. Many of you already navigated your way to a doctorate and shared ups, downs, wisdom, and stories.

Linda Griffin, you were there for my first course and the dissertation defense. In between, you challenged me, coached me, welcomed me as a co-teacher, and gave me freedom to pursue my interests. Betsy McEneaney, thanks for great courses, laughs, and your quantitative prowess. Dan Gerber, thank you for getting me to focus on details and for being first at the defense and saying, "what a pleasure to read your dissertation". You put me at ease. To the Honors College staff and advisors, thanks for co-creating joy while doing hard work.

To Greenfield (MA) Coffee, now Catalpa Coffee: Thanks for all the tea, coffee, treats, and just the right amount of café ambiance to energize this work.

Deepest thanks to Rachel and her twelve students at Finley Elementary School. You care so well for each other and the earth. Thank you especially for learning with me.
ABSTRACT

BUILDING TOGETHER:

PROBLEM SOLVING FOR SUSTAINABILITY CONSCIOUSNESS

FEBRUARY 2022

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This case study examined the relationship of problem-based learning (PBL) and sustainability education in a combined fifth and sixth grade classroom in the northeast U.S. Research questions focused on PBL instructional strategies that promote sustainability education, skills and understandings promoted by PBL, and the extent that PBL affects students’ sustainability consciousness. One teacher and eleven students participated. Problem-posing, reconstructionist, and sociocultural theories framed the study. Relevant themes were identified in a review of sustainability consciousness (SC) and PreK-12 PBL research reports. The themes revealed that SC is a growing framework with which to assess sustainability education and PBL research has strong links with sustainability education learning outcomes. Survey, interview, artifact, and observational data were analyzed to understand the fifth and sixth grade class as a case study in sustainability education. Results include a learning environment that emphasizes a pedagogy of sustainable thinking, student exhibition of sustainability education skills and understandings, and a lack of quantitative evidence of growth in students’ SC contrasted
with evidence of SC in students’ written work. Findings affirmed prior PBL research focused on group collaboration, interdependency, and reflection. The study identified the need to study PBL in real-world contexts rather than only through problem scenarios. Contributions to knowledge include adding to PBL research literature, highlighting the importance of learning experiences designed to meet a school’s mission, and increasing the use of a new survey instrument.

*Keywords*: Sociocultural, reconstructionism, problem-based learning, wicked problems, sustainability education, scaffolding, collaboration, interdependency.
The year 2011 was pivotal for Finley Elementary School. Rachel, the school’s fifth and sixth grade teacher, had just finished her graduate studies in educating for sustainability (EfS). She was so driven and inspired by EfS that she led an effort to change the school’s mission statement to essentially be the definition of EfS. To this day, the school’s mission statement is to “inspire and educate students to make decisions with an understanding of the interrelatedness of social equity, the economy, and the environment for today and in the future”. Since 2011, the school has been led by multiple principals, experienced teacher turnover, and withstood a considerable decrease in student enrollment. Even with these changes, the mission, teaching, and learning have survived and evolved.

In 2013, the fifth and sixth grade took on a problem in the playground: Encroaching poison ivy. The students investigated multiple solutions that would help eliminate or at least slow down the plant’s encroachment into the schoolyard. After engaging the problem-solving strategies and researching solutions using EfS principles, the students chose to bring in goats to eat the poison ivy. They chose goats and recruited a local farmer to let them borrow their animals because it was a sustainable solution: No pesticides or gas-burning mowers doing the work. For this project and solution, Finley Elementary School was named a 2013 Green Ribbon School by the U.S. Department of Education. The challenge of encroaching poison ivy continued none-the-less and in 2017-2018, that year’s fifth and sixth grade class was studied (Bocko, 2018) as a model EfS learning community as they worked on the poison ivy problem to discover solutions that did not involve goats.
Finley Elementary School, and Rachel in particular, perceive EfS as an ongoing practice. They recruit new teachers that have EfS experience and or are willing to learn about and integrate this model. They collaborate with a farm and sustainability organization to continue their development as a model of EfS through professional development focused on curriculum development, project-based learning, and farm to school activities.

The future of Finley Elementary School is unknown. In 2019, a drop in student population prompted community leaders and school officials to consolidate Finley with four other town schools into a new regional school district. The grade span of the school was changed from PreK – 6th grade to PreK – 3rd grade. Along with the unknown future of the school due to population shifts, the continuation of EfS at the school is uncertain. However, Rachel, the teacher subject of this dissertation, continues to teach and lead at the school as a second and third grade teacher with a full and intentional focus on EfS. This study along with Bocko (2018) are small windows allowing views into a small school with an intentional sustainability mission.
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CHAPTER 1: INTRODUCTION

“Without exaggeration it will come down to whether students come through their formal schooling as more clever vandals of the Earth and of each other or as loving, caring, compassionate, and competent healers, restorers, builders, and midwives to a decent, durable and beautiful future. If the latter, their education must begin in values that stress our connectedness in the fullest sense of the word. And it must enlarge their capacity for affection also in the fullest sense of the world.” (David Orr in Jickling & Sterling, 2017, pp. ix-x)

Connectedness can result when people collaborate to design solutions for the large and small problems each person encounters every day of their lives. Problem solving ranges from choosing what clothes to wear to navigating and contributing in the workplace to participating in political life to engaging as a citizen (van Merriënboer, 2013). Therefore, real world problem-solving extends from daily habit to intellectual, social, and cultural spheres (Jonassen, 2000; van Merriënboer, 2013). Numerous researchers and educators acknowledge that in today’s society people must be able to solve complex problems (Ertmer & Simons, 2006; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Luterbach & Brown, 2011; Mobilia, 2007; Senge, 2010). The challenge facing this acknowledgment is that problem solving is an “extremely complex cognitive process about which little is known” (van Merriënboer, 2013, p. 153). In turn, implementing problem-based learning (PBL) to teach academic content and practice specific skills in the real world is also complex. This study of PBL as an instructional strategy for sustainability education investigated how one teacher and her students reimagined what teaching and learning might be.

Problem-based Learning

The need to discuss PBL in the context of the significant societal challenges we face in the twenty-first century emerged in a review of academic literature. Adapted from
Wirkala and Kuhn (2011) for the purposes of this study, PBL is defined as (a) engaging a problem without prior study; (b) using existing knowledge for new understanding; (c) frequently developing solutions for real-life challenges; (d) working in collaboration with others; (e) reflecting on skills and dispositions for future use. The problem engaged by students in this study is the real challenge of how to design and construct a solar oven in a public elementary school classroom using only found and recycled materials. PBL began a consistent presence in educational literature with Barrows and Tamblyn (1980), after being established as a learning model in medical schools in the 1960s. The model has since spread to engineering, architecture, for our purposes here, Pre-Kindergarten to grade 12 (PreK-12) education, and beyond. PreK-12 empirical research, however, is limited (Belland, Glazewski, & Richardson, 2011; Ertmer & Simons, 2006; Goodnough & Cashion, 2006; Hmelo-Silver, 2004; Hung, 2011).

Researchers offer specific reasons for the limited number of PreK-12 studies. First, PBL is time consuming. Considering the persistent highly charged climate resulting from U.S. education legislation such as the Every Student Succeeds Act of 2015, “teachers may be reluctant to adopt an unfamiliar teaching approach, especially one that is perceived as being more time-consuming” (Ertmer & Simons, 2006, p. 41). Teacher preparation and instructional time is already consumed with implementing curriculum programs, preparing for standardized tests, and special education reporting.

Second, the relevant absence of PBL is due to the different skillset required for the instructional strategy (Ertmer & Simons, 2006). Few teacher education programs train pre-service teachers in how to design and facilitate PBL. There are examples of teacher education programs that employ PBL as the chosen instructional model to train pre-
service teachers (Filipenko & Naslund, 2016; Pourshafie & Murray-Harvey, 2013). Yet even this full immersion in PBL as learners is not readily transferred into graduates’ instructional practice in the classroom. Graduates express that they want a stronger facilitation role than PBL allows and that they need much more time to observe PBL in order to integrate it with their own practice.

Third, PBL is better suited to environments such as medical schools where learning is coordinated around integrated multidisciplinary problem-solving and not around separated subjects (Hmelo-Silver, 2004). This notion contrasts with PreK-12 education in which students more commonly study single subjects with limited time. Artino (2008), referring to Albanese and Mitchell (1993), agrees noting that PBL increases motivation in medical students and that these students are already highly motivated. They do not see the same for PreK-12 students, describing PBL for this group as “a single instructional intervention inserted among an entire traditional curriculum” (p. 7). The perceived mismatch between PBL and PreK-12 education limits its implementation and therefore the number of PBL initiatives that can be researched.

**Curriculum Standards and Problem-based Learning**

The Common Core State Standards (CCSS) for language arts and mathematics and Next Generation Science Standards (NGSS) may provide the integrated context for PBL to emerge from being lost to fragmented traditional curriculum. CCSS and NGSS offer benchmark learning outcomes that define what it means to be college and career ready. CCSS were developed with the understanding that if high quality standards were drafted with input from numerous sources, based on research, and aligned with higher education and workplace expectations, then implemented in PreK-12 schools, students
would achieve college and career readiness for the twenty-first century. CCSS are currently adopted in forty-one states, the District of Columbia, four territories, and Department of Defense Education Activity (Standards in your state, 2020). NGSS standards operationalize how public education can help PreK-12 students see “how science and engineering are instrumental in addressing major challenges that confront society today, such as generating sufficient energy, preventing and treating diseases, maintaining supplies of clean water and food, and solving the problems of global environmental change” (National Research Council, 2012, p. 9).

The Partnership for 21st Century Learning (P21) is an organization that has joined with CCSS and NGSS in promoting twenty-first century skills. P21’s mission is to serve as a catalyst for twenty-first century learning by building collaborative partnerships between businesses and organizations. Comparing their goals with CCSS, P21 advocates for “standards that adequately address both the core academic knowledge and the complex thinking skills that are required for success” (P21: Partnership for 21st Century Learning, n.d., para. 2). Indeed, CCSS themselves promote twenty-first century skills and problem-solving. The English Language Arts (ELA) standards are a:

natural outgrowth of meeting the charge to define college and career readiness, the Standards also lay out a vision of what it means to be a literate person in the 21st century [with] reasoning and use of evidence that is essential to both private deliberation and responsible citizenship. (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 3)

The first ELA standard for Speaking and Listening is an important citizenship and problem-solving skill: “Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others’ ideas and expressing their own clearly and persuasively” (p. 48). CCSS for mathematics is even more direct in
raising problem solving’s importance in the “varieties of expertise that mathematics educators at all levels seek to develop in their students” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, p. 6). The first Standard for Mathematical Practice focuses on expertise in which students (a) “make sense of problems and persevere in solving them”; and, (b) “understand the approaches of others to solve complex problems and identify correspondences between different approaches” (p. 6). Later, in describing the fourth practice titled “Model with Mathematics”, proficiency is described in which “students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace” (p. 7). While existing PreK-12 PBL literature alludes to links between PBL and real-world application, few resources focus on direct connections.

**Wicked Problems and Sustainability Education**

Two concepts, one social and one educational, compliment formal learning standards and provide a more direct link between PBL and real life. The first concept, wicked problems, emerged out of design thinking and social entrepreneurship (Kolko, 2012; Rittel & Webber, 1973). Wicked problems are defined as “a social or cultural problem that is difficult or impossible to solve for as many as four reasons” (Kolko, 2012, p. 10): inherent contradictions, varied opinions, substantial economic burden, and linkages to other challenging problems. Wicked problems, as a concept, aid in describing our complex world filled with social and environmental challenges that students are guided to encounter through public schooling.

The second concept, educating for sustainability (EfS), further specifies the focus of problems from a question of difficulty to the interconnectedness of environment,
economy, and equity factors. EfS is the use of academic content, learning methods, and outcomes to develop understanding of these interconnected concerns in order to participate in democracy and live sustainably, meet present needs without compromising the ability of future generations to meet their needs (U.S. Partnership for Education for Sustainable Development, 2009, p. 2). EfS has many common and interchangeable names. In 2002, the United Nations (UN) declared January 2005 to December 2014 as the “Decade of Education for Sustainable Development” (General Assembly resolution 57/254), leading to the often-used acronym ESD for education for sustainable development. The U.S. Partnership for Education for Sustainable Development (2009) offered a shortened version, “education for sustainability” (p. 3). More recently, Sobel, Gentile, & Bocko (2014) used a slightly different term, “educating for sustainability” (p. 4) to promote a more action-oriented approach to EfS.

For the purposes of this research, these more common terms were abandoned in favor of a more recent label, “sustainability education” (Le Grange, 2017, p. 93). Le Grange (2017) suggests that terms such as EfS are “instrumentalist” (p. 96), using education as a tool that will lead to an external state of being rather than sustainable behavior as inherent to teaching, learning, and society. Sustainability education may be a more flexible term, avoiding rigid definitions, opening up possibilities for discussions, and suggesting a generative process toward sustainability (p. 96). Sustainability education “connects the ideas, tools, and skills of all participants involved (community members, academics / teachers, and students) in multiple ways to produce ‘new’ knowledge in ‘new’ knowledge spaces” (p. 98). New knowledge is the targeted focus of sustainability
education in terms of integrated consideration of environmental, economic, and social justice issues.

Addressing wicked problems and implementing sustainability education are challenging pursuits. Taking on the challenge demands multiple, integrated approaches to learning and social action. PBL is a specific instructional method and core strategy for attending to wicked problems and sustainability given its focus on problem-solving integrated with learning academic content.

**Theoretical Framework**

PBL is designed to promote learning based on that premise that students can learn in a collaborative social context and gain knowledge and skills through problem-solving. PBL and sustainability education are predisposed to continuously recreate the world given its frequent emphasis on engaging students in generating solutions to real world challenges. The genesis for research into PBL as a tool for sustainability education is rooted in a theory of action: If PreK-12 students are to fully participate as citizens attending to current sustainability challenges, then their classroom teachers must be skilled at designing learning experiences in which students solve problems and practice skills for sustainability (Bocko, 2014). Sociocultural learning theory (Vygotsky, 1978) is the primary theoretical foundation on which this theory of action and research is built. Problem-posing education (Freire, 1993) and social reconstructionism (Brameld, 1955; Rugg, 1939) are more contemporary interpretations of sociocultural learning and specify this study’s approach in the context of PBL and sustainability education.

Sociocultural theory (Vygotsky, 1978) proposes that humans develop knowledge, understanding, and skills in social context. Sociocultural learning is meaningful problem-
solving using a variety of materials and communicating with other individuals to build on successes and overcome obstacles. Materials and tools are mediators between the learning environment and the learner that aid in the development of “functional relationships within the brain” (p. 133). Speech facilitates the interaction between individuals and increases in sophistication as problems become more complex. An interpersonal process leads to transformative intrapersonal learning (p. 57). Vygotsky’s zone of proximal development (ZPD) charts the growing edge of an individual’s learning. ZPD is the margin between what is known and what is not known. Students navigate the zone and learn with the help of an adult or proficient peer (p. 86).

Freire (1993) frames learning as students developing power by critically perceiving their world and actively participating in its ongoing transformation. Continuous transformation hinges on “problem-posing” (p. 12) learning experiences, engaging students in PBL by solving local, relevant problems such as those related to sustainability. Breaking away from the traditional model of students only learning from the experience and knowledge of the teacher, “people teach each other, mediated by the world” (p. 80). Student learning for Freire (1993) is invention and reinvention of the world. Most importantly, ongoing innovation must begin with engaging students in critical thinking characterized by trust, creative power, and, consistent with sociocultural learning, in partnership.

Social reconstructionism (Brameld, 1955; Rugg, 1939) engages students in creating a better society while they learn. One pathway to a better society is sustainability education, humans meeting present needs while not impeding future generations to meet theirs. Brameld (1955), one founder of social reconstructionism, identified the dual need
for students to learn for the benefit of themselves and society as a whole. Educational activities need to be ever-changing to match the dynamic context of current societal successes and challenges with students as active participants in that worthy endeavor. In the early twentieth century, Harold Rugg codified reconstructionism in curriculum and textbooks in order to pull students into what he called social analysis (Smith & Sobel, 2010). Rugg’s (1939) definition of social analysis integrated students, problem-solving, and social improvement.

Sociocultural theory envisions learning achieved in an inter- and intra-personal, real-world context. Vygotsky (1978) largely, however, experimented with the theory in the laboratory walled off from real life. Problem-posing education (Freire, 1993) introduces the idea that designing solutions through critical thinking and in learning partnerships will transform our world. Social reconstructionism further enhances the sociocultural perspective by framing schooling and student participation as real-life social improvement. Founders of reconstructionism (Brameld, 1955; Rugg, 1939) made sure to integrate their theory in the business of schooling via curriculum materials and textbooks. Research reports and teaching and learning activities that shed light on strengths and frailties of this theoretical frame were of most interest in this study. Integrating these complimentary theories has the potential to increase understanding of sociocultural learning by testing the theory in a setting characterized by real world problem-solving.
CHAPTER 2: LITERATURE REVIEW

Three sections comprise the literature review. The first presents sustainability consciousness as a concept and focus of research. The second briefly describes the context for a reimagination of the purpose of education to emphasize sustainability education. Third, a review of pertinent PBL literature is presented.

**Sustainability Consciousness**

One of the primary objectives of this research was to investigate the relationship between PBL and sustainability consciousness (SC). SC is “the experience or awareness of sustainability phenomena” including “beliefs, feelings, and actions” (Boeve-de Pauw, Gericke, Olsson, & Berglund, 2015, p. 3) integrated with the three dimensions of sustainable development: Environment, economy, and equity. This section of the literature review summarizes five research reports that describe the empirical study of sustainability consciousness in Swedish compulsory schools. The reports contain five conclusions related to the research conducted with Finley Elementary School’s fifth and sixth grade teacher and students: People need to develop consciousness about more than environmental concerns, the researchers arrive at mixed results for the effect of sustainability education on SC, that learner-centered teaching can increase SC, the existence of a temporary drop in SC in adolescence and a SC gender gap.

First, Gericke, Boeve-de Pauw, Berglund, and Olsson (2018) documented the development of the Sustainability Consciousness Questionnaire (SCQ) as a more holistic research instrument to measure a person’s sustainability awareness and action. Researchers used SCQ to collect data for all of the articles presented here. SCQ is a 50-item, Likert-scale questionnaire that integrates the concepts of knowingness, attitude, and
behavior with the three dimensions of sustainable development. A shorter 27-item instrument, easier to complete in a shorter amount of time (p. 10), also exists. The authors built SCQ on the model of “environmental consciousness” (p. 3) research and the work of Michalos et al. (2012) who studied individual environmental awareness in terms of knowledge, attitude, and behavior. Survey instruments created for these research projects are multidimensional yet Gericke et al. (2018) found that they did not integrate all three dimensions of sustainable development (p. 4). Therefore, to create SCQ they categorized each of the items created by Michalos et al. (2012) in one of the dimensions: Environment, economic, or equity. Gericke et al. (2018) concluded that through their work they have enlarged the concept of environmental consciousness: “People do not need to develop only environmental consciousness, but also a broad sustainability consciousness, including societal and economic perspectives” (p. 4). To analyze and adjust "fit of the model to the data" (p. 9), a number of statistical measures were utilized: Root mean square error of approximation (RMSEA), comparative fit index (CFI), and Tucker-Lewis Index (TLI). Gericke et al. (2018) believe that SCQ is a stronger measure given that its multiple dimensions better match the complexity of designing solutions for sustainability problems.

Second, two research teams (Boeve-de Pauw et al., 2015; Olsson, Gericke, & Chang Rundgren, 2016) used SCQ and arrived at mixed results of the effectiveness of sustainability education. Olsson et al. (2016) investigated the effect of sustainability education in Swedish compulsory schools: those that explicitly teach sustainability and those without this focus. The researchers collected SCQ data in both settings and compared results. IBM SPSS Statistics was utilized to analyze date. Analyses employed
include Cronbach's alpha for reliability, multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) to investigate students' SC. Sixth grade students in sustainability education schools exhibited a statistically significant but small increase in SC (p. 194) while ninth grade results showed no increase (p. 192). The conclusions were that explicitly teaching sustainability has a limited effect on SC (p. 195) and students struggled to perceive the full scope of sustainability (p. 196).

Boeve-de Pauw et al. (2015) looked closely at holism and pluralism as key variables that contribute to full understanding of sustainability. Holism is the recognition that sustainability integrates multiple content areas (p. 15696) and that multiple disciplines need to be addressed through sustainability education. Pluralism is acknowledging and engaging diverse perspectives, views, and values while solving sustainability problems (p. 15696). These authors also used RMSEA, CFI, and TLI to evaluate model fit. In turn, modification indices (MI) were used to make improvements (p. 15703). Based on their analysis of SCQ data from grades 6-12 students, the authors found that neither holism nor pluralism “occur convincingly” (p. 15709) in participating schools. Further conclusions include some indications that integrating the three dimensions of sustainability can increase SC, holism can promote sustainability knowingness, and pluralism can positively affect sustainability behavior. Overall, the authors’ concluded that in their study there is only some evidence that sustainability education helps in “securing a sustainable future for generations to come” (p. 15713).

Third, the mixed results presented here may be due to the lack of learner-centered teaching in schools with a sustainability education mission. Olsson and Gericke (2016) highlighted two versions of education for sustainable development (ESD) as developed
by Vare and Scott (2007), “ESD 1” and “ESD 2” (Olsson & Gericke, 2016, p. 37). ESD 1 is “fact-based and normative” (p. 38) with a narrow focus on acquiring knowledge needed to make sustainable choices. ESD 2, like pluralism and wicked problems, recognizes the varied perspectives associated with the “contradictions inherent in sustainability issues” (p. 38). ESD 2 engages students in taking ownership of their learning to enhance their interest and increase achievement (p. 38). Given that sustainable development is a complex and contradictory endeavor, an equally intricate version of sustainable education is required. Holism, pluralism, and ESD 2 show more promise for engaging students and increasing their SC. Similar research projects (Boeve-de Pauw et al., 2015; Olsson et al., 2016) determined that teachers need further training to successfully implement ESD 2.

Fourth, additional SCQ data analysis revealed a specific trend in students’ sustainability consciousness during adolescence. Olsson and Gericke (2016) ascertained “whether a decrease occurs in adolescents’ broader consciousness of sustainable development” (p. 35) between grades six and twelve. The authors followed this line of inquiry because an adolescent decrease for environmental concern was already established in the literature (p. 37) and little was known about the potential existence of a similar SC trend. Similar to other SC research reported here, reliability was measured using Cronbach's alpha and the SC scores of different age groups were analyzed via MANOVA, Wilks’ lambda statistics, and ANOVA (p. 42). Based on their analysis, they identified a SC drop as students enter adolescence for all aspects of SCQ. The drop exists for all students whether or not they attended a sustainability focused school and it was a temporary decline. The authors concluded that their research amplifies understanding of a
temporary dip in environmental concerns and adds economic and social variables to the results serving to “extend findings of several previous studies” (p. 45).

Lastly, one study investigated the effect of gender on SC and detected a gender gap (Olsson & Gericke, 2017, p. 363). Cronbach's alpha and principal axis factoring (PAF) were used to measure reliability and validity respectively. This study continued the use of MANOVA, Wilks' lambda statistics, and ANOVA to analyzed SC scores. An additional analysis, Cohen's $d$ was added to specifically investigate gender differences in SC results. Cohen's $d$ makes it "possible to detect trends and tendencies in differences between groups of students", in this case the measure was limited gender only in binary terms between girls and boys. Girls consistently scored higher on the SCQ than boys and older female students in grade 12 displayed an even larger gap (p. 365). The gap was found in overall scores and in each of the dimensions, environmental, economic, and equity. The gap was more pronounced in schools that intentionally practice sustainability education (pp. 367-368) even while sustainability education is often described as “transformative and inclusive” (p. 366).

In conclusion, the five research reports concerned with SC document the development SC survey that includes environmental, economic, and equity dimensions, mixed results for the implementation of sustainability education, the need for teaching and learning that address the complexity of sustainability, a temporary drop in SC in early adolescence, and evidence that girls consistently score higher on the SCQ than boys. The research methods and conclusions presented in these reports contributed directly to the study conducted at Finley Elementary School. The descriptions of holistic, pluralistic, and ESD 2 instruction were valuable concepts with which to analyze teacher
interview data and artifacts related to instruction. In addition, the 27-item SCQ was adapted and administered with students as a quantitative measure of SC before and after the central learning experience.

**Reimagining Education**

The Swedish schools described above that intentionally implement sustainability education consider sustainability as the purpose of schooling. The same is true for Finley Elementary School given the school’s mission is the definition of sustainability education. Schools in the United States have been perceived as serving varied purposes since they were first organized in the mid-nineteenth century.

There is some evidence that we are at an educational crossroads similar to that faced in the era. At that time, education was viewed as a vehicle for unifying the country and preserving democracy. In retrospect, democratic equality was the purpose of education (Labaree, 1997) and a way to confront the challenge of building and maintaining a democracy. Political and educational leaders perceived the relatively new republic to be on “shaky ground” (p. 20) and by founding “common schools” (p. 19) across the country, the democracy might be steadied. Arguably, schools that used to teach “civic virtue” (p. 20) in support of the republic found some success. This is still represented in our curriculum today in the form of civics and social studies coursework (p. 20). Now the question considered by sustainability educators is whether or not we can follow a similar path to build a more place-based and sustainable society.

Following this path may help us steady the shaky ground we are on in present day when one considers the global economy, climate change, social justice struggles, and the need for increased sustainability. Based on a fast-changing international economy,
organizations such as the Partnership for 21\textsuperscript{st} Century Learning have advocated for the critical skills that are needed to navigate and work in a complex and relatively young 21\textsuperscript{st} century (P21: Partnership for 21\textsuperscript{st} Century Learning, n.d.). P21 boasts considerable corporate backing that desires a social efficiency (Labaree, 1997) of sorts, adapting education to fill current workforce needs. More consistent with democratic equality, the new century is also facing up to the impacts of climate change. One recent research report (Gillis, 2016) found that high levels of greenhouse gases are melting the West Antarctic ice sheet that could raise sea levels by six feet by the year 2100. This sea level rise would drastically change the natural and built landscape along coastlines. As outlined in the \textit{National Action Plan for Educating for Sustainability} (Sobel, Gentile, & Bocko, 2014), education can play a role steadying these more contemporary societal challenges. The plan’s purpose is to inspire students “to make decisions that balance the need to preserve healthy ecosystems with the need to maintain vibrant economies and equitable social systems” (Sobel et al., 2014, p. 6). The plan also joins with Labaree (1997) in at least tempering social mobility as the dominant purpose of schools. The competitive and more-is-better nature of this educational purpose is contrary to sustainability’s goal to meet “present needs without compromising the ability of future generations to meet their needs” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3).

Thoughtfully integrated sustainability education can build on the example of democratic equality with compelling and meaningful learning experiences with future generations in mind. The work of sustainability education researchers points to the possibility that the time may be right to reimagine the purpose of schooling in the U.S.
Problem-based Learning Research Themes

The PBL research portion of the literature review investigated existing synergy between PBL and sustainability education. The U.S. Partnership for Education for Sustainable Development’s National Education for Sustainability K-12 Student Learning Standards (2009) was used as a heuristic device to discover PBL and sustainability education connections. Different objectives were pursued in the twenty-nine reviewed studies, yet analysis yielded five themes: Knowledge for designing solutions, tools for taking action, working together for change, interdependency for well-being, and reflection for improved actions. Only one reviewed PBL study intentionally integrated sustainability education. The U.S. Partnership for Education for Sustainable Development standards repeatedly cite problem-solving as a vital skill. The results of this review show that PBL is an essential instructional model that meets sustainability education outcomes and is deserving of increased attention and study.

Each of the five themes is described by presenting research reports that define the category and identifying direct links to sustainability education standards outlined by the U.S. Partnership for Sustainable Development. The reader will note that a subset of research reports is referenced in more than one theme. The review is a condensed version of a more comprehensive report published by the author (Bocko, 2017).

Knowledge for designing solutions. Content knowledge and understanding may increase success in designing solutions and achieving sustainability education outcomes. Numerous research reports contrast PBL and traditional instruction. Of the studies described here, five focus solely on a PBL and traditional instruction comparison (Fatade, Mogari, & Arigbabu, 2013; Nowak, 2007; Sungur, Tekkaya, & Geban, 2006; Wirkala &
Kuhn, 2011; Zhang, Parker, Eberhardt, & Passalacqua, 2011) while three emphasized the comparison and integrated additional variables (Drake & Long, 2009; Liu, Horton, Omanson, & Toprac, 2011; Maxwell, Mergendoller, & Bellisimo, 2005) Research reported in this section addressed sustainability education Standard 3: Students learn “the knowledge, skills, and attitudes necessary to continuously improve health and well-being” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). Findings in the studies were mixed yet suggest PBL promoted content acquisition.

Comparing PBL and traditional instruction. Evidence was found in three experimental studies (Fatade, et al., 2013; Sungur et al., 2006; Wirkala & Kuhn, 2011) that PBL led to increased academic achievement. High school mathematics students participated in Fatade et al. (2013). Mathematical understanding in PBL and traditional control groups was measured before and after instruction. Results showed that PBL students were better at increasing mathematical understanding. Sungur et al. (2006) researched differences between tenth grade PBL and traditional biology instruction. Assessment results revealed that PBL participants demonstrated higher proficiency in the “construction of knowledge” and “moving toward better solutions” (pp. 158–159). Wirkala and Kuhn (2011) compared middle school PBL and lecture-discussion outcomes in terms of comprehending and applying content. Results suggested that PBL students “show better long-term retention and ability to apply new material” that “actively engages them and enables them to put new ideas to use” (p. 1180).

In contrast to experimental methods, Zhang et al. (2011) employed grounded theory (Glaser & Strauss, 1967) to examine how a veteran kindergarten teacher utilized PBL to teach students about earth materials. Analysis of teacher planning,
implementation, and professional development artifacts along with assessment results showed that after PBL more students were able to include key information about earth materials in responses. The authors suggested that the teacher’s in-depth understanding of PBL and adapting instruction contributed to these results.

Two studies provided disconfirming evidence regarding PBL advantages. Nowak (2007) examined eighth grade student learning in PBL and non-PBL classrooms. Non-PBL students who took astronomy and geology tests performed better. However, PBL and non-PBL students took the astronomy assessment later in the year and PBL students were shown to retain more knowledge further out from the time of instruction. Sungur et al. (2006) added to the discussion of PBL and retention in their finding that PBL and non-PBL assessment results were not significantly different when it came to “simple recall” (p. 159).

*Integrating additional variables.* Comparing content learning between PBL and traditional instruction was enhanced with the investigation of additional variables (e.g. motivation, teacher experience, transfer of problem-solving skills) in an additional set of studies. Motivation in a media enriched PBL environment was studied by Liu et al. (2011) in a middle school setting. Students participated in a scenario to find new planetary homes for aliens whose home planets were destroyed. Results from a science assessment and motivation questionnaire showed that science knowledge increased for PBL students. Motivation was “above the mean” (p. 256) and, notably, students most commonly described the project as “fun” (p. 257).

Maxwell et al. (2005) integrated teacher content expertise with a study of content learning. Assessments measured macroeconomics understanding and teacher background.
Data analysis implied that student learning significantly increased in PBL groups. The strongest increase was found in student groups taught by a teacher with an undergraduate degree in economics (Maxwell et al., 2005, p. 324). The heightened teacher expertise potentially confounds results that PBL improved learning and may point to strong pedagogical content knowledge (Shulman, 1986) as the cause.

Drake and Long (2009) added multiple variables to their study investigating fourth grader stereotypical images of scientists, time-on-task, and transfer of problem-solving skills. PBL students demonstrated somewhat better content acquisition, slightly less “stereotypical attitudes” (p. 7), and more appropriate time-on-task behavior. Most striking was that PBL students identified more and a wider variety of problem-solving strategies that they utilized.

In summary, eight studies suggested that PBL increased student learning compared to traditional teaching and some disconfirming evidence was found. Sustainability performance indicators describe the integration of content learning and PBL. One indicator states: “identify skills and strategies required to create effective group change for a given issue” (U.S. Partnership for Education for Sustainable Development, 2009, p. 9). PBL may be better at developing content understanding via participation in sustainability education problem solving.

**Tools for taking action.** Instructional tools may enhance the content learning discussed in the first theme. Multiple studies highlighted tools for taking action. Hard scaffolds are instructional aids (e.g. worksheets, planning templates, technology tools, and software) that can be prepared ahead of time to help students overcome typical challenges of the PBL task (Brush & Saye, 2002, p. 2). One subset of research featured
hard scaffolds in the form of hypermedia (Belland et al., 2011; Pedersen & Liu, 2002; Simons & Klein, 2007). The remaining studies investigated more traditional paper and pencil hard scaffolds such as worksheets and concept maps (Choo, Rotgans, Yew, & Schmidt, 2011; Weshah, 2012). All studies addressed sustainability education Standard 3: “develop a multidisciplinary approach to learning the knowledge, skills, and attitudes” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3).

*Featuring hypermedia.* Three studies focused on the use of hypermedia as a scaffold. Hypermedia is a variety of communicative, electronic media with high interactivity and significant control afforded to users (Pedersen & Liu, 2002, p. 356). Pedersen and Liu (2002) investigated the impact of video tutorials on sixth grade student success in finding homeless aliens a habitable planet (as in Liu et al., 2011). Tutorials were hosted by a virtual expert scientist who modeled strategies for the alien rescue. The modeling was shown to improve self-directed work, reasoning for solutions, and ability to “stay focused on a complex problem for three weeks” (Pedersen & Liu, 2002, p. 376).

Similarly, Simons and Klein (2007) analyzed the influence of hypermedia during a seventh grade PBL scenario: Planning an air balloon trip around the world. The study measured levels of hypermedia scaffolding (none, optional, required) related to achievement levels and approach to problem tasks. Students who worked in the scaffolding optional and required conditions displayed better note taking skills yet failed to show content learning improvements.

Belland et al. (2011) investigated the impact of a “Connection Log” (p. 671) during PBL. The log was a web-based guide designed to support students to define the problem, determine needed information, find and organize information, develop a claim,
and link evidence to that claim (pp. 672–673). Research questions focused on the log’s impact on argument construction and quality in four seventh-grade science classrooms of varying academic levels. Data analysis revealed that the log appeared to help students understand questions, identify relevant information, and generate an effective argument (p. 687).

*Investigating traditional hard scaffolds.* Two additional studies exemplify research on traditional paper and pencil scaffolding. Weshah (2012) uncovered some evidence that concept mapping and reflective writing improved learning and reflective thinking skills in tenth grade students. Choo et al. (2011) found differing results in their investigation of a single worksheet consisting of a series of guiding questions. Participants were high school students studying immunology. They were assessed on concept recall and important influences on their learning. Results found that control group students scored higher than students utilizing the worksheet. This outcome implies that the worksheet had no influence though it was shown later that the control group had a higher level of topical prior knowledge.

In summary, four of five studies found at least some evidence of hard scaffolds promoting learning and success in PBL. In particular, evidence indicated that modeling in hypermedia and concept mapping helped students gain knowledge and skills. The evidence reflects sustainability education performance indicators calling for students to “create a flow chart, timeline, or some other type of graphic organizer” (U.S. Partnership for Education for Sustainable Development, 2009, p. 9) in order to take action. Taken together, outcomes in the highlighted studies point to support for using electronic and hard copy graphic tools for change in the context of sustainability education.
Working together for change. Hard scaffolds are complimented by soft scaffolds, situational aids provided through the interactions between teacher and students that promote learning (Brush & Saye, 2002, p. 2). Six research reports focused soft scaffolds (Choo et al., 2011; Ferreira & Trudel, 2012; Goodnough & Cashion, 2006; Sage, 1996; Simons, Klein, & Brush, 2004; Wirkala & Kuhn, 2011). One subset of reports investigated teacher actions that promote collaborative success and another group examined student actions. The studies attend to sustainability education Standard 3 in which students learn “via both personal and collective decisions and actions” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3).

Teaching collaboration. One particularly strong scaffolding strategy was for the teacher to model, coach, and fade during PBL. Sage (1996) observed a teacher demonstrating active listening, coaching students to do the same, and gradually reducing their interaction so students could facilitate listening on their own. Students who progressed to this type of self-direction appeared to have higher levels of motivation in three urban classrooms, two elementary and one middle school. Goodnough and Cashion (2006) employed Collaborative Inquiry (Bray, Lee, Smith, & Yorks, 2000) between colleagues to answer questions about student interactions during PBL. They found that high school students new to PBL can be “reluctant to share their thinking” (p. 288) and need intentional coaching to participate successfully.

Simons et al. (2004) presented a case study focused on one sixth grade teacher of a “Global Connections” (p. 215) class who promoted collaboration with four instructional techniques: Questioning, peer support, feedback, and management. Teacher questioning prompted student thinking, peer support distributed cognitive load (Salomon, 1993),
feedback deepened understanding, and structured communication and daily expectations made tasks more manageable to students. However, student achievement gains were not statistically significant. The teacher and students identified lack of time as the most likely cause of lower achievement. Similarly, Wirkala and Kuhn (2011) identified teacher encouragement as important to group success. They also assessed whether or not collaboration was essential to PB and found that performance between team-based PBL and individual PBL did not differ significantly.

*Focusing on student interaction.* Positive outcomes resulting from student collaborations were found in a separate set of research reports. Choo et al. (2011) suggested that “soft scaffolds, such as tutoring and collaborative small group learning, are crucial for student learning in a PBL environment” (p. 523). Goodnough and Cashion (2006) reported that students identified “negotiating and sharing within a group, research skills, and presenting skills” (p. 289) as abilities gained from the teacher coaching small group work. Students shared that being engaged in active and novel learning experiences were reasons for liking PBL. Ferreira and Trudel (2012) investigated high school student attitudes toward science, problem solving, and sense of classroom community. Students expressed their attraction to the “sense of control” (p. 28), open discussion of ideas, and debating perspectives.

In summary, the six studies presented here suggested positive outcomes from the use of soft scaffolds. In particular, teachers found success with a progression from modeling and fading to limited teacher instruction. With strategies such as these in place, students gained negotiating, researching, and self-direction skills. These results are consistent with sustainability indicators calling for students to “perform effectively on
teams” (U.S. Partnership for Education for Sustainable Development, 2009, p. 6) and “identify skills and strategies required to create effective group change for a given issue” (p. 12). However, two studies found that collaboration did not improve student achievement. Even with these disconfirming findings, evidence in support of other benefits resulting from teacher and group interaction is relatively strong.

**Interdependency for well-being.** The investigation of collective problem-solving was brought into more focus through analysis of a subgroup of studies that revealed specific interdependencies displayed during PBL. Three research reports pointed to benefits for students with special needs (Belland, Glazewski, & Ertmer, 2009; Belland et al., 2011; Hsu et al., 2012) while a fourth contradicted this evidence (Simons & Klein, 2007). These studies are consistent with sustainability education Standard 2 that references “social systems and how these interconnected systems affect individual and societal well-being” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). Research presented here highlights mainstreamed and low-achieving students and describes how varying abilities interact. Mainstreamed students had special needs and were taught alongside other students in general education classes (Belland et al., 2009). Low-achieving students were identified based on assessment results, teacher observations (Belland et al., 2011), and relative absence, mobility rates, and performance on reading tests (Simons & Klein, 2007).

**Benefiting students with special needs.** The majority of research reports outlined here suggest that all students benefit from PBL. Belland et al. (2009) found that student participants thought about problems in different ways, fulfilled different roles, and supported each other throughout problem-solving. Even with diversity in cognitive
approaches, special needs status, and achievement levels, students were able to support each other to arrive at a solution. Most striking about the use of the “Connection log” (Belland et al., 2011, p. 671) is that when comparing high and low achieving classes, “effect among lower-achieving students was approximately twice the magnitude as the effect among all students collectively” (p. 686). The authors cautioned that just because they arrived at this result, there are no guarantees that the outcome is conclusive or will be consistent in future studies.

*Leaving students behind.* Simons and Klein (2007) presented a potential challenge to the benefits of interdependency. They found low-achieving students were often “left behind” (p. 69) during PBL. Consistently in this study, high-achieving students performed better than low-achieving students when content learning, using research information, and perceived level of difficulty were assessed. The authors point to the teacher as a possible remedy to this finding. They suggest that the instructional leader placing greater emphasis on PBL unit objectives and providing support to meet those objectives may improve low-achieving student performance.

In summary, this small research set illuminates high and low achieving students’ participation in PBL and sustainability education. Evidence was presented for moving toward equity when struggling learners and general education students learn together. Results in this theme relate to the sustainability education “Relationships” performance indicator: “Students interact respectfully with others, including those with whom they have differences.” (U.S. Partnership for Education for Sustainable Development, 2009, p. 5). Few studies were found to constitute this theme and one reported contradictory results. Overall, evidence points to the need for further study to learn more about
interdependency in PBL and sustainability education.

**Reflection for improved actions.** Reflective thinking is an example of what sustainability education Standard 3 terms a “multidisciplinary approach to learning” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). Three research reports demonstrated links between reflective thinking, PBL and sustainability education (Dovros & Makrakis, 2012; Song, Grabowski, Koszalka, & Harkness, 2006; Weshah, 2012). The studies define reflective thinking as choosing strategies, monitoring progress, and evaluating solutions as skills (Weshah, 2012) that must be active, thoughtful, and persistent (Dovros & Makrakis, 2012). The research further described how PBL promoted reflection and associated sustainability education skills.

**Promoting reflective thinking.** Dovros and Makrakis (2012) investigated how teachers intentionally guided students through “radical sustainability transformation” (p. 79) and fostered reflective thinking. Students engaged in controversies surrounding genetically modified foods (GMF), deconstructed the issue, prepared to take action, and continued learning while they took action on the issue (Kostoulas-Makrakis, 2011). Students practiced reflective thinking using an e-learning environment to contemplate GMF beliefs, compare ideas, and reconstruct dispositions. Weshah (2012) also identified the need for teachers to deliberately promote reflective thinking using a model from Delisle (1997): Connect with the problem, set up problem-solving structure, visit and revisit the problem, produce a product, and evaluate. In contrast to e-learning, this study used hard copy, teacher-generated graphic organizers and guide sheets to facilitate reflection and problem-solving.
Song et al. (2006) added the importance of adjusting reflective activities according to age. They compared middle school and college student perceptions regarding reflective thinking aids. Factors included ill-structured tasks, real-world problems, teacher explanations and questions, partners, think time, exploring topics of interest, drawing pictures, writing, and answering questions. Both age groups similarly perceived the learning environment and scaffolding as helpful for reflective thinking. However, this overall perception differed in detail by age. Middle school students in an aeronautics scenario identified working with partners most helpful. College students studying statistics pointed to teacher questioning, writing, and ill-structured tasks as most valuable. The authors suggested that to effectively promote reflection using PBL, practitioners must consider developmental stages.

**Resulting skills.** The three studies suggested that PBL can be helpful in skills development. Dovros & Makrakis (2012) research documented a shift in mental models and the disruption of how individuals frame their thinking, decision-making, and actions. Student conclusions regarding GMF were thoughtful and measured. They pointed to noteworthy evidence of GMF benefits, that long-term effects are unknown and could be disastrous (p. 83). The study reported that students gained a vital sustainability skill: They “acquired the basic skills needed for creative citizens that live in a world that changes” (p. 85). Weshah (2012) agreed, if students follow an intentional real-life problem-solving process using hard scaffolds, they will be better equipped for future encounters with authentic challenges. Song et al. (2006) found that middle school reflected more through social interaction promoting “conceptual skills” (p. 65). College
students in the same study chose more independent activities as helpful and that may support development of self-direction.

In summary, three studies provided some evidence that PBL is helpful in promoting reflective thinking. In addition, reflective thinking strategies such as deconstructing issues, comparing ideas, evaluating solutions, and working in groups and individually are consistent with the high school sustainability performance indicator that encourages students to “reflect on lessons learned regarding change strategies” (U.S. Partnership for Education for Sustainable Development, 2009, p. 12). Taken together, the research reports begin to outline how to guide students through intentional problem solving for cognitive development. Three studies are not enough to draw concrete conclusions yet encourage further study.

The results of this literature review demonstrate that the connections between PBL and sustainability education are strong. The wide majority of studies suggested that PBL is an effective instructional model in PreK-12 education. Each of the five themes provided further understanding of PBL coupled with sustainability education standards. The themes suggest that PBL content learning at least equals that of traditional instruction, intentional use of hard scaffolds and collaborative problem solving improves learning for all students, and problem-solving skills are promoted through reflection. Each theme, however, includes some disconfirming results for these findings. Due to these contradictions and the fact that only one reviewed study intentionally linked PBL and sustainability education, more research is needed to more fully understand real-life problem solving.
Purpose and Research Questions

The descriptions of PBL’s real world context in terms of learning standards, wicked problems, and sustainability education along with a theoretical frame built on sociocultural learning converge to highlight reimagined instructional practice. The gap in PreK-12 PBL research and discussing PBL in the context of 21st century challenges are substantial needs that frame this study. Within this context, an opportunity to expand the PreK-12 PBL research literature was revealed. Therefore, the purpose of this study was to examine the relationship of PBL and sustainability education learning outcomes in a combined fifth and sixth grade classroom who sought to solve a sustainability challenge: How to cook food without using wood as a fuel source. Research questions are: What PBL instructional strategies promote sustainability education? What sustainability education skills and understandings are promoted by PBL? To what extent does PBL affect students' sustainability consciousness?
CHAPTER 3: METHODS

The examination of PBL as an instructional strategy for a sustainability education followed a case-study, mixed-method approach. Research design elements were drawn from multiple researchers and authors (Creswell, 2009; Merriam, 1998; Merriam & Tisdell, 2016; Starman, 2013; Teddlie & Tashakkori, 2009; Yazan, 2015; & Yin, 2017). Qualitative case-study methods were weighted heavier than the quantitative assessment portion in the research design. Assessment results were primarily used to confirm or disconfirm qualitative results (i.e. interview transcripts, field observations, and artifacts).

Case study research is defined as an in-depth description and analysis of a bounded phenomenon such as a program, person, or process (Merriam, 1998). One particular classroom, comprised of one teacher and eleven students, served as the bounded learning experience and primary unit of study. This research was a “disciplined configurative” (Starman, 2013, p. 34) case study given that it relied on established theory to explain the case. A case study framed by sociocultural learning theory can increase the study’s “conceptual validity” (Starman, 2013, p. 36), identifying and analyzing indicators that best represent a theoretical concept. The teacher and students designing a solution to a sustainability problem was an example of sociocultural learning, “individuals interacting with their social worlds” (Yazan, 2015, p. 137). The learning engaged participants in solving real-world problems in collaboration with local individuals and organizations. The research is also considered a “building block” (Starman, 2013, p. 34) study, one of a growing set of sustainability education studies that, when put together, contribute to more in-depth understanding.
Three case study descriptors offered by Yazan (2015) provide additional details for the nature of this study. First, the research was “particularistic” (p. 139), precise in its focus, in its examination of a specific group’s lived experience while they endeavor to solve an intentionally-designed sustainability challenge. Second, the study was “descriptive” (p. 139), yielding a thick, rich portal of the teacher and students designing solutions. Third, the research was “heuristic” (p. 139), seeking new understanding of a phenomenon, as it illuminates understanding of PBL and sustainability education in a public elementary school classroom. Designing and implementing the research project according to these descriptors was expected to reveal specific instructional strategies employed by the teacher, students’ emergent sustainability skills and understandings, and indications of students gaining academic content knowledge.

Solutions to the problem and student learning outcomes represent the case study’s unit of analysis. As demonstrated in the literature review, a PreK-12 classroom that intentionally engages in designing sustainability solutions is rare. Starman (2013) argues that the exceptionality of a phenomenon is precisely why case study design should be chosen. Case studies have the potential to bring to light experiences that are “interesting, unusual, striking, and may cause changes” (p. 35). The essence of a deliberate, dynamic learning experience will be best captured by case study methods that are purposely designed yet flexible to “discover the unknown within well-known borders” (Starman, 2013, p. 42). In the familiar context of PreK-12 education structured by governmental mandates and accountability measures far removed from daily reality, case study research served to reconnect us to the unique lived experience of students and educators.
The majority of data collected about the lived experience were qualitative. The research, however, was designed as a mixed-methods study given that the qualitative data were augmented by a quantitative measure. Mixed-methods studies are those “in which the investigator collects and analyzes data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study…” (Tashakkori & Cresswell, 2007, p. 4). Prior research (Bocko, 2018) revealed that students who engage in PBL and sustainability education can exhibit emergent understanding of sustainability as a concept. The earlier research methods however relied solely on qualitative data that were not sufficient to yield indicators of progress on specific sustainability learning outcomes. Integrating a quantitative pre- and post-assessment that measures change in understanding sought to address this weakness found in the prior study. Including the assessment increased “internal validity” (Merriam & Tisdell, 2016, p. 242), how well research findings match reality, by comparing it to the qualitative data to determine convergence and or differences between data sets. The research followed the parallel mixed design (Teddlie & Tashakkori, 2009) of mixed methods research: Qualitative and quantitative “phases of the study… occur in a parallel manner, either simultaneously or with some time lapse…” to “address related aspects of the same basic research question(s)” (p. 143). The results of qualitative and quantitative data analysis are discussed further in the discussion section of the research report.

Case study and mixed methods were incorporated throughout the design of this study. The following subsections provide further methodological details regarding setting, participants, learning activities, sequence of study, data collection and analysis, and trustworthiness.
**Setting and Participants**

Finley Elementary School, a public, pre-kindergarten to grade 6 school in the northeast United States was chosen for this study. The school’s mission is the definition of sustainability education: To inspire and educate students to make decisions with an understanding of the interrelatedness of social equity, the economy, and the environment for today and in the future.

Rachel, the teacher, and eleven students from the combined fifth and sixth grades classroom participated in the study. Rachel has been teaching since 1997 and holds a Master of Education degree with a concentration in sustainability education. She engages students in PBL and sustainability education throughout the year. The students in the class were a mix of four girls and two boys in fifth grade and two girls and three boys in sixth grade. Table 1 displays this grade-level information along with student names (pseudonyms). Finley Elementary School has been striving to implement sustainability education since the creation of their new mission and focus in 2011.

Table 1

*Participating Students and Grade Levels*

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<thead>
<tr>
<th>Grade 5</th>
<th>Grade 6</th>
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<tbody>
<tr>
<td>Anne</td>
<td>Henry</td>
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<tr>
<td>Greta</td>
<td>Peter</td>
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<tr>
<td>Jane</td>
<td>Rosa</td>
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<td>Michael</td>
<td>Ruth</td>
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<td>Ringo</td>
<td>Samson</td>
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<td>Teddy</td>
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The school and participants matched the desired setting for this study: A public PreK-12 classroom intentionally practicing PBL and sustainability education for at least five years. Choosing a public PreK-12 classroom was intended to promote “analytic generalizability” (Curtis, Gesler, Smith, & Washburn, 2000, p. 1003). Given that 90% of U.S. primary and secondary school aged students attend public schools (101 American School Statistics, 2020), results from research in a public school are more likely to be applied to other similar public settings. Intentionality with PBL and sustainability education was essential since these methods are central to the study. Rich data were more expected to emerge if the teacher and students are purposefully engaging in real-world learning that is relevant to their lives and the local community. The study site having at least a five-year history of intentional implementation was necessary given that research questions focus on established, ongoing school activities not on instructional strategies in the early stages of development and application.

**PBL Learning Experience**

The core learning experience investigated in this study was the fifth and sixth grades challenge to design and construct a solar oven. The specific question they were asked to answer captures the problem they were solving: “What materials are good thermal insulators and also have a low impact on the environment?” (Museum of Science, 2011, p. 77) Rachel built the learning experience on an existing curriculum unit called *Now You’re Cooking: Designing Solar Ovens, Energy and Green Engineering for Elementary Students* (Museum of Science, 2011). The unit is part of a Museum of Science (Boston, MA) program called *Engineering is Elementary* (EiE): “A curricular program that integrates engineering with elementary science topics. Connections with
literacy, social studies, and mathematics can also be made.” (Museum of Science, 2011, p. 1) What follows is a description of the sequence of learning activities completed by the teacher and students, foundational text embedded in the unit, PBL process employed by the teacher, supplemental books read by the class, and writing assignment that coincided with the final design and use of solar ovens.

**Sequence of learning activities.** Rachel loosely followed the lessons as organized in *Now You're Cooking* (Museum of Science, 2011) to guide her students to design and build four model solar ovens. Table 2 represents the core activities that she completed with her students. She noted that she used the curriculum manual to “get

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyday Examples of Technology</td>
<td>Examined common examples of technology; discussed how objects were designed to solve problems; and, identified materials of which objects were made.</td>
</tr>
<tr>
<td>Story: <em>Lerato Cooks Up a Plan</em></td>
<td>Read <em>Lerato Cooks Up a Plan</em> story; discussed green engineering field; and, asked and answered questions regarding environmental impact of technology.</td>
</tr>
<tr>
<td>Life Cycle Assessment</td>
<td>Investigated the life cycle of paper; discussed resources required and environmental impacts of paper production.</td>
</tr>
<tr>
<td>Thermal Insulator Experiment</td>
<td>Conducted experiments to assess performance of different materials as thermal insulators; analyzed materials regarding their environmental impacts; and, discussed how experiment results may inform solar oven designs.</td>
</tr>
<tr>
<td>Solar Oven Design &amp; Construction</td>
<td>Used the NGSS and EiE engineering design process to design four solar ovens; used recycled and found materials; applied thermal insulator learning to optimize performance; conducted tests to identify design flaws; and, improved designs.</td>
</tr>
</tbody>
</table>

*Note: Adapted from Museum of Science, 2011, p. 10.*
my students thinking about the engineering process… and then we followed a couple of
the lessons but there got to be a point where I just sort of deviated… because it just
seemed too mechanical to go by”. The activities are further described through the
presentation of findings in a later section of this report.

**Foundational text.** *Lerato Cooks Up a Plan* is a storybook embedded in the EiE
*Now You’re Cooking* (Museum of Science, 2011) curriculum. Lerato is a young girl from
Botswana. The story shares how she, her family, and community members learn how to
cook without burning firewood. Lerato learns that wood is in very short supply, takes a
great deal of human effort to collect, and adversely impacts the environment. The group
designs and builds a solar oven to overcome this challenge with Lerato coordinating the
effort. They capture the heat and light energy of the sun instead of burning wood. The
insulation system that Lerato designs using green engineering principles is the most
important feature of the design. That feature makes it possible to use the solar oven
effectively to cook the family’s meals. The text introduces students to the field of green
engineering and minimizing environmental impact. In the end, the experience helps
Lerato gain confidence for attending university like her older sister’s friend.

**PBL process.** Rachel followed the NGSS engineering design process to guide her
students in PBL. Figure 1 is an image of the NGSS engineering design process.

Engineering in this context is “any engagement in a systematic practice of design to
The NGSS emphasizes “engineering design practices that all citizens should learn”
(NGSS Lead States, 2013a, p. 1).
Figure 1. NGSS Engineering Design Process, Grades 6-8. The graphic presents the design process in three parts: Define, develop solutions and optimize. (NGSS Lead States, 2013a, p. 5).

EiE provided a five-step version of the NGSS engineering design process. The steps are: “Ask”, “Imagine”, “Plan”, “Create”, and “Improve” (Museum of Science, 2011, p. 23). Both design processes are drawn from *A Framework For K-12 Science Education: Practices, Crosscutting Concepts, And Core Ideas* (National Research Council, 2012). The framework states that the overall goal of the document is to ensure that “all students have some appreciation of the beauty and wonder of science” and “possess sufficient knowledge of science and engineering to engage in public discussions on related issues” (p. 1). Table 3 displays how the NGSS and Museum of Science engineering design processes align and complement each other.
Table 3
Comparison of NGSS and Museum of Science Engineering Design Processes

<table>
<thead>
<tr>
<th>NGSS</th>
<th>Museum of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>Ask</td>
</tr>
<tr>
<td></td>
<td>Imagine</td>
</tr>
<tr>
<td>Develop Solutions</td>
<td>Plan</td>
</tr>
<tr>
<td></td>
<td>Create</td>
</tr>
<tr>
<td>Optimize</td>
<td>Improve</td>
</tr>
</tbody>
</table>

**Supplemental texts.** Rachel and her students referred to two additional texts during data collection for this study: *The Boy Who Harnessed the Wind* (Kamkwamba & Mealer, 2015) and *The Omnivore’s Dilemma: A Natural History of Four Meals* (Pollan, 2006). Each book influenced the solar oven project work in different ways.

*The Boy Who Harnessed the Wind* (Kamkwamba & Mealer, 2015) is a story of William, a Malawian boy who overcame poverty, drought, famine, government rationing, and political riots that conspired to force town residents to abandon their community. He, however, recognized other elements in a flawed system and used them as leverage points to solve a problem. They included access to the school library, his knowledge of electrical engineering, and collaboration. In the face of a system working against him and his community, he with his family and friends designed and built a windmill that powered an electric water pump used to irrigate crops for a successful harvest. Earlier in the school year and after reading the book, Rachel challenged her students to design and build windmills that would produce electricity. Students were inspired by the story and prepared for the design and construction of solar ovens given that Rachel also used the engineering design process for this project.
The Omnivore’s Dilemma (Pollan, 2006) explores the food choices we make today and how they are influenced by our past. The book seeks to answer the question: Which food choices are the most ethical and sustainable? The author conducts life cycle assessments of four meals from the beginning of the food chain to the plate. Conclusions are that corn is influential in food production, the meaning of the term organic is questioned, and buying local is a good choice. Local food is better because it cuts down on transportation costs and environmental impacts, keeps money local therefore reducing influence of corporations, and the quality is superior. Some of Rachel’s students read the original book and some read the young readers edition (Pollan, 2015). Tracking meals from food source to plate complemented the life cycle assessments done as part of the solar oven design and construction project.

Writing assignment. Students were challenged to choose and write about teen activism at the end of the school year and near the conclusion of the solar oven project. Rachel adapted the assignment from a writing prompt found in Units of Study in Argument, Informational, and Narrative Writing: Grade 6 (Calkins & Jones-Rooy, 2014). The purpose of the teen activism writing assignment was to research and write about teen activists, young adults who seek to change the world for the better. Students were asked to write in the informative and explanatory text genre. For fifth grade that means the writing will “examine a topic and convey ideas and information clearly” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 20). Sixth grade informative writing conveys “ideas, concepts, and information through the selection, organization, and analysis of relevant content” (p. 42) Characters profiled in the EiE curriculum and supplemental texts detailed above
served as inspiration for who students wrote about. Students chose between arguing a specific point, persuading the reader to a point of view, or simply providing factual information about teen activism. The choice students made depended on their individual writing skill level. Some students wrote an information report on a single teen activist and other students synthesized the characteristics of multiple activists to determine the qualities of teen activism. Examples of high profile teen activists who students wrote about: Malala Yousafzai, an activist for female education rights (Yousafzai & Lamb, 2013), Greta Thunberg who demands action on climate change (Alter, Haynes, & Worland, 2019), and Alex Lin, pioneer in reducing electronic waste (E-waste Youth Activist, 2008).

**Sequence of the Study**

The study progressed through the following stages after the identification of setting and participants: (a) pre-assessment of sustainability consciousness; (b) interview, observation, and artifact collection; (c) constant comparative analysis throughout qualitative data collection; (d) post-assessment of sustainability consciousness; (e) qualitative and quantitative data analysis; and, (d) formulation of results.

**Quantitative Data Collection**

Prior to PBL and sustainability education activities, students completed the Sustainability Consciousness Survey, a 27-question pre-assessment that measures student sustainability consciousness adapted from questionnaires used in multiple Swedish studies (Boeve-de Pauw et al., 2015; Gericke, Boeve-de Pauw et al., 2018; Olsson & Gericke, 2016; Olsson & Gericke, 2017; Olsson et al., 2016). A full copy of the survey is provided in the appendix. The purpose of the pre-assessment established students’
baseline sustainability consciousness. After the full implementation of PBL and solar oven construction, the same questionnaire measured a post-assessment to measure growth in conceptual understanding. Pre- and post-test results were compared to qualitative data outcomes as part of data analysis. Quantitative assessment results collected before and after the students’ learning experience were considered secondary to the qualitative data set collected. The quantitative data attended to a specific need “to corroborate findings generated through other methods” (Teddlie & Tashakkori, 2009, p. 161).

**Qualitative Data Collection**

Data were collected to identify instructional strategies, skills, and understandings directly from the experience of teachers and students. Specifically, data were assembled from interviews, researcher participant observations, and teaching and learning materials. Consistent with case study research, these data were assembled as representations of a specific “contemporary phenomenon in a real-life context” (Yin, 2002, p. 13) as experienced by a particular group of students and their teacher. All data were collected concurrently and constant comparative method (Glaser, 1965) was employed.

One teacher and eleven students in the class participated in semi-structured interviews. Interview questions are presented in appendices A and B. Interviews were audio recorded and transcribed. Two teacher interviews were conducted via phone after school hours in order to avoid taking the teacher away from valuable instructional time during the researcher’s site visits. Each teacher interview lasted at least one hour. Student interviews took place during school hours when demands on students were more flexible and time away from formal learning is minimized. Each student interview lasted approximately 45 minutes.
Seven field observations of students and teachers in action with PBL and sustainability education were conducted and documented. Observations lasted between two and four hours. During observation visits, artifacts such as unit plans, planning packets, and student work were collected for analysis.

The purposes of the researcher’s notebook are to record field observations and expand those records into thick description (Rossman & Rallis, 2012) and ongoing reflective comments (Merriam & Tisdell, 2016) representing the researcher’s reactions to the study. Notes recorded during observation visits included descriptions of classroom and field activities, student and teacher quotes, and ideas for artifacts to collect. Raw observation records were transformed into research memos that integrated field observations with theory and attempted the articulation of emerging themes and central phenomena resulting from research activities.

Ongoing interpretation and comparison revealed patterns useful to data analysis and drawing conclusions. Contents of the notebook, interview transcripts, and artifacts comprise the source material for the study’s audit trail.

**Quantitative Data Analysis**

Quantitative data were analyzed in three distinct ways. First, the reliability of survey results was tested. Second, the significance of growth in SC was measured based on pre- and post-test results. Third, descriptive statistics displayed additional detail.

Sustainability Consciousness Survey data were uploaded into IBM SPSS version 27. Reliability was measured using Cronbach’s alpha (Tavakol & Dennick, 2011). This study investigated SC as a whole and in the subcategories of knowingness (K), attitude (A), and behavior (B). Each subcategory integrated the environmental (Env), economic
(Eco), and equity (Eq) dimensions of sustainability. Pre- and post-test Cronbach’s alpha values were calculated for survey results as a whole, 27 items KAB EnvEcoEq. In addition, pre- and post-survey values were calculated individually for K EnvEcoEq, A EnvEcoEq, and B EnvEcoEq.

Given that this study’s sample size was small and data potentially non-normal, a nonparametric test was used to analyze mean values between pre- and post-surveys in order to measure SC growth. The nonparametric Wilcoxon Signed-Rank Test (WSRT) was used to analyze growth in SC. WSRT can be considered equivalent to a t-test, does not assume normality, and is designed to compare two sets of data from the same participants (Hollander, Wolfe, & Chicken, 2014). Similar to the reliability measure, WSRT was calculated for KAB EnvEcoEq and in subsections K EnvEcoEq, A EnvEcoEq, and B EnvEcoEq. The minimum possible score for individual items and students was one. The maximum score possible was five. Each student's scores for each item were added together and divided by the number of items to calculate the mean. The mean for KAB EnvEcoEq and the three subsections was determined using SPSS version 27. Unlike the wide majority of survey elements, two items within the questionnaire were phrased negatively in an attempt to counteract respondent biases. Prior to conducting the WSRT, these items were reverse coded in order to make them numerically consistent with all other items in the survey.

These statistics were compared to qualitative data results as one method of confirming or disconfirming outcomes determined via the investigation of participants’ self-reported experiences.
Qualitative Data Analysis

Analyzing multiple data sources to reveal the lived experiences of case participants was iterative. Analysis commenced as soon as the first qualitative data were collected and continued as new data were added.

Adapted from Charmaz (2014), themes, patterns, and meaning were revealed in interview transcripts in stages through (a) open coding, “naming each word, line, or segment of data” (p. 113); (b) axial coding, the process of identifying frequent and significant codes in potential relationships; (c) categorizing significant and relational codes; (d) selective coding, identifying a core abstraction based on prior coding steps. Scott’s (2004) “Conditional Relationship Guide” helped frame selective coding and generate a codebook. Qualitative research software NVivo was employed in order to code and organize data.

Field observation notes and artifacts were analyzed using a process consistent with interview transcript coding. The majority of collected artifacts are text-based. Therefore, it was appropriate to apply a text-based coding process. While analysis of field notes and artifacts was secondary to interview transcript coding, the secondary analyses provided comparative data to interview outcomes in order to make sense of the participant experiences.

Memo-writing was employed throughout all data analysis for this study. Specific purposes for memos were to operationalize categories, further describe context, and explore where collected artifacts fit within emerging results. Researcher memos were a primary tool for “theoretical sampling” (Charmaz, 2014, p. 192). This final type of analysis is defined as seeking and collecting important information in order to elaborate
and refine emerging results (p. 192). During this final stage, borrowing from Morrow and Smith (1995), a central phenomenon (category) was sought around which the participants’ learning experience revolved.

**Trustworthiness**

In this case study, the aim was to gain a deeper understanding of how a specific group of students and their teacher experience designing solutions to a sustainability problem. Researchers must adhere to “norms for acceptable and competent research” (Rossman & Rallis, 2012, p. 60), honor participants ethically, and demonstrate sensitivity for the politics of the research topic in order to facilitate a trustworthy study. Norms for competent research include prolonged engagement, triangulation, and recording an audit trail of research activities.

This study was conducted over the course of a full year in an intensive pattern (p. 62) during the 2018-2019 school year. Access to the study site, data collection and analysis, writing the research report, and presentation of findings were completed by May 2019. Prolonged engagement ensures that the researcher will be fully orientated to the setting, can overcome preconceptions, build trust with participants, and have ample time to recognize and account for distortions in the data (Cohen & Crabtree, 2006b). During this time period, multiple sources of qualitative data were collected and analyzed. The teacher and students were interviewed, artifacts collected (Cohen & Crabtree, 2006a), and the researcher observed field and classroom activities. Observations were recorded in a researcher’s notebook and in memos. Prior to and after students participated in the PBL and sustainable education unit, they completed a quantitative sustainability understanding assessment. Collecting and analyzing “multiple sources of data” over “multiple points of
time” (p. 65) promotes triangulation: Comparing and contrasting different data sources to confirm emerging findings (Merriam & Tisdell, 2016). Triangulation increases the likelihood of a well-developed understanding of the site and research participants.

This entire research process was recorded in a researcher’s notebook to promote ongoing reflection and establish an audit trail (Merriam & Tisdell, 2016). Intentional, continuous record keeping, and reflection of the research process provided a thorough record to refer back to if any ethical problems arose. One ethical challenge that could have arisen was participant concern over multiple data sources and how that information is handled (Rossman & Rallis, 2012). To avoid this challenge, security regarding data collection and storage was included in the informed consent form. Participants could have also expressed concern with how research outcomes would be shared outside of the research context. Participants were assured that while the words they share would be used in developing conclusions, every step was taken to protect their anonymity. Participants were also informed of the study’s potential benefit to inform future development and implementation of meaningful, real world learning experiences for children. All of these steps attended to ethics and helped the research to “uncover the complexity of human behavior in a contextual framework” (Merriam & Tisdell, 2016, p. 244).
CHAPTER 4: FINDINGS

The purpose of this study was to investigate the relationship between PBL and sustainability education learning outcomes in a combined fifth and sixth grade classroom. The students were challenged to design a solution to a specific sustainability problem. Results were revealed through analysis of sustainability consciousness survey data, interview transcripts, field observations, and artifacts collected at the research site.

The findings are detailed in four different sections. The first section presents the pre- and post-survey quantitative data based on results of the Sustainability Consciousness Survey. Reliability and growth statistics are reported. Qualitative results are organized in three subsequent sections: Pedagogy for sustainability thinking, exhibition of sustainability understanding, and growth in sustainability consciousness. Data presented in these sections represent some evidence of a relationship between PBL facilitated by the teacher, skills and understandings demonstrated by students, and indications of students’ deeper sustainability cognizance and behavior.

Each qualitative section is comprised of multiple themes that can be linked to elements of the theoretical framework. Rachel embodied a pedagogy of sustainable thinking. The instructional strategies employed by her were dynamic and interpersonal, matching the complexity of our world and the practice of sociocultural (Vygotsky, 1978) teaching and learning. They also promoted student participation in social improvement (Brameld, 1955; Rugg, 1939). Given how Rachel facilitated learning, students exhibited sustainability skills and understandings as presented in the second qualitative section. Student abilities presented in this segment of the findings were evidence of critical thinking and heightened participation in inventing and reinventing the world (Freire,
The growth in sustainability consciousness section contains some evidence that students were beginning to integrate sustainability knowingness, attitude, and behavior into their lives. This growth was evidence of emergent readiness to participate in real-life social improvement and transforming our world (Brameld, 1955; Freire, 1993; Rugg, 1939) for the better.

**Sustainability Consciousness Survey**

Reliability and mean value analyses for the SC survey results are reported in this section. Only nine of eleven student participants completed the survey before and after the solar oven project activities. Three students did not participate due to absence on the day the survey was administered or lack of consent to participate in that portion of the study. Cronbach’s alpha values were calculated to measure reliability (Tavakol & Dennick, 2011) and results were mixed. The Wilcoxon Signed-Rank Test (WSRT) was employed to measure significance due to the small sample size (Hollander, Wolfe, & Chicken, 2014). WSRT results affirmed the null hypothesis: Students would not demonstrate growth in SC. Analysis of pre- and post-survey mean values for individual students revealed some interesting findings regarding particular students.

Cronbach’s alpha values between 0.7 and 0.9 are desired to demonstrate reliability (Olsson et al., 2016, p. 189). Referencing Field (2013), Olsson et al. (2016) also noted that “one can expect values below 0.7, if items cover a wide range of meanings…” (p. 189). One can argue that the SC survey is wide-ranging with its integration of the three Es, elements of SC, and twenty-seven items. Table 4 presents values for this research. Pre- and post-values for the whole instrument (KAB EnvEcoEq) and behavior (B EnvEcoEq) fall within the desired Cronbach’s alpha range. However,
calculated knowingness (K EnvEcoEq) and attitude (A EnvEcoEq) values fell below the lower end of the desired range.

Table 4. Cronbach’s alpha values for the SC survey.

<table>
<thead>
<tr>
<th></th>
<th>Cronbach’s alpha</th>
<th>Cronbach’s alpha</th>
<th>Number of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Survey</td>
<td>Post-Survey</td>
<td></td>
</tr>
<tr>
<td>KAB EnvEcoEq</td>
<td>.90</td>
<td>.86</td>
<td>27</td>
</tr>
<tr>
<td>K EnvEcoEq</td>
<td>.74</td>
<td>.58</td>
<td>9</td>
</tr>
<tr>
<td>A EnvEcoEq</td>
<td>.72</td>
<td>.54</td>
<td>9</td>
</tr>
<tr>
<td>B EnvEcoEq</td>
<td>.79</td>
<td>.88</td>
<td>9</td>
</tr>
</tbody>
</table>

Actual mean scores for KAB EnvEcoEq and subsections K EnvEcoEq, A EnvEcoEq, and B EnvEcoEq can be viewed in Table 5. One can observe that change between pre- and post-tests was minimal and in some cases scores decreased. The

Table 5. Students’ pre- and post-test SC mean scores.

<table>
<thead>
<tr>
<th>Student (Grade)</th>
<th>KAB EnvEcoEq</th>
<th>K EnvEcoEq</th>
<th>A EnvEcoEq</th>
<th>B EnvEcoEq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Anne (5)</td>
<td>3.8</td>
<td>4.0</td>
<td>3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Greta (5)</td>
<td>3.5</td>
<td>3.7</td>
<td>3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Jane (5)</td>
<td>4.3</td>
<td>4.2</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Michael (5)</td>
<td>4.0</td>
<td>3.7</td>
<td>4.4</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Henry (6)</td>
<td>4.7</td>
<td>4.6</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Peter (6)</td>
<td>4.3</td>
<td>4.2</td>
<td>4.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Rosa (6)</td>
<td>4.7</td>
<td>4.8</td>
<td>4.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Ruth (6)</td>
<td>4.4</td>
<td>4.2</td>
<td>4.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Samson (6)</td>
<td>3.5</td>
<td>3.4</td>
<td>3.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>

50
minimal change is particularly clear in the fully integrated grouping of KAB as concepts and the Env, Eco, and Eq dimensions of sustainable development.

Statistical significance was expected in students’ SC growth when comparing pre- and post-survey data. WSRT values less than .050 would indicate statistically significant growth. With p-values well over .05, none of the WSRT asymptotic values in Table 6 showed a statistically significant change from pre-test to post-test.

Table 6. Wilcoxon Signed-Rank Test (WSRT) values measuring SC growth.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Standardized WSRT Value</th>
<th>Asymptotic Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAB EnvEcoEq</td>
<td>9</td>
<td>.54</td>
<td>.59</td>
</tr>
<tr>
<td>K EnvEcoEq</td>
<td>9</td>
<td>1.27</td>
<td>.21</td>
</tr>
<tr>
<td>A EnvEcoEq</td>
<td>9</td>
<td>1.28</td>
<td>.20</td>
</tr>
<tr>
<td>B EnvEcoEq</td>
<td>9</td>
<td>-.95</td>
<td>.34</td>
</tr>
</tbody>
</table>

Unlike the group as a whole, charting individual student pre- and post-survey mean values shows that some students did demonstrate growth in certain SC areas. The results are mixed, however, between knowingness, attitude, and behavior and among individual students. For both knowingness and attitude, the majority of student scores decreased between pre- and post-survey results. The majority of students did demonstrate growth in behavior.

Figure 2 shows that six of nine students’ mean knowingness scores decreased. One student’s (Henry) mean remained the same and two students’ scores increased. Greta’s knowingness increased by more than .60 while Michael’s knowingness decreased by more than -.60. In contrast, he spoke at length about sustainability in his interview and is quoted frequently in the qualitative findings below. Overall and consistent with WSRT results, knowingness mean data support statistically non-significant growth.
Figure 2. Change in means for SC Knowingness between pre- and post-survey results. Note: Students with no bar showed no change between pre- and post-survey results.

Similarly, Figure 3 shows that five of nine students’ mean attitude scores declined. Two students’ scores were exactly the same in pre- and post-surveys and two students’ scores increased. Michael’s SC attitude grew by approximately .20 while Henry’s mean appreciably decreased by more than -.40. He also had significant input during his interview about his experience and how it relates to sustainability. Greta is not far behind Henry with an almost -.40 decrease in her score. Overall, in agreement with WSRT results, SC attitude mean change data point to statistically non-significant growth.
Figure 3. Change in means for SC Attitude between pre- and post-survey results. Note: Students with no bar showed no change between pre- and post-survey results.

Figure 4. Change in means for SC Behavior between pre- and post-survey results.
In contrast, SC behavior mean values displayed in Figure 4 show that six of nine students’ scores increased. Most increases were modest though Anne recorded a whole point rise between surveys. Second to Anne was Henry with a more than .25 improvement. Three students’ scores decreased. Michael’s SC behavior reduction was most pronounced at more than -.25 while Samson’s decreased by approximately -.20. Unlike SC knowingness and attitude, the majority of students demonstrated increased scores with Anne posting a substantial upturn on the SC behavior section of the survey. While the majority showing an increase did not result in statistically significant SC growth, these data may show that students are demonstrating a deeper understanding of acting to build a more sustainable world.

In review, the collection of results from Cronbach’s alpha, WSRT, and students’ mean SC survey score analyses fall short of reliable and statistically significant SC growth. Only some individual students on particular SC subcategories presented an increase in the mean. The pre- and post-test mean scores of SC behavior were the only set that displayed a majority of students with increased values. One unexpected finding may help explain the lack of statistical significance in these quantitative findings. As explained in the next section of findings, the entire group of student subjects of this study participated in sustainability education for far longer than originally known.

**Pedagogy of Sustainability Thinking**

The teacher subject of this research, Rachel, followed a pedagogy of sustainable thinking: A practice of teaching that guided students to conceptualize and actualize sustainability. She sought to guide students to consider competing concerns, live sustainability, and participate in democracy. Her work was underpinned by a specific
philosophy of education: “My favorite educational philosopher will always be John Dewey… I always come back to [him].” Rachel noted that “in education we really do children a disservice when we disconnect it or isolate it along departmental lines”. Connecting teaching and learning across subject lines strongly influenced her pedagogy.

Two themes comprise the pedagogy of sustainable thinking: Integrating critical concepts that build a foundation for sustainability and exciting learning and action to spark student imagination and achievement. The themes are Rachel’s primary approaches to promote sustainability thinking. She voiced that sustainability education is her paramount learning outcome woven throughout the curriculum:

I think it’s just the umbrella, it’s just there. It’s the big idea and it’s the big idea on which I hang everything else. When I was studying [sustainability], one of the things that just kept coming back to me again and again was how anything and everything within humanity could be connected to educating for sustainability.

She used a metaphor to elaborate, “it was just how you tilted the mirror, shifted your thinking or thought about it in order to get there”. The findings below show how Rachel was adept at shifting her and her students’ thinking to make important connections and prepare to take action.

**Integrating critical concepts.** The integrating critical concepts theme is defined as the teacher guiding students to understand the complex interplay of multiple ideas in order to effectively design solutions to sustainability problems. Table 7 outlines the theme’s key findings. The theme is comprised of four complimentary instructional strategies: Investigating the interconnectedness of environment, economy, and equity (the three Es), utilizing sustainability to address multiple curriculum standards, engaging students in interdisciplinary engineering challenges, and intentional questioning.
### Table 7. Instructional Strategies that Integrate Critical Concepts

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigate the interconnectedness of the three Es (environment, economy, equity).</td>
<td>Investigating the three Es and their interconnections was fundamental to teaching sustainability. The teacher posted graphic representations of the three Es and filtered all of her teaching and learning through sustainability.</td>
</tr>
<tr>
<td>Utilize sustainability to address multiple curriculum standards.</td>
<td>The urgent need for sustainability drove the teacher to use the concept to address multiple curriculum standards. The teacher believed she could connect any curriculum standard to sustainability. She integrated reading, writing, and scientific projects with sustainability.</td>
</tr>
<tr>
<td>Engage students in interdisciplinary engineering challenges.</td>
<td>Engineering is a field of study that strongly aligns with sustainability education. The teacher chose the engineering design process to frame the solar oven project because engineering, as a discipline, helps humans solve problems, integrates green technology, and naturally addresses multiple subject areas.</td>
</tr>
<tr>
<td>Employ intentional questioning techniques.</td>
<td>Teacher questions helped students integrate ideas and elicit evidence of accurate understanding. The teacher was intentional but not scripted in asking her students challenging questions that helped them make connections.</td>
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</tbody>
</table>

Techniques that inspire students to make connections between seemingly discrete pieces of information. The teacher purposefully and consistently chose to guide students to integrate concepts rather than teaching in a fragmented way. She also intentionally focused on integrated concepts in the context of the three Es rather than a broad effort for students to see general interconnections.

Investigating the three Es and their interconnections was fundamental to teaching sustainability. Rachel saw herself as multi-dimensional: “Am I an environmentalist? Absolutely. You know, but I’m also an economic instructor. I am civics instructor. I’m a
social equity ambassador.” Linking these dimensions was important: “I deliberately make those connections for my students.” She alluded to systems thinking, a number of elements working together as a whole: “I want my students to have that understanding of how these systems work together. That you can’t simply pull one out separate and expect everything to continue as normal.”

Rachel believed so much in students’ readiness for understanding the three Es that she posted a chart in her class that portrays the integration. The “gear wheel” posted in her classroom is provided in Figure 5. The graphic includes important information regarding her approach to integrating the three Es. First, she adds the word “systems” to each of the three Es and represents each circle as a gear further suggesting elements working together. Second, while not labeled, the concentric nature of the graphic and green, overlapping center represents sustainability. Third, she added action words to each

![Image of the gear wheel](image_url)

*Figure 5. Graphic representation the three Es. This image illustrates the integration of environment, economy, and equity for sustainability.*
of the Es that guide her students’ thinking: “Protect” environmental systems, “support” and “build” economic systems, and “foster” and “promote” social equity systems. Rachel is opportunistic with the three Es saying that “I’m constantly tugging on those threads so that they emerge.”

Her curriculum is intentionally designed and consistently taught through the sustainability lens. “You could take any piece of curriculum that I teach, or any… I think that anyone teaches, and when you start to take a look at it, it’s all about sustainability…” The sustainability focus is continuous: Rachel stated, “I filter all of my curriculum through that” and “[sustainability] is threaded through all human experience”.

The urgent need for sustainability drove the teacher to use the concept to address multiple curriculum standards. Rachel said, “The solar ovens are just one piece, I think, of this and it could have been anything else, any other project… I want to teach EfS, I have to”. She conveyed a sense of urgency: “I think that sustainability, and educating for sustainability, is crucial to the future of our planet… and because of that, I will teach this every day.” Sustainability gives her meaning as a teacher: “My job is to cultivate minds and mindful thinkers and if I can plant the seeds of… a sustainable future in those minds, I’m going to every single time…”.

Balance, however, is needed. Rachel said, “that doesn’t mean I’m going to sit down and lecture children on EfS every day, but it does mean that I am going to chip away at this through lessons and conversation”. She teaches sustainability through complex thinking and hands-on projects, “some days it’s going to be more complex and more analytical. We’re going to read stories, think about it in a different way, and write about it or do a project in which we solve something”. One prime example of complex
thinking is conducting a life cycle assessment: “the process of identifying all of the resources needed to create and use a technology and the impacts on the environment resulting from the technology through its lifetime and eventual disposal” (Museum of Science, 2011, p. 23). The students completed one such assessment of paper during the first field observation (March 22, 2019). Figure 6, a graphic representation of a second assessment of plastic bags that Rachel drew while introducing the concept to students.

![Figure 6](image.jpg)

*Figure 6. Plastic bag cradle to grave poster. The graphic displays a poster created by the teacher to explain the meaning of life cycle assessment. The life cycle assessment is also known as “cradle to grave” evaluation as displayed in Rachel attends to state and school district curriculum standards while intentionally teaching sustainability:*

> As a teacher, what I want to do is make sure that… I leave them thinking and if I’m going to get them thinking because we’re making something… my job is to figure out how to have them make something that [is] connected to the curriculum and the standards.

The EiE curriculum affirms the importance of linking to standards: “Aligning instruction and assessment with educational standards is important. Extensive review of educational
standards in both science and technology/engineering grounds each unit.” (Museum of Science, 2011, p. 3). Rachel finds alignment uncomplicated: “All I have to do is pick a standard and then figure out how to do a project from that. And that’s easy.” For example, the primary NGSS learning outcome, or “performance expectation”, targeted by both the wind turbine and solar oven projects was to “apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.” (NGSS Lead States, 2013b).

The solar oven project was not overly prescribed even though it was focused on a single standard. Rachel repeatedly used the word “organic” to describe the project work. For example, alluding to it being her second experience building solar ovens with students, she said, “this time I wanted it to be more organic”. Students need “to be doing their own thinking instead of me saying… ‘this is the first step, the second step’…”. Rachel seeks balance between curriculum standards and being responsive to student needs and ideas.

Reading stories and writing essays can elicit student input and inspire their work in sustainability problem-solving. Rachel described this as “going from a text as an inspiration”. The CCSS learning outcome targeted through reading: “Analyze how and why individuals, events, and ideas develop and interact over the course of a text” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 18). The texts read by students presented strong characters and innovative sustainable ideas.

They read The Boy Who Harnessed the Wind (Kamkwamba & Mealer, 2015), early in the school year to prepare to build a wind turbine. Rachel commented on what
amazed students about this book: “What really engaged them was that this was a real human being. This was a real kid who is their age, who is facing death, and who used his mind to survive and that… really captured them.” *Lerato Cooks Up a Plan* (Museum of Science, 2011) was a precursor to designing solar ovens. This text provided a starting place for asking students questions. One exchange, witnessed during the first field observation (March 22, 2019), provided an example: Rachel asked, “what are the impacts on the environment in this story?” *The Omnivore’s Dilemma* (Pollan, 2006) outlines the intersection of food choice and sustainability. Rachel said, “I had two students who, in the reading of that book, became vegetarians and were supported by their families”. This choice demonstrated growth: “That tells me there’s a shift in how they’re thinking and where they’re taking control.”

Students also researched and wrote about prominent teen activists from around the world. The teen activism writing assignment (Calkins & Jones-Rooy, 2014) gave the students an opportunity to be inspired through writing in addition to reading. The CCSS learning target was: “Write informative / explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 18).

Engineering is a field of study that strongly aligns with sustainability education. The characters in the abovementioned texts and teen activists all engaged in engineering. Rachel chose to teach sustainability problem-solving through engineering. During the first field observation (March 22, 2019), she stated that “the NGSS engineering design process” is the model of PBL she uses. Three important learning outcomes are embedded
in the NGSS engineering design process that point to the integration of concepts:

Students take into account “the larger context within which each problem is defined”, “identify elements of different solutions and combine them”, and “test and revise solutions… in order to arrive at an optimal design” (NGSS Lead State, 2013a, p. 4).

The solar oven curriculum is consistent with the NGSS engineering design process: “Engineering fosters problem-solving skills, including problem formulation, iteration, and testing of alternative solutions.” (Museum of Science, 2011, p. 2). The curriculum presents the engineering design process in five cyclical steps: Ask, imagine, plan, create, and improve (Museum of Science, 2011, p. 23).

Inspired by these guidelines, Rachel discussed engineering with her students. Figure 7 is a poster that she penned during one discussion. She isolated three important engineering terms that she wanted her students to understand: Engineer, technology, green engineering. An engineer is a person who designs a “thing to advance humanity and solve problems”; technology

![Figure 7. Poster of engineering related terms. This image displays evidence of the teacher’s presentation of engineering terminology.](image)
is a system, “process, thing that solves a problem”; and, green engineering is “a technology that impacts the environment as little as possible” and “process or system that helps the environment”. The EiE curriculum affirms the use of green engineering as “a way that minimizes the environmental impact during the creation, use, and disposal of technology.” (Museum of Science, 2011, p. 9).

The EiE curriculum further establishes green engineering, specifically solar oven construction, as an integrative learning experience. The curriculum highlights interconnections in the field of engineering: “engineering projects integrate other disciplines…” and “can enliven math and science and other content areas… by illustrating relevant applications” (p. 2). Through references to the International Technology and Engineering Educators Association (ITEEA) standards, the curriculum points to the responsive nature of green engineering: “Creative thinking and economic and cultural influences shape technological development.” (p. 15) Students, in other words, will come to understand that “engineers often have to balance several variables when designing a technology” (p. 123) that minimize environmental impact.

Teacher questions helped students integrate ideas and elicit evidence of accurate understanding. Intentional questioning techniques assisted the teacher and students in investigating the three Es, understanding sustainability, and completing engineering challenges. Rachel primarily asked two different types of questions, “lower cognitive questions” (LCQ) that “ask the student merely to recall…material previously read or taught by the teacher” and “higher cognitive questions” (HCQ) that “ask the student to mentally manipulate bits of information previously learned to create an answer or to
support an answer (Cotton, 1988). While Rachel asked both types of questions, she emphasized HCQs: “I think I’m, in my head, asking myself, how do I get them engaged and thinking, analyzing and making a connection between this reading or what we’re doing and the bigger concepts.” Later in the interview, she noted that “[students] can make guesses. But I want my students to make connections.”

The questioning was not scripted. “There’s intention… I do not create a list of questions I read ahead of time, I sometimes will actually jot down a question and be like, oh, I need to ask this question.” Further, “Am I conscious of it? No, I’m not really, I mean, am I premeditated, like I’m going to ask this question followed by this…? No.” There is hope that questions “are not always the ‘right there’ questions”. “Right there” inquiries are factual in nature and simply require recall. They are “right there in the book”, she said. Her favorite questions: “I like to ask why. I like to ask, what do you think? I like that. [And] how so?” Rachel recognized the importance of attending to how students are responding to questioning.

A lot of my questioning… has to do with their engagement response. Am I feeling it? Are they drifting and do I need to reengage them? And can I do that through a question? … How can I get them thinking?

Questioning is contingent on how students respond and how a teacher manages answers.

As Rachel led discussions with students, she gauged their response to the content.

**Exciting learning and action.** Rachel established a strong foundation of purpose through the integration of critical concepts. She then used specific instructional strategies to increase students’ excitement for and action with academic content. The theme of exciting learning and action is defined as establishing optimal conditions for designing solutions and the application of new learning. Student learning is actualized through PBL
while they design and build together to solve sustainability problems. Exciting, in this case, is used as an action verb highlighting the process of actuating thought. Rachel’s own excitement is rooted in her passion: “I think you have to teach to your passion… and it doesn't matter what that passion is ... The students are reading that, that you are excited about it.” The “it” in this case is sustainability as the core concept of her pedagogy. Henry, one her students, affirmed Rachel’s claim about passion: “It's really exciting… it’s always something different in the day, like something new or exciting”.

Exciting learning and action were accomplished by optimizing the learning environment, designing solutions to problems by constructing projects together, facilitating with intention, and working in groups. Table 8 provides a concise outline of this theme. The theme has two properties: Minds-on work in which a teacher intentionally plans and thinks about a learning experience in real time; and hands-on work during which the teacher guides students to be actively engaged in creating an object. Attending to the learning environment and facilitating are minds-on acts. Building together and working in groups are hands-on endeavors.

Table 8. Instructional Strategies that Excited Learning and Action

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
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<tbody>
<tr>
<td>Design and take advantage of learning environments conducive to sustainability thinking.</td>
<td>A diverse, functional, and engaging learning environment was imperative to a pedagogy of sustainable thinking. The teacher led mindfulness activities, intentionally designed her indoor space, and used the schoolyard and surrounding town as contexts for teaching sustainability.</td>
</tr>
<tr>
<td>Invite students to have fun while building together.</td>
<td>Students were more excited to learn during PBL when fun was mixed with building something together. Having fun while constructing projects made learning more accessible. The teacher believed that fun and motivation originate in not always knowing the answer.</td>
</tr>
</tbody>
</table>
Facilitate tailored learning experiences to promote deep thinking and perseverance.

Intentional facilitation promoted tailored learning experiences, deeper thinking, and learning through struggle. The teacher was responsive to students, looking for a pivotal moment that she can point out to promote deeper thinking. She tailored learning based on whether her students required structure or needed to “just get started”. She chose to guide students through struggles rather than give them answers.

Guide students to work in groups in order to solve sustainability problems.

Guiding students to work in groups was an important instructional strategy used to teach sustainability. The teacher facilitated problem-solving in small groups and multiple teams with a common objective. She wanted students to grow interpersonally and learn how to cooperate in groups rather than compete.

A diverse, functional, and engaging learning environment was imperative to a pedagogy of sustainable thinking. Rachel attended to mindfulness activities, indoor classroom arrangements, and taking advantage of the schoolyard and surrounding landscape to enhance her learning environment for sustainability PBL. Student readiness to seek meaning and be curious can be promoted by mindfulness. Rachel practiced mindfulness with her students every day: “we started with 15 to 20 minutes of mindfulness and mixed it up with Yoga and breathing and sometimes being silly together”. She believes that weaving mindfulness into their days “can help our brain” and should include gratitude: “Expressing gratitude can help us physically, emotionally, and intellectually.” Mindfulness aids in overcoming stressful situations:

I work to teach them… how to push through the hard moments. We practice mindfulness every single day and, in the moment, when they’re really stressed and they’re right there and they cannot see it and get it because… you can see their stress level is so elevated.
She perceives mindfulness to be a healthy response to stress that makes space for students to be excited to learn: “I encourage them… to take a break and walk away from things. I teach them the value of that as a strategy.”

Rachel’s intentional organization and use of her indoor classroom environment complimented mindful practices. She believes that “your room teaches by what you do and do not present in it, by what you display, by everything you choose to put in that placement”. The room sends a message: “In that room, you are teaching the children what to value and what not to value”. She continued, “When I go into my room, [I] ask myself what I am teaching through this physical environment and if this is what I want to be teaching.” Summing up the intentional classroom arrangement, she said, “I don’t want to say I love to arrange furniture because that’s not quite what I’m doing. I love to create this space for learning and I really think of… the space as my partner”.

Consideration for the physical learning environment extends beyond a single classroom and the school walls. Rachel described the outdoor space available to her:

I have one of the most awesome outdoor spaces that a teacher could get… we have this huge open space. We have the outdoor classroom in the field with poison ivy and ticks and… we have the woods… there’s a trail back in there and it’s pretty fantastic.

Unlike her indoor space, Rachel does not see much need to add or arrange physical items in the schoolyard. “The playground is interesting to me in that kids don’t need… an enormous amount of stuff to play.” Students play foursquare, basketball, tag, and make up games.

The environment beyond the schoolyard is also a tool for place-based learning: Using the natural, built, and cultural environment as context for learning. She commented that “I can teach them about the place… where [they] are and the history of their town
and their village and… the special things around their schoolyard… and the history of it all.” In sum, Rachel sees her immediate surroundings as integral sustainability and PBL. “I think that [for] educating for sustainability… I will teach through my place because I have this fantastic place at my disposal”.

Students were more excited to learn during PBL when fun was mixed with building something together in the classroom and local places. The curriculum Rachel chose integrates fun with learning together in the classroom and local places: “We develop interesting problems and contexts and then invite students to have fun as they use their knowledge of science and engineering to design, create, and improve solutions.” (Museum of Science, 2011, p. 2). Rachel stated that “I want my classroom to be a place that is pleasant, that children enjoy coming to… they are going to be challenged, but at the same time they're going to have a good time...” She commented on projects that are more enjoyable, complex, and part of a perceived PBL trend:

If you have a project or an idea, it’s ideal if it comes out of a real… existing problem. I think more complex is coming up with that genuine problem. In a funny way… some of what is coming around again is the idea that we need to be not teaching kids facts and information, but how to do things and solve problems.

Rachel wants to facilitate engaging problem solving. “Give me something that… I don’t know the answer to… and let’s figure it out because that’s… real. It’s engaging. It’s exciting.” She also believes it is easy to miss the emphasis on the experience of designing a solution in the curriculum standards:

In all of the NGSS, it is about the problem. It is about the project. It is about finding a solution… And I think it’s easy to skim over that and be like, no, the standard says that we’re looking at, you know, photosynthesis.
Rachel integrated enjoyment with designing solutions by saying, “I think that most people like having fun. If I were to really analyze it… when you're enjoying something, your affective filter is minimalized so that you're more open and accessible to learning”.

Rachel believes that when students build together, they are “almost always engaged and motivated”. The construction of a raised garden bed frame inside the carefully organized classroom provides a story about a challenging student becoming highly engaged:

I had one student, Teddy, who’s really difficult to get involved and engaged with stuff. He often will just look at you and be like, ‘no’. And there’s no budging him. I let him go first… I wanted him to go first. And my vision was that… you know, however many kids, we had eight corners to put together and… everybody was going to get a turn. And [he] picks up the screw gun, scoots his corner together, and then motions to [another student to take a turn].

She observed Teddy fully engaged and becoming a leader of his fellow students.

In another experience, Rachel reversed a student’s perceived dislike for history:

“One of my students said that they hated history, Rosa.” During a Mesopotamia history unit, students were given a design challenge: How to get water from the Tigris River to the agricultural fields. Rosa and her classmates designed a model irrigation system that successfully transported the water and skimmed barley from the water as an added benefit. Rachel reported that Rosa “thought that was thrilling as a social studies project”. Students are engaged and benefit academically while building together: “I actually think that the projects and hands-on stuff levels the playing field for kids who might have more challenges academically.”

The process of learning is different depending on whether students read, write, talk, or actually build and object. Regarding the Teddy and Rosa stories above, Rachel
said, “the kids that I have the hardest time engaging and motivating… [are] almost always engaged and motivated through building and construction”. She continued:

If someone asked you what did you read when you were in fifth grade or what did you write about, you wouldn’t remember it, but if somebody asked you what you build or what you did, I think that those projects stick with the students [and they would say], ‘oh yeah, I built this really cool project in which I built this bridge that held 260 pounds’. That’s exciting.

Rachel reflected that she occasionally will have a student who loves writing and wants to write all day. However, she observed, “there isn’t a kid I’ve ever met who’s like, can we please write another essay” She more often hears, “can we make something?”

Intentional facilitation during construction projects promoted tailored learning experiences, deeper student thinking, and learning through struggle. Her facilitation style is responsive, tailored, and supportive. Once students are engaged and building together, she turns to specific teacher moves that may prompt the next step in the process, help individual students, or encourage small groups to change direction.

Teacher actions and strategies are often determined by student responses. Rachel labeled her facilitation this way: “So much of my teaching, my thinking when I’m teaching, is responsive.” She emphasized further, “I’m responding to my students and I am trying to dig and push… and get them to think”. Her behavior just after students begin work on a task allow her space to decide what she will do next.

I can’t predict where it’s going to go. But I kick back, and I watch and maybe I’m getting a drink of water or catching my breath and taking that like mindful moment and be, okay, what’s happening here? What am I learning? What am I seeing? What’s working, what’s not working? And who just said that really cool thing right there?

While observing she is ready to capitalize on a pivotal moment, “when I see it, I try to capture it”. She is watching for an “aha moment”, when a “light bulb goes off or some
kid makes a comparison or an analysis or an analogy that it’s so dead on”. In these moments, she takes action, “that’s when I push in right there and get everyone together, ‘you gotta hear this’ and then we go back” to individual or small group work. Improvisation may be required in order to capitalize on the light bulb moments. She conveyed an allure to uncertainty, “I don’t know if all teachers have the capacity to improv… but there’s an energy there”. She said, “I think [improvisational comics] have the storyline, but you know… I’m going to be pulling out of my hat anything I need to in order to make it work”.

When responsive teaching is working well it leads to understanding that the teacher can amplify. One technique Rachel attempted was leading a closing discussion: “If I was really having an awesome day, what I manage to do at the very end is pull back together for a scientific discourse and discussion… we summarize and that’s when I’m really on.” A bulletin board in the classroom provides phrases that students can use during discussion to fully participate. Examples include “I disagree because…” and “I agree with you because…”. What will be included after the “because” prompts students to back up their claim. Figure 8 displays the bulletin board including the full complement

Figure 8. Discussion bulletin board. This image displays phrases which students can use to back up claims during discussions.
of encouraged language. Whole group discussion, small groups discussing at worktables, and talking to the student next to you were common throughout the seven field observations during this study.

Teachers constantly tailor their instructional strategies in response to the present moment and the overall character of their students. The majority of students in Rachel’s class during this study, unlike other years, did not work well with rigid structure: “I think that the benefit of [organizational structure] didn’t exist with this group”.

She saw something different for this group: “What I was seeing was that their need was to actually dig in and just start doing this and solving the problem and talking about it.” Once they get started, she said, I “listen to what I’m hearing them say and trying to make sure that that conversation goes, that is going to a place where I think that they’re actually solving the problem”. Referring to structure in the form of worksheets, she commented, “I think that the solar oven unit, you could spend a quarter of a year or more if you wanted to do every single worksheet activity…”. She chose the best curriculum items that would make her “students grow and really look, be able to engineer solutions and see themselves as capable problem solvers.”

She knew the students very well and was able to effectively tailor their learning experiences. All eleven participating students started at Finley Elementary School as Pre-K students and, with just one or two exceptions, had spent all of their school years there. More important to this study, every student in the class was either in Pre-K or Kindergarten when sustainability education became the school’s mission in 2011. She described this history:

[The students] were incredibly fortunate that the teachers who led their foundations were gifted teachers and so they just, they, from the time they were
four and five years old, were having this really rich learning environment that was meeting all of their needs intellectually, emotionally, and pulling them together as a community.

Michael, one of her students, affirmed her deep knowledge of the group: “She’s… seen us from preschool and kindergarten to fifth and sixth grade… and really knows how we learn and think”.

The deep relationships Rachel had with students helped her make important choices. For example, she knew when to let them struggle in order to gain new understanding and skills. She recalled the wind turbine project inspired by *The Boy Who Harnessed the Wind* (Kamkwamba & Mealer, 2015):

> We spent weeks building windmills and… one of my thoughts was that William had not had anyone teach him how to do this. I wasn’t going to teach them how to do this or give them help with this [to] figure it out.

Struggle can lead to frustration. She commented, “it’s always interesting… who lays down on their desk and sort of checks out. And that happens.” Seemingly talking to her students about what they do when are struggling, she said: “And you need to go get a drink of water because you don’t know. And you go to the bathroom and you wash your hands a few times because you don’t know.” She does not give in: “While I recognize that it’s really difficult, I want my students to be able to push through that, to be successful with it.”

Rachel shared a specific example of a group struggling and then finding success. She observed Ruth, one of her students, closely as she led her group to design a solar oven. Rachel grew concerned. “I saw some major problems with it that I deliberately chose not to point out in that moment because I wanted [Ruth] to find them.” She was holding back: “I didn’t want to be like, ‘oh, you have to do it like this, so it’ll work’ and
it would work perfectly”. Overcoming failure is important: “I wanted them to have that experience … because if you fail then you have the ability to reengineer and ask more questions.” In the end, Ruth’s group prevailed. They “pushed through all of that and figured out what the problem was and then felt like this incredible sense of pride of, ‘it didn’t work, I figured it out, and then I made it work’”.

To “push through” is a pivotal concept that Rachel also called “riding the razor edge of cognitive dissonance”. “I explained to them what cognitive dissonance is… ‘it’s that moment when you were struggling with something and you kind of feel the tears pricking behind your eyes cause you are like, I don’t know’”. Rachel almost has admiration for the dissonance:

That is an amazing place to be because it’s a little scary, as all adventures are, but it means that your brain is creating a neural pathway. Your brain is assisting and is really actively struggling and working to solve a problem, something you don’t know yet. And that’s where learning happens.

Rachel will help students but not give in, “it’s hard and the hard things are where it’s worth it”.

Guiding students to work in groups was an important instructional strategy used to teach sustainability problem solving. Collaboration in Rachel’s class worked on two different levels: Problem-solving together in small groups and multiple teams working on a common project together. Group work can lead to sustainable thinking and action for students. Rachel said, “I think it's key, especially if we're going to build a sustainable future, that we know how to talk to one another and work collaboratively to solve really big problems.”

Small groups are not always successful, and they often need direction. “What happens is that the dominant person in the group will have an idea and then everybody
just goes along with it. And so, they don’t really have to think about it”, Rachel said. She
shared a remedy:

In some of the group work, what I’ll do is I will actually start them off working by
themselves so that everyone has to think on the problem. Then you come together,
and you share out and you’d discuss how you’re all of the different ideas, not just
the one idea that’s the loudest, most charismatic person came up with.

Students can grow interpersonally. She noted that “I had a couple of kids who really grew
in their ability to work as a member of a group… who found it to be really personally
challenging, who came to different places with it… I think that’s incredible”.

Rachel pays attention to equity as she guides group work. Starting with individual
work can make collaboration more equitable: “That’s the way I tried to give people who
have small voices, a bigger voice or a more equal playing field within that group work
that they do.” She described how she takes this pursuit of equity to a personal level for
individual students: “As a teacher, one of my challenges is to find the thing that those
kids are bringing to the table and be able to help that shine… and to help other people see
it and value it.”

Interestingly, Rachel also sought equity between the four small groups designing
and building a solar oven. During field observations, it was obvious that she had designed
the solar oven learning experience as cooperative rather than competitive between
groups. The purpose was to avoid interpersonal struggles: “I try… to get away from the
competition of it’s ‘our group against your group’ that always ends up in… kids are
wailing because so-and-so is stealing my idea.” She continued, “if I can convince
[students] that we are all teams working for the same company… working together and
we should share our ideas with one another, it really helps”.

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Better ideas and outcomes are benefits to multiple groups collaborating to solve a problem. Rachel prompted a struggling group to talk to another group who overcame a similar challenge: “I think you need to go talk to that team over there”. She also facilitated a meeting between groups: During the fourth field observation (April 26, 2019): Each solar oven design group took a turn sharing a challenge with the class in order to get feedback. In this way, the workload is shared between individuals and groups in the class. Ruth said, “we can be more efficient, and more productive… I think it will make the outcomes better”.

**Exhibition of Sustainability Understanding**

The fifth and sixth grade student participants exhibited sustainability understanding: Expressions of learning how to conceptualize sustainability and perceiving how to take action based on new learning. Facilitated by Rachel’s pedagogy of sustainability thinking, students designed a solution to a specific sustainability challenge, found joy in their work, attended to detail, and developed ownership for their learning. Rachel further described her pedagogy that influenced her students: “I think what I want to create is a joy in the rich, diverse newness of our planet and the ability that we have to learn and grow together. That is my manifesto.” Data collected from the students provide some evidence that her methods of teaching and learning encouraged them to develop sustainable thinking and behavior. Jane provided an overview for how she responded to the solar oven project: “I liked the activities because building the solar ovens was fun because we got to build and we got to test it and we got to like fix some stuff that we had problems with...”
Exhibition of sustainability understanding also includes two themes: Discovering solutions by following the engineering design process and learning as enjoyment characterized by having fun and accomplishing serious tasks. The themes represent evidence of Rachel’s leadership in developing sustainability thinking. Michael shared his perspective on the impact of the solar oven project:

If we didn't get the solar oven done that would have really shown us the year without the, like everything we really got into in science…we did some things with like physics and stuff, but it's all really dealt with sustainability.

The evidence shared below elaborates on how students revealed sustainability understanding during solar oven project. Their deep understanding and enjoyment of the process were facilitated by an intentional design process.

**Discovering solutions by design.** Rachel’s use of the EiE curriculum to integrate sustainability and active facilitation propelled the design and construction of four solar ovens. The students responded with ideas and hard work as they learned by building together. Discovering solutions by design is a joint effort between teacher and students to answer critical solar oven questions that also have implications for the broader concept of sustainability. Evidence for this theme was drawn from students’ interview question responses, writing, and actions that point to sustainability understanding and action.

Students recognized Rachel’s active role in guiding them through a deliberate process. Peter commented, “She doesn’t just give us the actual problem, like the whole piece… in the whole, she splits up the project.” That “helps me to focus on the one part that we’re doing instead of all the parts. Not as overwhelming maybe”. Henry commented that “she also is always… just pushing us just a little bit in the right direction”. He continued, “she’s telling us what direction to walk, but she’s letting us do...
the walking beat”. In short, Greta shared that the teacher helped “us bring [the solar ovens] to life”.

For this case study, the definition of design is “a plan for how to build a solution to a problem” (Museum of Science, 2011, p. 23). The project was an “engineering design challenge”: “students design, create, and improve solutions to an engineering problem” (p. 4). Henry shared his summary of the process:

After you understand what [the problem] is asking you, you need to plan what you're going to do in order to actually solve it. And then after you plan it, you then attempt to solve the problem and then if the solution doesn't work… then you have to like check and see what [you did] wrong and how could you improve on that. And then if it does work, you can then say, should I try to make it better or should I just leave it be.

Design challenges were purported to “allow students with varying academic abilities to succeed…” (Museum of Science, 2011, p. 4). Rachel’s eleven participating students did display diverse academic and problem-solving skills. Evidence of student success and learning was apparent at some level for each student.

Discovering solutions by design was evident in students’ expressions reflecting the engineering design steps: Ask, imagine, plan, create, and improve (p. 23). Table 9 summarized this theme. Two properties characterize this theme: Students realizing new ways to think about the engineering design and discovering solutions to design flaws. In addition, there is ample evidence of students adjusting small details on the ovens to improve cooking results.
Table 9. How Students Discovered Solutions During the Solar Oven Project

<table>
<thead>
<tr>
<th>Evidence of Discoveries</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask: Students took the time to understand the nature of the problem that they were solving.</td>
<td>Students understood a solar oven design challenge by asking and answering important questions. They understood that in order to solve a problem you have to understand what the problem is asking you. They used the <em>Lerato Cooks Up a Plan</em> story to help them understand.</td>
</tr>
<tr>
<td>Imagine: Students imagined multiple and varied solutions for a sustainability problem.</td>
<td>Once the main line of inquiry was established, students imagined various solutions to ensure that the best design was discovered. They brainstormed solar oven design ideas, recorded plans, and predicted the high temperatures their ovens would reach.</td>
</tr>
<tr>
<td>Plan: Students designed and planned how to implement what they believed was the best solar oven model.</td>
<td>Students chose the most promising design, began planning, and documented details. Planning steps included: Sketching the design in detail, choosing insulation, describing environmental impact, and securing final approval from the teacher.</td>
</tr>
<tr>
<td>Create: Each small group within the class constructed a distinct solar oven model based on their design.</td>
<td>Students brought detailed sustainable solutions to reality during the creation phase. They used simple and inexpensive materials for the ovens: Cardboard boxes, aluminum foil, black paper and wool, shredded paper, sawdust, and other items as insulation. Each material served a specific design purpose.</td>
</tr>
<tr>
<td>Improve: Students tested their solar ovens in order to gather data and make improvements.</td>
<td>Students recorded oven temperatures under various conditions and perfected ovens based on data. Examples: Adjusting the angle of sunlight reflectors and sealing discovered heat leaks.</td>
</tr>
<tr>
<td>Students exhibited basic understanding for the idea that the engineering design process is not linear.</td>
<td>Students experienced all five elements of the design process and often returned to earlier phases of development to make improvements. Example: When students encountered a flaw in the improvement phase, they then returned to the imagine phase to refine their design.</td>
</tr>
</tbody>
</table>

Students understood a sustainability design challenge by asking and answering
important questions. Henry best captured asking as the first step in the engineering design process: “Like when you come to a problem, first you need to understand what the problem is asking you”. The storyline in *Lerato Cooks Up a Plan* framed what the problem was asking of the students. The sustainability question embedded in the story focused on taking advantage of solar energy to overcome a shortage of fuel wood for cooking: How can you design a simple technology that captures heat and light energy from the sun for cooking food? Lerato, the story’s main character, and Rachel’s students were asked to complete their design, testing, and use of the ovens with the least environmental impact.

Once the main line of inquiry was established, students imagined multiple and varied solutions to the sustainability challenge to ensure that the best design was discovered. Small groups of students engaged in early project activities to imagine how to design a solar oven. Students described this step in their own words. Rosa said that the “best ideas don’t come easily, you’re going to have to think about how this is actually going to work instead of just like building a box and putting sawdust inside of it, because there's more to it than that.” She added, “just kind of think outside the box”. Imagining solutions takes time and the students were given a considerable amount to brainstorm. “[Our teacher] gives us these opportunities to brainstorm more ideas. Like we had a whole day pretty much to think of ideas about how we can make solar ovens better and more usable and more efficient”, Rosa said.

Students also imagined the solar oven outcomes. As the imagining stage was concluding, Rachel asked the students to predict the high temperatures their ovens would reach. Figure 9 displays a chart that includes student prognostications. Guesses ranged
from a low of 80 degrees to a high of 300. Student brainstorming, ideas, and predictions were supported by the solar oven curriculum unit. One of the unit learning outcomes states that “when designing an object, it is important to be creative and consider all ideas” (Museum of Science, 2011, p. 15).

Figure 9. Solar Oven Temperature Predictions. The image displays a range of temperatures students believed would be reached by the ovens.

Students chose the most promising sustainable design that they imagined and began planning and documenting design details. Planning involved small groups choosing their best idea collaboratively, sketching it on paper, recording insulation choices, describing environmental impact, and getting their plan approved by Rachel. Jane expressed her understanding of planning: “You can't just like have a student just build the oven. You would have to, you have to maybe draw, draw out designs like how we did it and then sort of try a design”. Ruth agreed and highlighted the required detail:
She didn't even let us start building at first. She had us draw ideas of what our solar oven might look like. She wouldn't let us cut any part of the box… sketch out an idea of how we would put in the insulation, what the interior cook box would look like.

Anne described it as “kind of like a blueprint”. Figure 10 is one example of a sketch that includes a three-dimensional drawing with insulation choices and the location of the interior cook box. During the third classroom observation (4/12/2019) as Ruth noted, Rachel would not let students start construction right away. Some of the small groups expressed frustration for the delay out loud during the busyness of planning. Students were anxious to start cutting, insulating, and testing yet Rachel had to formally approve designs first.

Students brought detailed sustainable solutions to reality during the creation phase of engineering design. When Rachel approved small group plans, they were allowed to begin constructing their solar ovens and move toward design testing. The choice of materials was an early consideration during the create phase for the small groups. The EiE curriculum states that “activities and design challenges have purposefully been designed so that they use simple and inexpensive materials” (Museum of Science, 2011,
p. 3). Rachel collaborated with the students to identify useful materials for the project and find them at school or bring them in from home.

Each group used a larger cardboard box that holds printer paper to frame the oven as they were readily found at school. The groups used either a shoebox or smaller box that once held envelopes as the “cook box”: the insulated space nested in the oven that held the food being cooked. Rachel and the students collected many items that were tested as insulation: Goose feathers, hay, Styrofoam, shredded foam, shredded paper, sawdust, wool, rice hulls, soybeans, and compost. Aluminum foil placed on flaps directed more light into the cook box. String held the reflector flaps in position to maximize oven performance. Rachel cut used plexiglass to sizes determined by students and it was used to allow light energy into the cook box and captured heat. Black construction paper lined most of the cook boxes to absorb light and heat. Various types of tape held important parts of the oven in place.

The wide majority of these materials were integrated into the solar ovens. Figure 11 is a top-down view of one group’s oven. This group chose to line their cook box with black construction paper and integrate a relatively large plexiglass window. The students

![Figure 11](image-url) **Figure 11.** Solar oven with large window. This image shows a completed solar oven with a black-lined cook box.
in this image were adjusting the reflector flaps. Figure 12, in some contrast, displays a constructed oven that includes a repurposed yardstick that elevates the cook box and aluminum foil rather than black construction for lining. These variations in the finished solar ovens demonstrate that while student groups used common materials for the overall construction, their ideas and performance predictions led to distinct designs.

![Figure 12. Aluminum-lined solar oven. This image shows a completed solar oven with rulers elevating the cook box.](image)

Students tested their constructed solar oven designs to complete the improve step of the design process. Ruth captured improving as a step, “you really have to sort of go with the flow… if your experiment doesn't work at first, you can always go back and adjust it. And my group really worked on that part of it…” Henry summarized Rachel’s approach: “So like she lets us work to get it.” Students understood experimentation as a way to test their ovens and adjust the model to improve performance.

They were guided by Rachel to employ a number of testing strategies. Rosa described some of the strategies:
When we were testing our solar ovens, we were actually keeping a log of the temperatures it reached… we got to see when our solar oven was the hottest… so we put it in the shade for a little bit to see how well our insulation maintained the hottest temperature… and what we had to do to make it better.

Figure 13 displays the log or data sheet that Rosa mentions in her description. Multiple types of insulation were time-tested in the ovens to arrive at the best option for retaining heat. Samson shared that the goal was to “make it so that the oven can rise in heat and just keep on rising and stay at that level in the shade”. He continued: “When it went into the shade the first time it did really well… the second time we lost a lot, so we're trying to like figure it out like strong insulation.” Testing her oven and recording data helped Anne: “So when you actually draw it down and you'll look at the data, you could actually see, ‘oh, this is why it didn't work, let's change it to this’”.

Students made specific adjustments to their solar ovens based on their testing and resulting data. Ruth commented on her group’s work to change the flaps designed to reflect light into the cook box: “We just recently cut off part of our reflectors, so they're not squares. We did that after hearing … about how most groups made the reflectors at an angle, so they weren't reflecting into the box.” Samson explained why cutting the flaps helped these parts of the oven work together: “We cut off part of the side panels so that
they could tilt in and the top one could tilt in as well.” Two students mentioned heat leaks as another weighty problem that needed to be improved. Samson said, “I'm also trying to prevent places in the box where the heat would actually leak out”. Jane commented, “You have to keep fixing it so that like, it's not going to have like all these problems like how the heat might leak out, you'd have to like make adjustments to that…”.

Heat leaks were addressed by the groups working together. Figure 14 is a picture of Rachel’s chalkboard notes that highlight challenges the small groups encountered during testing. The listed challenges include angle of reflectors, the thermometer moving, the tilt of the whole oven, and heat leaks. Through discussion between small groups testing their different ovens, students determined that leaks first had to be pin-pointed and then insulation must be adjusted to seal gaps that allow heat to escape.

Students referenced all five elements of the engineering design process and demonstrated that they participated in a proper design protocol. The EiE curriculum states that “all the steps are important to good design” and they require “attention and
persistence” (Museum of Science, 2011, p. 128). Calling the elements of the process steps can lead one to believe that PBL using engineering design is linear: One step must follow and precede another. However, the curriculum cautioned against this view: The process is “a guide to proper engineering design, but not a recipe or a requirement” (p. 128). The process “comes in many forms” and designers “may do the steps out of order, or skip a step, depending on the needs of a particular project” (p. 128). There is evidence of Rachel and her students participated in an iterative, non-linear process to design and build the ovens. When students realized that their oven was not performing well during testing, they returned to the ask phase to work out what the flaw was and how to fix it. While considering a flaw and how to repair it, they re-imagined the solar oven design. Students trimmed reflector flaps, changed what they used for insulation, and redistributed insulation. They re-created their oven to improve performance.

**Learning as enjoyment.** Rachel’s students responded to her goal to excite learning in an environment they have a good time and are challenged at the same time. They expressed enjoyment as they improved their solar ovens and participated in the PBL project focused on sustainability. Learning as enjoyment is balancing having fun and being serious, focusing on large problems that demand exacting work, and promoting a feeling of individual and group accomplishment. Students recognized a number of activities that promoted fun and hard work while they navigated the engineering design process. Rachel described the process as a “Goldilocks problem”, one in which students “have to stretch, but they have the ability to solve it. [Students] enjoy that process”. Fun learning activities, in this case, were those that inspired excitement about the content, descriptions of pleasure for the experience, and a feeling of joy.
Rachel engaged her students in fun along with understanding many significant sustainability challenges. She intentionally taught in a fun way because she believes it is a way to maximize learning. She commented, “I think with… fifth and sixth grade, you can ride that razor edge of humor… it's right up to the line of one more step and this would be wildly inappropriate, but you can push it to that edge”. Ruth affirmed her teacher’s attention to limits and doing serious work: “Like she's funny, she uses humor when she's teaching, but if you're just fooling around and not like paying attention, she will let you know to tell you that you have to pay attention and do your work”. Analysis of interview and artifact data revealed student appreciation of mixing fun, hard work, and serious themes. Three properties characterize learning as enjoyment: Joy for individual and group work, a sense of accomplishment, and attention to detail. Table 10 previews the detailed findings of this theme.

Table 10. How Students Demonstrated Learning as Enjoyment

<table>
<thead>
<tr>
<th>Evidence of Understanding</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Students exhibited an ability to balance having fun and serious work on solar oven designs.</td>
<td>Students understood they can balance fun and focus on serious solutions to sustainability problems. They commented on the teacher being fun while presenting challenging work. One student expressed how they enjoyed solving the little problems with solar ovens.</td>
</tr>
<tr>
<td>Students demonstrated concentration and detailed work.</td>
<td>The large and serious sustainability problem demanded concentration and exacting work. Students balanced being playful, attending to details, and working hard while interacting with all of the three Es.</td>
</tr>
<tr>
<td>Students expressed a sense of accomplishment.</td>
<td>Students experienced a sense of accomplishment while creating their solar ovens. Students expressed that accomplishment originated in creating working ovens, cooking on their own, being resourceful, and collaboratively working in and between groups.</td>
</tr>
</tbody>
</table>
Students understood that they could balance fun and their focus on serious design solutions to sustainability related problems. Samson described Rachel’s joyful way of teaching and the balance between fun and challenging issues: “She does a lot of very funny stuff like… she just does so much that can make you laugh really hard. It's also a little bit challenging in certain places.” Michael succinctly referenced the balance: The “sustainability part was fun. Really hard too”. Peter referred back to the fun of making improvements, “it's just really fun to figure out all the problems with the solar oven or how we can fix them”. Almost every student commented on the fun while designing and building the solar ovens. Anne however, expressed a disconfirming view that points to a need, at times, to temper having fun: “It's really kind of, sometimes it's unfocused because we're goofing around a little bit, most of the time it's pretty focused and it's easier for me to concentrate.”

The large and serious sustainability problem demanded concentration and exacting work. Exacting work includes understanding when it is appropriate to be playful, attend to details, and work hard to discover the most promising solution. Henry described how mindfulness promoted readiness for exacting work: “We normally turn the lights off and sit down in the chairs or on our back, and… just breathe and think about the day and get ready for it.” Rachel commented on engaging in solving significant sustainability problems: “They're really interacting with them, all of [the three Es], and their imagination to solve large problems.” Indeed, students designed a way to perform a critical human activity, cooking food for survival. Greta made an environmental connection: “We don't just build the projects because they're fun, we actually build them so we can help the environment, or we like we get to learn about things that help.” To the
fullest extent possible, students experienced what Lerato and her family went through to ensure that they could cook meals even when they ran out of wood as a natural resource. Rachel established boundaries so that she and her students could pay attention to the critical side of their work:

My guess would be that most of my students would say I'm strict because I draw really clear boundaries. Like this is the line. I'll let you know that this is where it is and so we can play, but we also have to do this work and there are certain places that we're just not going to go.

Rosa confirmed Rachel’s limits: “At the same time, she can be strict sometimes, but it's a very good reason because our class is rambunctious”. Ruth agreed, “she does raise her voice sometimes. She, sort of, changes personalities. I guess she goes from being super nice and funny to like less nice”.

The rambunctious students mostly maintained focus while having fun. Their concentrated attention was best exemplified in detailed measurements for plexiglass windows in the ovens. Ruth shared that Rachel “had us do like really precise measurements for the plexiglass windows and like the hole, that the window would be

![Figure 15. Plexiglass Window Measurements. The image includes playful group names and measurements for each group’s solar oven window.](image-url)
either over or under”. Figure 15 displays these precise dimensions. Notice that the chart includes playful group names such as “Burnt Food” and “Solar Superstars” related to constructing the solar ovens. In addition, the chart includes very specific measurements, in one case to one one-hundredth of a centimeter.

Individuals, small groups, and the whole class experienced a sense of accomplishment while participating in the sustainability challenge. Rachel and her students successfully designed and built functional solar ovens. They melted cheese on to tortilla chips and made fudge in their ovens. After preparing the snacks, Samson encapsulated the experience: “The fact solar ovens work shows us that like we have an accomplishment…”. He continued, referencing cooking as an individual skill, “the special, the really unique thing about it is that we are able to cook food on our own. And like us as young teens are nowadays, we are trying to, parents are teaching us how to cook [but] very slowly”.

Students also felt a sense of accomplishment and enjoyment because the small groups were challenged to be resourceful, especially in finding common items that could be used as insulation. Michael explained this notion while sharing what advice he would give other teachers leading a similar project:

Be resourceful. But and like solve problems on their own. You've got to teach them, well what you have to do is you can't just give them all the supplies because then they're not going to really know. They're not gonna know how to get supplies. It's like giving them a kit and then they can just assemble it instead of having to find it.

Rosa made the case for hands-on group work to find supplies and complete the project:
Make it more like hands-on. We did do the whole project hands-on, basically. But sometimes kids don't really like the reading part of it. So, if you made that a whole class thing and read the part to the whole class because some, it's really hard for some kids to do that by themselves. So, when the teachers do that as a group, kids feel, they might feel like they are better at understanding that they do just as good as the other kids.

Returning to the ideas of fun and enjoyment, Peter reported that “I like working with a group. It's a lot more fun as a group”.

Rachel organized the solar oven project as a cooperative effort between individuals and groups for two reasons: To reduce competitive friction and teach an important problem-solving lesson. Ruth described how her teacher structured the project between small groups:

She sort of made up a story for it… we are a company trying to make solar ovens and instead of having the whole entire company work on one solar oven and not being super productive, we would be doing work but we’d only be getting one model done, she split us into teams within that company so that the company can get three or four models within the same amount of time… she made it seem like we’re one big group just broken into little groups.

Samson shared how this idea reduced competition and argument:

There are probably times if it was competitive, there would… be times where we would argue… and then you couldn’t get anything done and then we’d be stuck and we had no other ideas while the other groups had perfect ideas that made theirs better… sharing their knowledge makes it so that all show that all of us are equal.

Jane said as an alternative, “If one of us had a problem, we could go and ask another group about how they solved that problem because some of us have the same problems and we solve them in different ways.” Henry expressed how differing this is: “We all help each other and it’s like just really exciting and different from my understanding of most other classrooms.” Rachel believes that “that builds their collaboration, their cooperation and listening or expression skills”.

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She shared her view about solving bigger sustainability problems: “When you solve a problem in our world… We don’t work in a vacuum. You don’t work on something by yourself”. She further believes that “the biggest work that’s happening in our world is happening among people who are either working on a team or… working in collaboration with partners”. Anne recalled that her teacher encouraged them to “work with other teams to see what they think different or think the same”. She continued: “I elaborate with other teams… when I elaborate, I can see from other people’s point of view.” Seeing how other people think is important for how Rachel teaches: “I think by doing the type of instruction that I do, what I do is, I want to honor everyone's strength… everyone is needed for what they bring, and we all bring different things to the table.”

**Growth in Sustainability Consciousness**

Rachel’s pedagogy of sustainable thinking and some evidence that students increased their understanding of sustainability led to students also demonstrating growth at a deeper level: In their development of sustainability consciousness (SC). SC is the awareness of sustainability belief, feeling, and action integrated with environmental, economic, and equity concerns, the three dimensions of sustainable development (Boevede Pauw, Gericke, Olsson, & Berglund, 2015, p. 3). The awareness and integration of sustainability concepts can serve as a framework to measure a person’s capacity to participate in a society that meets its present needs without compromising future generations from doing the same. Rachel realized that her students had only achieved a nascent understanding of sustainability. However, she affirmed her objectives related to inspiring a better future: “Do I want them to know that there is a lack of equity within our
world? Oh yeah. Do I want them to know that child slavery exists? Yeah. I want them to know economically our world is divided.”

Growth in sustainability consciousness includes three themes according to the definition of SC. The themes are knowing sustainability, demonstrating a sustainable attitude, and behaving sustainably. Given Rachel’s belief that “anything and everything with humanity could be connected to educating for sustainability”, these SC themes are consistent with her pedagogy and student learning that can result from it.

Data drawn from students’ teen activism papers, a culminating assignment completed at the conclusion of their solar oven project, is heavily featured in this section. Students investigated a number of issues in their papers that relate to SC. Rosa shared some of the topics: “Some topics include protesting against government’s failure to announce that we are in the midst of a climate crisis, women's rights, girls education, fight for homeless animals, gun laws, rights for black people, gay people, protesting against overbreeding animals...”. Interview and artifact data complimented evidence from student writing. Students’ writing and interview responses provided some indications that students were developing an emergent SC.

**Knowing sustainability.** Rachel’s students referenced what they need to know in particular contexts in order to live sustainably. Knowing sustainability is understanding the fundamentals of sustainability, recognizing the future impact of current human behavior, identifying renewable resource alternatives to unsustainable energy consumption, and realizing that comprehending sustainability is challenging. The findings presented below provide evidence for each one of these knowing sustainability’s elements. “Knowingness” (Gericke et al., 2017, p. 4) is the term used for this theme in
SC research. SC researchers differentiate knowingness from factual truth. “There is seldom one way of solving [sustainability] problems and most often compromises have to made… what is factually correct in one context might not be so in another context.” (p. 4)

The knowing sustainability theme was organized according to the contextual concept of knowingness rather being limited to simply knowing facts.

Students encountered contextual differences and then spoke and wrote about them. Greta expressed the idea of countries and states being in different situations: “I think one of the like pieces of information or knowledge is probably, some people don't have like the same resources or materials that we do, our, like, our country or state does so.” The teen activism papers also demonstrated the variance between contexts and sustainability issues with which young people are struggling. Examples of topics within the papers include equal access to education as an equity issue, reduction of electronic waste as an environmental effort, and helping homeless people as an economic concern.

Two properties characterize knowing sustainability: Sustainability challenges focused on more than one dimension of sustainable development and students’ knowingness grew out of their factual knowledge. Table 11 is a concise presentation of this theme.

Students displayed some knowingness about the fundamentals of sustainability. Specifically, they began to understand connections within systems and between the dimensions of sustainable development. Rachel expressed how students made connections beyond just knowing facts: “At one point somebody talked about the connection between the food system and ‘we could cook in our solar oven and … we wouldn't use fossil fuels’, starting to understand the impact of fossil fuels within the food system.” Ruth demonstrated some understanding of how the dimensions may work
Table 11. Evidence of Student SC Knowingness

<table>
<thead>
<tr>
<th>Evidence of Understanding</th>
<th>Description</th>
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<tbody>
<tr>
<td>Students demonstrated knowingness for the fundamentals of sustainability.</td>
<td>Students displayed real time growth. They commented on food systems complexity, sustainability as more than environmental, and the importance of balancing the three Es.</td>
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<tr>
<td>Students recognized the impact of current human behavior on future generations.</td>
<td>Students discussed temporal considerations between generations. They wanted to start acting now to leave a good planet for future people.</td>
</tr>
<tr>
<td>Students identified renewable resource alternatives to current unsustainable energy consumption.</td>
<td>Students recognized that some products like fossil fuels are harmful to the environment and that we do have better choices.</td>
</tr>
<tr>
<td>Students realized that understanding sustainability is challenging.</td>
<td>Analysis of student data revealed a struggle with knowingness. Some students expressed not knowing what sustainability is or not understanding one or more of the dimensions. Equity was most challenging.</td>
</tr>
</tbody>
</table>

It's also about economics and social equity. Just being fair to the environment and people and money.” Jane saw balance as an important factor: “It's the balance between like money and the environment and social equity and how, [if] it's unbalanced then like it could hurt.” Greta also commented on the dimensions working together, “If one part of it doesn't work, then the environment and then social equality doesn't, it starts to get like doesn't stay equal anymore. And it starts, it doesn't, they don't work”. In his teen activism paper, Peter focused on one young leader’s work to address climate change. One of his subjects was the now well-known figure, Greta Thunberg (Alter, Haynes, & Worland, 2019). He wrote about Ms. Thunberg’s choice to learn about the context of climate change: She is “knowledgeable because she stayed home from school… because she wanted to research climate and what she can do to help”. He continued, pointing out the
importance of knowing each unique problem’s details: “This is important because without you knowing about the problem you’re facing, then you couldn’t know how to fix the problem you are dealing with.”

Even though these student comments hint at knowingness, additional evidence demonstrated that, as Rachel said, “the connections are still being formed between the systems.” Students often discussed each dimension of sustainability one at a time rather than in relation to one another, as observed during the first field observation (March 22, 2019). Recorded student comments focused only on basic economic matters: “The boy didn’t have enough money to go to school.” And “they didn’t have enough money to buy water.” Students also described the fundamentals at a broad level the majority of the time even if they did mention multiple dimensions. For example, Greta said, “Like go back to sustainability. Like it helps our environment and fairness and equality and it was interesting learning about how solar ovens go back to sustainability and it helps for sustainability.”

Students discussed the importance of knowing that our present actions impact future generations. Solutions to sustainability problems must take temporal considerations into account. Rosa related the solar oven project to these considerations, the ovens

are actually making a statement that we're trying to make the world a better place and when we make these, we're telling people that… it's important for us to know and to learn about these things because if we don't do a good job at our job… on the planet or passing it off to future generations, they're not going to have a good enough planet to live in.

Jane wrote about Amira Ferjani, a sustainability activist, in her teen activism paper. She shared a quote from Amira that says, “[The U.S.] Congress, they’re pretty much old
people. . . we’re going to be here, our kids are going to be here. We want to leave a good world for them.” Jane continued, writing that Amira was emphasizing that “we need to stop talking about the climate crisis and start acting” for the benefit of future generations. Ruth talked about the present and future in terms of opportunity, saying that we need to “leave this planet the best it can be for future generations. Because if we don't do that, the kids aren't going to have the best opportunities that we did.”

Students demonstrated understanding of renewable resources in the context of recognizing the impact of current actions on future generations. Greta pointed out knowledge that she can apply to sustainability challenges: “I learned about how some materials impact the environment in a bad way and that some other materials impact the environment like in a good way, like [renewable] resources.” Samson identified a non-renewable resource in the context of climate change. “Right now, we're facing a very big problem of climate change and people like Greta Thunberg are trying to make the government change their ways, change from fossil fuels to more renewable resources like wind, sun…” he said. Michael referenced the local food movement, “this is a huge part of it called local sustainable about this one farm that like he won't ship food. You have to come down there and pick it up”. Michael recognized that this farmer is trying to cut down on non-renewable resource consumption by not shipping his food. Recall that his SC scores for knowingness decreased from pre- to post-test. Yet, here he shared a knowing awareness for the food industry and sustainability. Anne and Henry discussed building solar ovens as being sustainable. Anne said, “I learned about how when you burn the wood it sets off this thing into the air that's bad for the earth. But when you use solar ovens, it would help the earth…” Henry affirmed that “we’re not in this problem…
our solar ovens are using renewable energy and that connected to sustainability because it’ll last for as long as the sun lasts, which is pretty much forever”.

Analysis of student data revealed them struggling with their sustainability knowingness, especially regarding equity. Student comments range from expressing what they do not know to rather sophisticated understanding. Consider Peter saying, “I don't really know what sustainability is. All I know, I know I like a little bit of it. It's like helping the earth.” As evidence of a struggle to understand rather just not knowing, Peter followed with, “I think maybe having a better place for, well I think it is, is having it like a better place for people in the future.” Ringo said, “I don't know, because I really forgot what [sustainability] means.” Jane described her growing understanding, “the first time we took the [sustainability consciousness survey] on our computers I didn't really know what it was and now I sort of understand it more.”

Equity appeared to be the concept with which most students were struggling with rather than simply not understanding. Jane also specifically identified equity as a clear gap in her understanding, “I'm not really sure what social equity is… I sort of understand it, but no”. Without using the word equity, Rosa wrote about it in relatively sophisticated terms as fairness in relation to the work a young activist, Malala Yousafzai:

a young teenage girl who was shot in the head, fought through common stereotypes because in her community, some people believed that it was a waste of time or ridiculous to send girls to school. She didn’t. The Taliban, a violence run movement primarily in Pakistan, frightened girls to the point where they weren’t going to school.

Rosa further demonstrated her knowledge of equity in her interview when she said, “like there's problems with social equity, that people aren't being treated fairly.”
Students with levels of understanding somewhere between these two examples alluded to equity in relation to other concepts. Greta also referenced fairness, “I think sustainability in my own words is helping our environment and making things fair for everyone in the world.” Michael said, “what happens with the sustainability is that conflict happens because people don't have fairness”. Greta added, “so it'd be like making it fair for everyone and helping our environment”. Peter alluded to equity as helping, “I think maybe sustainability also means like people helping one another. Having good community where everybody helps another person if they need it.” Samson defined equity by referencing equality: “It's kind of… equality throughout like a certain area, like either the world, a country, a state, just a place maybe. Greta built on his thinking and asked, “Does fair mean equal?” Ringo asked another question that brought up social interaction: “Was a part of it, the equity part, that's about people being together in different ways?”

**Demonstrating sustainability attitudes.** Analysis of teen activism papers revealed students’ growing understanding of attitude as an important compliment to knowingness. In their SC research, Gericke et al. (2017) define attitude as an emotion, mood, or feeling and, more specifically, “an enduring positive or negative feeling about some object, person or issue” (p. 5). Rachel asked the students to identify characteristics of teen activists in their papers. Students recognized specific characteristics that shaped what attitudes were necessary to engage in teen activism. For the purposes of this research, an attitude is a position that young people believe will lead to the change needed for a sustainable future. The theme of demonstrating sustainable attitudes is comprised of enduring attitudes that Rachel observed in her students and the students
discovered in their teen activism writing. Specific and essential attitudes were caring for other people, visualizing the future, opening people’s minds to critical issues, acting immediately, working hard and being persistent, and taking risks. Table 12 summarizes demonstrating sustainability attitudes as a theme.

Rachel used the teen activism paper as a way to help students develop their confidence and ability to act by researching other young people who fought for specific causes. She said, “I want to be having the kids learn to think for themselves maybe. I think that's the purpose of education, okay… to help kids develop those skills”. In her paper, Ruth emphasized one way she sees youth thinking for themselves, “But don’t think you have to be an adult to be an activist. Kids are taking charge too.” Rosa wrote

Table 12. Students’ Growing Understanding of Attitude

<table>
<thead>
<tr>
<th>Evidence of Understanding</th>
<th>Description</th>
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<tbody>
<tr>
<td>Students exhibited a caring attitude toward each other.</td>
<td>Students looked after and helped each other grow: Encouraging classmates when having a hard time, building up each other’s strengths.</td>
</tr>
<tr>
<td>Students recognized the importance of visualizing the future.</td>
<td>The vision for the future targeted taking care of each other and the planet. Students recognized ambition for a sustainable future.</td>
</tr>
<tr>
<td>Students identified the value of opening people’s minds to critical issues.</td>
<td>Opening up people’s minds can help achieve a better future. Young people can have a voice and they can change how people think.</td>
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<tr>
<td>Students observed that teen activists feel that acting immediately is essential to solving critical problems.</td>
<td>Acting immediately is needed to address the magnitude of societal problems. Students noted that nothing will change unless they act because leaders are not doing their job.</td>
</tr>
<tr>
<td>Students found that to be successful as an activist one must work hard and be persistent.</td>
<td>Hard work and persistence can lead to success. Young activists find solutions faster when they are stubborn and keep fighting.</td>
</tr>
<tr>
<td>Students discovered that taking risks is needed to solve critical problems.</td>
<td>Teen activists have confidence to take risks when they integrate these attitudes. Students identified additional descriptors related to risk taking: Determination, honesty, and fearlessness.</td>
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</table>
about a positive outcome of social action: “Teen activism shows power and strength in kids’ voices.” Three properties further describe the attitudes presented here: They are relational, time-based, and single-minded.

Rachel observed two ways that students were thinking for themselves as they looked after and helped each other grow. First, she witnessed an ethic of care when individual students were having a hard time. She said, “They're fantastic. They care about each other. I didn't have a single mean kid. You know, they, they truly care about each other. When someone's having a bad day, they ask each other like, ‘are you okay?’ This was so important that, she said, “one of my students spoke about this at graduation”.

Second, Rachel remarked that they championed each other. The student who spoke about student relationships at graduation said that “they really work hard to support each other”. In contrast to only caring for each other on bad days, Rachel said, “we build people up, we build strengths within our community”.

Two students stressed the importance of having a vision for the future in order to take care of each other and the planet. Ruth recognized looking to the future by focusing on ambition in teen activists. She wrote that “ambitiousness is an important trait for an activist to have because it helps them make goals for themselves that are higher and less likely to happen but if they do, a lot of good can come to the world.” In her interview, Rosa added:

Well, like the ocean isn't supposed to be filled with waste. There isn't supposed to be beached whales with massive amounts of trash inside of them. There's not supposed to be landfills all over world. Um, it's not supposed to. This is just not supposed to be like, this is supposed to be better.

Rosa’s desire for a better future was framed by current environmental degradation.
The students were attracted to the idea of opening up people’s minds to help achieve a better future. Rachel understands why her students want to open minds. “There are people who just don't care and who are, you know, pretty immune to [sustainability problems].” Rosa wrote that “teen activism is important to our society because it … opens the mind of people who think kids are just here to learn and do what they’re told.” She continued with the idea of making people aware of issues writing that “if there weren’t people like them actually doing something, violence would spike, people wouldn’t know about the climate crisis, computers wouldn’t be viewed as they are now, and people would be illegally enslaving children regularly.” Jane added that “teen activists change the way people think”. Further on in her writing, she wrote again about Amira Ferjani noting that “she works to change the way people think, fix world problems, and most of all, change lives”.

Acting immediately to solve problems was identified as important by students. Rosa focused on Iqbal Masih, a former child slave who fought to end abusive child labor in Pakistan. She wrote that taking immediate action was a question of life and death for him: He “protested against child slavery. His life was basically a death trap. He would die if he continued working as a slave, but if he escaped, he would die also because he was using his voice”. She also described Nick Joseph, Parkland, Florida school shooting survivor, and his encouragement to act now: He is “basically saying if people who are working to protect us aren’t actually doing their job, stop wasting our time and let’s get someone in there who’s going to help us instead.” Writing about her namesake, Greta Thunberg the activist, Greta noted the consequences of not acting: She “is determined because she is really trying to get people to do something and think about [climate
change] and what the future is going to look like if no one is doing anything.” She shares an interesting insight here about SC attitude yet her SC scores decreased between pre- and post-tests. Henry’s scores also decreased on this measure and, consistent with that, his interview answers did not provide any further information about his SC attitude. Michael generalized a belief about why we need to act now: “We need to have way more sustainability than there is in the world right now.”

The students recognized that taking action is hard work and demands persistence. Ruth labeled hard work as industriousness: “Industriousness is a good trait for activists to have because industriousness means to be hard-working and diligent, which means to care about your work or what you’re doing, and that is pretty much the definition of an activist.” Samson referenced Iqbal’s strong work ethic based on his level of success. He wrote that Iqbal “was a great person because he was hardworking. One example is when he was able to stop multiple illegal child slavery factories in just a few months.”

Three students focused on persistence as a related attitude to hard work. Ruth wrote about persistence using stubborn as a synonym:

To be a good teen activist, you should be really, really stubborn. Another teen activist that is stubborn is Greta Thunberg… Greta wants people to address the climate crisis. She wants world leaders to stop ignoring this problem and start doing something about it. To gain the attention she needed to accomplish this, she started skipping school. She added in one of her interview answers, “you shouldn't give up on something. You can always just keep fighting.” Peter noted that Greta Thunberg “doesn’t give up when people don’t listen” and “keeps trying at something”. Michael found two teen activists that demonstrated persistence. Malala Yousafzai fought for girls’ access to education in Pakistan and was shot by people who wanted her to stop. Michael wrote: “She survived.
Even though her recovery took some time she continued to protest and still is protesting.” He also wrote about Alex Lin’s persistence to get the support of hundreds of followers to reduce electronic waste: He “had to work and work to have that law passed because the first time he asked the state he was rejected, but then he came back with a petition that had 400 signatures on it!”

In the end, the students recognized that these collected attitudes lead to teen activists having the confidence to take risks. Continuing to talk about Greta Thunberg, Peter said that she speaks up to “like a lot of world leaders, which is pretty cool…, she has that much confidence”. Greta wrote about taking risks in relation to other traits: “Some characteristics I think teen activist have are they are risk takers, they’re determined, and they are honest.” She also paraphrased J.K. Rowling (1998) in the voice of Albus Dumbledore by writing that “it takes a great deal of bravery to stand up to our enemies, but a great deal more to stand up… for what you believe in”. Samson summed up the importance of risk taking with an equivalent term that describes teen activists: They are “fearless”.

**Behaving sustainably.** Sustainable behaviors can result from students’ knowingness and attitudes. Olsson et al. (2016) defined these behaviors as “self-reported intentions to act” (p. 184) associated with the subthemes of the three Es. Rachel’s students, however, identified teen activists’ bold real-life actions that helped them achieve their goals. She recognized that her students were not quite at the point of even measured action, let alone daring behavior:

I don't know that they're at the point where they can say, ‘Oh, I am not going to buy that plastic wrap made in China because it was, it produced under, you know, a social system that isn't right. And it was destroying the environment at all sorts of levels. And I can buy it for 42 cents because of the condition that this was
produced under.’ I don't think they're there. They're still 10, 11, maybe 12 but I want those seeds to be planted.

She planted seeds of action: “I want [students] to have that emotion to drive them to make a change or to work for change and to understand that you have the capacity to make a difference.” Adapted from Olsson et al. (2016) for the purposes of this study, behaviors that make a difference are the students’ self-reported intentions to act sustainably and actions taken by teen activists to solve problems. Sustainable behavior evidence shown here provides some support for the majority of students showing an SC behavior increase in pre- and post-test scores of the SC survey. While statistically significant growth was not found with behavior, there is some consistency when comparing qualitative and quantitative data. Behaving sustainably as a theme is summarized in Table 13.

Notably, the students demonstrated an understanding of how important it is to not just believe in sustainability but to also act on those beliefs. The students described behavior in the simple terms of “doing something”. Rosa said of Rachel, “She makes sure

<table>
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<th>Table 13. Behaviors Recognized by Students</th>
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<tbody>
<tr>
<td>Evidence of Understanding</td>
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<tr>
<td>Students identified protest as an important behavior.</td>
</tr>
<tr>
<td>Students found that speaking up about sustainability problems can lead to needed change.</td>
</tr>
<tr>
<td>Students discovered organizing as vital to solving sustainability challenges.</td>
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that we know about world problems and that we do things to fix it”. Anne wrote in her 
paper that “teen activists are kids who stand up and do something …”. Rosa wrote about 
what may happen without teen activists: “If there weren’t people like them actually doing 
something, violence would spike, people wouldn’t know about the climate crisis…”.
Henry said that to solve problems, in the past, “people acted”. Jane wrote that to solve the 
climate crisis people have to “start acting”.

The students identified three noteworthy behaviors in the teen activists they 
studied. They recognized that protesting, speaking up, and organizing can help solve 
sustainability problems and make the world a better place. Two properties distinguish this 
set of sustainability behaviors: They are bigger in magnitude than making sustainable 
buying decisions such as plastic wrap as described by Rachel above. In addition, the 
bigger magnitude actions can be dangerous.

Students identified protest as a key action for improving our world. Peter wrote 
that “teen activism is where somebody of a group of people see what’s wrong in their 
community and protest to try to solve it.” Henry wrote, “today, teen activists are 
protesting… Not all for the same reason, but for the same outcome, change.” In his 
interview, Michael added, “Malala Yousafzai was shot by the Taliban for protesting the 
fact that in her country girls can’t go to school”. Protest for Ruth is putting a stop to 
something that is not right. She wrote: “Take Martin Luther King Jr. for example. He 
thought that something in the world wasn’t right, unequal rights for all people, and tried 
to put a stop to it.” Michael recognized that protest can also be trying to get leaders to 
start acting. He discussed Greta Thunberg in his interview: “What she's fighting against is 
the inaction of world leaders against climate change.”
The students recognized that youth using their voice and speaking out is an essential behavior. Henry wrote that speaking up is “getting the attention not only of the world leaders, but of future leaders, all the kids and teens that could become important leaders for ending climate change, ending child labor, ending pet abandonment, and many more important problems.” He also wrote about how Iqbal Masih traveled from Pakistan to speak out against slavery and child labor: “[Iqbal] sailed across seas to speak about child labor in Massachusetts. He was assassinated five months later.” Even with the dangers that many teen activists experienced, Greta made the point that they “are not scared to say what they believe”. Ringo wrote her paper on Alex Libby, an Iowan boy who was bullied and then featured in a documentary. She noted that, sometimes, youth speak out in films: “[Lee Hirsch] made the documentary Bully to help people relate to what Alex went through and to show they aren’t alone and they too can find someone to pull them up when they’re down.”

Organizing was also identified by students as an important behavior. Organizing is forming organized groups with a specific purpose, recruiting people to join a cause, and raising money to achieve such objectives as getting laws passed. Ringo also described Alex Libby as an organizer: “Alex helps people that are bullied now. Alex created an organization called Stand Up for the Silent, their mission is to bring awareness to bullying and the desolation it causes.” Anne wrote about Iqbal Masih recruiting others to fight against child labor: “…he went to America and met a group of 6th graders to help him make child labor illegal”. Henry noted that Iqbal’s trip was, in part, a success: “He inspired those kids to create a website from which they made 100,000 dollars, which they then used to build a school in Pakistan, where he was born.” Rosa celebrated how much
money Malala Yousafzai was able to raise: “She has raised more than $10 million toward education projects around the world.” Financial support can lead to success. Even through it was a challenge, Michael wrote that Alex Lin “had to work to have the Rhode Island state government pass a law against E-waste dumping in the state”.
CHAPTER 5: DISCUSSION AND CONCLUSION

The purpose of this case study was to examine the relationship of PBL and sustainability education outcomes in a learning community including the teacher and her fifth and sixth grade students. Meaningful data were collected and analyzed leading to answers to research questions, connections and additions to existing research, and potential for future research. Unexpected and conflicting results were discovered and are included in this chapter. The discussion of quantitative and qualitative findings and limitations is presented first followed by the conclusion and recommendations.

Discussion

Teachers often bring their personal and professional passions to their instructional practice. This study focused on one such teacher, along with her students, who considered sustainability education as her unifying model of learning. As such, Rachel engaged her students in PBL by integrating the three Es of sustainable development and an engineering-related problem-solving design project. These were the major pedagogical models by which she taught that advanced students’ sustainability thinking and understanding.

The models and evidence of student learning became the focal points of this study allowing the researcher to address the key research questions with quantitative and qualitative data. Quantitative data analysis of Sustainability Consciousness Survey results revealed no statistically significant growth in students’ sustainability consciousness (SC) when comparing before and after the solar oven project. Qualitative findings, though, portray a learning community characterized by intentional sustainability education, students’ active sustainability thinking, and some evidence of growing SC.
This discussion of the findings is comprised of four sections. The first section reviews the SC hypothesis and results of quantitative data analysis. The next three sections are organized according to the study’s research questions focused on instructional strategies employed by the teacher that promoted sustainability education, student demonstrated sustainability skills and understandings promoted by PBL, and the extent to which PBL affected students’ SC with further interpretation of quantitative survey results. Each section summarizes the answers to research questions, reviews how the answers are supported by the findings, draws connections with existing knowledge, and describes unexpected and conflicting data. Limitations of this research study follow these four discussion sections.

**Hypothesis: Students’ SC will increase as a result of the solar oven project.**

Students completed the SC survey before and after the implementation of the solar oven project as a method of measuring growth in SC. Cronbach’s alpha reliability testing resulted in mixed outcomes, results of Wilcoxon Signed-Rank Test (WSRT) measures did not show statistically significant SC growth, and comparing students’ mean scores pre- and post-project showed some noteworthy growth for individual students.

The mixed Cronbach’s alpha results may be caused by a number of factors. Two are most likely the sources of lower values. First, achieving reliability in a measure is hindered by a low number of items in a questionnaire (Tavakol & Dennick, 2011). The SC survey designed for this study of fifth and sixth grade students was adapted from a 27-item questionnaire rather than the 50-item version documented by Gericke et al. (2018). Choosing to administer a shorter survey that is presumably easier to complete may have affected Cronbach’s alpha values. Second, low values may also suggest there is
weak inter-relatedness between survey items (Tavakol & Dennick, 2011). If low values are found to be caused by poor correlation between items, items may need to be revised or eliminated from the survey instrument (Tavakol & Dennick, 2011). There is some indication that low sample size can also affect Cronbach’s alpha results (Bujang, Omar, & Baharum, 2018) yet that indicator is inconclusive in this study.

One unexpected discovery about the students likely contributes to students not demonstrating statistically significant SC growth as measured by WSRT. Every one of the students started at Finley Elementary School in Pre-Kindergarten or Kindergarten and, with minor exceptions, remained students in the school until the year of this study when they were in fifth or sixth grade. The majority of students were participating in sustainability education with various teachers for up to eight years in a row. The survey administered in this study was designed to measure growth between before and after participating in one discrete PBL initiative during one of their last years in the school. The students, however, had been reportedly participating in sustainability education for a much longer period of time. The longevity of student sustainability education experience may have led to a ceiling effect in the SC survey data: A ceiling effect occurs when "a large proportion of subjects begin a study with very high scores on the measured variable(s), such that participation in an educational experience cannot yield significant gains among these learners" (Straus, O'Connell, & Storksdieck, 2021). Students scored high on the post-test in addition to beginning with high pre-test scores. Authors of A Framework for K-12 Science Education wrote that “to develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas’ interconnections over a
period of years rather than weeks or months” (National Research Council, 2012, p. 26). The same guideline can be applied to complex and interdisciplinary sustainability explorations even though this quote specifically references science. Students will develop thorough understanding and effective actions to achieve sustainability when sustainability education is part of every year of teaching and learning.

Individual students, based on their pre- and post-mean scores for SC elements, did stand out in terms of SC growth and regression. What follows is a brief discussion of suggestive increases and decreases in individual scores for knowingness, attitude, and behavior. A sample of individuals’ pre- and post-survey mean scores are compared to qualitative SC findings.

Greta’s SC knowingness mean increased by .60 and she was prominently featured in the qualitative findings of knowingness above. She was quoted nine times regarding the knowledge and understanding of complexity that is needed to build a sustainable world. Michael, in contrast, recorded a drop in SC knowingness. What he said was featured much less in the qualitative findings with only three quotes. He was noted as one student who struggled with the meaning of equity while expressing some understanding of renewable resources as fundamental to sustainability.

Michael’s growth trajectory reversed in terms of SC attitude. His mean score increased by more than .20 between the pre- and post-survey. He only contributed one comment to the SC attitude findings yet it expressed a heartfelt need act now to have more sustainability in the world. Henry’s pre- and post-values decreased by more than -.40. Based on interview and artifact data analyses and as recorded in the qualitative SC attitude findings, he did not appear to share considerable understanding for attitude.
Data analysis regarding SC behavior revealed the single largest increase in mean scores between pre- and post-surveys. Anne’s SC behavior value increased by an entire point (1.0). Her contributions to the qualitative behavior findings were not large. However, she clearly communicated that teen activists exhibit SC behavior because they are actually “doing something” like recruiting others to their cause. Michael also recorded the largest decrease in mean SC behavior scores at -.25. Interestingly, he figured prominently in the qualitative findings for SC behavior. In his teen activist writing, he thoughtfully covered important points about protesting and organizing to create a better and more sustainable world.

In summary, pre- and post-test solar oven project SC survey results did not show statistically significant growth. The considerable number of years that the students had been participating in sustainability education is a plausible reason for little evidence of SC growth. The design of the sustainability education standards, consistent with the National Research Council (2012), assume that it takes time to understand what is important to “know and be able to do to be sustainability literate” (U.S. Partnership for Education for Sustainable Development, 2009, p. 2). The standards are interdisciplinary and span multiple education levels and at least 13 years from grades K-12. The learning outcomes are “a guidance document for integrating sustainability concepts into K-12 teaching and learning” (p. 2). In this way, educating for sustainability consciousness is not limited to a single subject or year of study. Like many educational pursuits, it is designed to develop over time while children are in school and continue into adulthood when those students are now able to “seek sustainable livelihoods, participate in a democratic society, and live in a sustainable manner” (p. 2). The student standouts for
demonstrating both SC growth and regression provided some evidence for a group of learners in a dynamic process of developing their literacy for sustainability.

**What PBL instructional strategies promote sustainability education?**

Rachel’s pedagogy of sustainable thinking first integrated important concepts through investigating the three Es, addressing multiple curriculum standards, engineering projects, and higher order questioning. She then excited learning in her students with the intentional design of learning environments, fun, tailored learning experiences, and coordinated group work. In addition, all of these instructional strategies enabled her to address sustainability education standards.

Integrating concepts describes Rachel’s instructional strategies broadly. Through the integration of conceptual understanding, she guided students to practice holistic thinking, active and responsible citizenship, engineering design as a PBL approach in the real world, and inquiry that can lead to deep thinking.

Rachel expressed that each of the three Es and all of them working together are a system. The interconnectedness of these concepts was fundamental to her teaching. Holism (Boeve-de Pauw et al., 2015) as a concept was introduced in the literature review. Rachel’s systems view of the three Es appears to be rooted the origins of holism. Smuts (1925) wrote that “the idea of wholes and wholeness should… not be confined to the biological domain; it covers both inorganic substances and the highest manifestations of the human spirit” (p. 86). Rachel applied the integration of the three Es to her teaching which led to a synthesis that “affects and determines the parts, so that they function towards the ‘whole’” (p. 86). Her use of the three Es as a guiding concept shaped her
pedagogy into a meaningful endeavor rather than merely the sum of academic disciplines and discrete activities.

In doing so, Rachel guided her students to meet multiple learning standards embedded in the CCSS and NGSS. Recall from the introduction that the NGSS intend to help learners be able to navigate “major challenges that confront society” (National Research Council, 2012, p. 9). The CCSS for English Language Arts (ELA) aim, in part, to promote “responsible citizenship” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 3) through documented learning outcomes. Rachel believed that striving for sustainability is a major societal challenge. She further believed that understanding the three Es and behaving more sustainably is being a responsible citizen. Engineering projects also connected to curriculum standards as Rachel’s chosen method for guiding students to experience and participate in solving sustainability problems. She endeavored to help students “solve problems arising in everyday life, society, and the workplace” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, p. 6) by teaching universal mathematical practices. She guided students to design, build, measure, test, and calculate the performance of their solar ovens. They worked to solve the everyday problem posed to them in a story: Cooking food in a sustainable way with a renewable resource.

The choice to follow the engineering design process as the PBL model was telling. She agreed with the National Research Council (2012) who identified engineering as “instrumental” (p. 9) in designing solutions to sustainability problems. Engineering design is consistent with this study’s adapted definition of PBL (Wirkala & Kuhn, 2011)
characterized by no prior study, use of existing knowledge, real-life context, working in teams, and reflection. The solar oven project was a novel problem for the students. They used existing knowledge gained from prior design projects (e.g., creating windmills). While the students were not forced to build solar ovens for their own survival, they were able to perceive real-world applications and future implications in the context of the story, *Lerato Cooks Up a Plan*. The students completed the project in collaborative teams and practiced reflection as they tested and refined their designs. Rachel’s students developed their voice and power in these teams through problem-posing education (Freire, 1993) by practicing engineering design. Problem-posing education engages students in solving local and meaningful problems. While designing, building, and testing solar ovens, Rachel and her students taught each other “mediated by the world” (p. 80).

Higher order questioning helped Rachel explore sustainability issues and promote critical thinking with her students. Her question choices are affirmed in Simon et al. (2004). This research found that questioning promoted student thinking. In addition, they discovered that feedback and answers generated from inquiry deepened student content understanding. Rachel’s questioning techniques were also consistent with the recognition that students participating in PBL can think about problems in various ways (Belland et al., 2009) and the practice of pluralistic teaching (Boeve-de Pauw et al., 2015): The teacher letting go of communicating predetermined solutions and facilitating learning so that students understand the world through their own perspective and build their own capacity for sustainability (p. 15696). If the teacher and students answer sustainability-related questions together, they can benefit from varied perspectives to arrive at the best solution and generate their own solutions. Questioning as a method of critical thinking is
a key element in the sustainability education standards. Critical thinking is an “essential tool of inquiry that involves interpretation, analysis, evaluation, inference and synthesis, as well as explanation of the evidential, conceptual, methodological, or contextual considerations upon which that judgment is based” (U.S. Partnership for Education for Sustainable Development, 2009, p. 13).

Given that the sustainability challenges we face are wicked problems (Kolko, 2012), a teacher modeling how to experience contradictions and respond to varied opinions is a promising strategy. Rachel demonstrated how she guided students to rise to the challenge of wicked problems now and in the future. The National Research Council (2012) amplified the notion of students’ capacity to participate in PBL in the present. “The capacity of young children – from all backgrounds and economic levels – to reason in sophisticated ways is much greater than has long been assumed” (p. 24).

In contrast to integrating concepts, exciting learning and action as an element of the pedagogy for sustainable thinking was more focused on the immediacy of instructional strategies and operationalizing them. Intentional design and use of learning environments were inspired by a specific text. Rachel’s purposeful use of fun to promote learning and effort to tailor learning experiences were consistent with data discovered in the PBL literature review. Orchestration of group work was also consistent with the literature review along with theories related to project management and sharing the cognitive load during collaborative learning.

Rachel’s use of her indoor classroom was inspired by The Third Teacher (O’Donnell, Wicklund, Pigozzi, & Peterson, Architects Inc., VS Furniture., & Bruce Mau Design, 2010), a book written by architects and designers to inspire educators to use
space and place to improve how children learn. The environment (natural and built) is the third teacher. She kept plants and guppies in an aquarium in the classroom. The class studied their growth and movements. In addition, one wall of her classroom included a large window looking over a pasture next to the school. “Bringing the outside in” in these ways helped “dissolve the opposition between the [human made] and the natural” (p. 75). Rachel told a story about her students, led by Teddy, building a large raised garden bed frame inside her carefully organized classroom. She organized the room to the Third Teacher guideline to “make classrooms agile” (p. 89). Rachel accepted that furniture needed to be moved frequently and viewed her classroom as her partner. “It’s remarkable what you can do if you are given the right kinds of furniture… how you can engage different modes of learning” (p. 89). PBL and building together were the modes most often chosen by this teacher.

Place-based education is also a tool for sustainability education. Rachel expanded her chosen learning environment to include the playground, schoolyard, adjacent field, and hills surrounding Finley Elementary School. She recognized how lucky she was, describing these natural and built environs as “fantastic” in her interview. They were superb because they fit with an important guideline in the Third Teacher, allowing grass and leafy plants to “flourish in play spaces” providing “endless opportunities for play and discovery” (O'Donnell et al., 2010, p. 97). In these spaces, “you learn that you can make things happen” (p. 97). The places provide a context for designing solutions and building together: “Children… need places where they can learn by touching, manipulating, and making things with their hands.” (p. 175)
Rachel also chose place-based education as a model with which to study the village where her school is located and to teach local history. In that way, she could guide her students to solve problems and contribute to community in the present and prepare them to do the same as adults. She participated in “curriculum thinking and school design aimed at deepening students’ connection to their communities in ways that make those communities better places to live” (Smith & Sobel, 2010, p. 21). Rachel wanted to focus on solving sustainability problems with her students in order to make the world a better place. She presented local and immediate problems in the context of the bigger concept of sustainability and linked to similar challenges faced around the world. “Once children have had an opportunity to learn more about things with which they are already familiar, they can then be directed to phenomena that are more distant and abstract.” (p. 24) The sustainability challenges we currently face are consistent with this place-based framework. They are local, global, and wicked (Kolko, 2012), complex and contradictory in their nature.

Given that Rachel engaged her students in challenging and complex problems, it is not surprising that she also placed a premium on having fun. She borrowed a phrase, affective filter, from the field of second language acquisition. Krashen (1982) believed that negative emotions (affective responses) hinder the process of learning a new language. Learning is more accessible when negative affective responses are reduced or made more positive. Instead of language learning, Rachel introduced and guided her students through abstract and systems-oriented sustainability projects. With fun, she believed she lowered the affective filter to her students’ sustainable thinking.
Based on her observations and interactions with students, Rachel tailored learning experiences to ensure that they were enjoyable and contributed positively to community life. The findings presented her responsiveness to individual students and the whole group of learners who endeavored to build solar ovens. She sought to discover each student’s distinctive contribution and, as she noted, “help that shine”. Attending to student needs and contributions is consistent with the PBL interdependency theme in the literature review. Just as Belland et al. (2009) found that individual learners viewed problems differently and filled different roles, Rachel recognized her role to actively bring student perspectives and contributions to the surface. Simons and Klein (2007) affirm her understanding that it is the teacher’s role to closely facilitate PBL activities. These researchers suggest the teacher can ensure that all participating students gain new skills and understandings during PBL. When Rachel brought multiple student perspectives to the surface, she was strengthening the social system in her classroom. Along with her active questioning practices, promoting varied viewpoints during problem-solving discussions helps establish pluralism (Boeve-de Pauw et al., 2015) in the learning community.

Rachel was deliberate in her use of small group work to help individual students shine and to integrate varied perspectives that could lead to sustainability design solutions. She believed a key feature of a sustainable future is the ability of individuals to talk to each other and work together. Her emphasis on group work demonstrated her adherence to sociocultural learning, the belief that an interpersonal experience can lead to personal progress (Vygotsky, 1978). In addition, as featured in the literature review, Choo et al. (2011) agreed labeling small group learning as “crucial” (p. 523) to PBL.
Goodnough and Cashion (2006) found that the teacher played a vital role in teaching students how to negotiate while working together. Rachel guided the students to behave like engineers. Collaborating “with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas” (National Research Council, 2012, p. 52)

Rachel also facilitated cooperation between small groups working on solar oven designs in order to arrive at the best design solutions. While she, in part, did this to reduce the likelihood of intergroup friction if they were competing, she also increased the problem-solving strength of the whole group. Cognitive load theory (CLT) and distributed cognition (DC) are concepts that can describe a teacher’s work to guide multi-group cooperation to effectively find the best solution. CLT is used to “devise cognitively effective and efficient instructional procedures” (Kirschner, Sweller, Kirschner, & Zambrano, 2018, p. 217). Cognitive load is the “total working memory resources required to carry out a learning task” (p. 218). Similarly, DC is the shared thinking across individuals, other people, and tools (Valanides & Angeli, 2008, p. 311). Rachel repeatedly directed students from one group to learn from another group’s mistakes, successes, and innovative ideas. More distinctive though, DC describes learners engaged in working through “alternative conceptions” (p. 309) during design and construction. Hearing and discussing alternatives is more likely to lead to the best design solutions.

Amplifying the conceptual learning in and between groups was Rachel’s goal. While commenting on building together in groups, she expressed that she had and “awesome day” when she had time to bring the whole class together after hands-on work for discourse that summarized key learning. The importance of this reflective practice
was captured in the literature review. Researchers found that reflection can help reconstruct dispositions and improve learning, if visiting and revisiting the problem is facilitated by the teacher (Delisle, 1997, Dovros & Makrakis, 2012, Weshah, 2012).

In summary, Rachel’s pedagogy of sustainable thinking is aligned with U.S. Partnership for Education for Sustainable Development (2009) learning outcomes. Her work to help students integrate concepts is supported by research and literature related to holism, responsible citizenship, engineering, and inquiry. The sustainability education standards describe integrating important concepts as investigating “interconnected concerns in order to participate in democracy and live sustainably” (U.S. Partnership for Education for Sustainable Development, 2009, p. 2). The effort to excite sustainability learning and action is consistent with prior study on the topics of environment as the third teacher (Kolko, 2012), place-based education, affective responses, pluralism, interpersonal learning, cognitive load theory, and reflection. PBL and action for sustainability are reflected in a performance indicator embedded in the standards. The problem-solving indicator states that students will “identify an issue in their community and analyze it from the perspective of environmental, social/cultural, and economic concerns… and design a solution” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). Further, teacher facilitated reflection is one way to focus discussion on students being able to “know the difference between actions that they can take themselves and those that require involvement of other people” (p. 8).

**What sustainability education skills and understandings are promoted by PBL?** Rachel’s students responded to the pedagogy of sustainable thinking by exhibiting problem-solving abilities and insights throughout the engineering design process. They
enjoyed learning while designing solar ovens as shown by a balance of fun and serious work, detailed concentration, and a sense of accomplishment. The students’ exhibition of learning was consistent with sustainability education learning standards.

Students demonstrated their knowledge and growing competence for the engineering design process as a model for PBL during solar oven project work. Evidence included understanding what the design problem was asking of them, imagining solutions in rough sketches, documenting a final plan in a blueprint-style drawing, building and testing the ovens, and improving the model for real-world use. Researchers believe that the engineering design process and academic content are intertwined. They are “convinced that engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science” (National Research Council, 2012, p. 12). Students’ solar oven designs were evidence of integrated engineering, science, and sustainability understanding.

Researchers also understand the importance of students applying their learning in real-life contexts. “In this way, students can better see how science and engineering pertain to real-world problems and explore opportunities to apply their… knowledge…” (p. 32). Rachel’s students embraced the engineering design process, practiced it, repeatedly expressed their understanding and applied their skills and understanding to a real-world problem: Designing an oven with the least environmental impact. Engineering design is consistent with pluralism emphasized by Boeve-de Pauw et al. (2015). “There is usually no single best solution but rather a range of solutions” (National Research Council, 2012, p. 52) that can be generated by a group of problem-solvers with diverse perspectives. The best solution can be determined from the multiple ideas and diverse
viewpoints. Rachel’s students participated in the interplay and consideration of several solar oven design details within and between small groups.

Solar oven project work was a lively and enjoyable endeavor for the students given the exchange of varied ideas. Learning as enjoyment apparently transferred from Rachel to her students. The students appreciated her humor, the fun they had during project work, and how joy was coupled with hard work. Three students explicitly stated that they benefited from the mix fun and challenging work. Rachel’s effort to inject fun into her teaching along with students’ positive response is consistent with neuroscience and joy in education. Referencing Kohn (2004), Willis (2007) calls the students’ positive response “exuberant discovery”. “Students retain what they have learned when the learning is associated with strong positive emotion” (Willis, 2007). Billings and Roberts (2014) write that in “authentic discussion, students experience the thrill of discovering and constructing meaning” (p. 61). Zull (2004) wrote that “when we solve a problem, we have feelings of pleasure and satisfaction” (p. 70). PBL in the context of sustainability education is challenging work, especially given that we are engaging youth in navigating wicked problems. Humor and enjoyment are essential variables that can increase learning and help students choose the most promising design solutions.

Student recognition of the coupling of playfulness and exacting work was an unexpected finding. The children seemed to emulate their teacher who spoke very directly about humor can allow for learning and hard work. They welcomed meditation to prepare for the day’s work and their teacher being strict sometimes in order to be precise in their work. While this group of Rachel’s students responded less favorably to highly structured hard scaffolds such as worksheets, they were still required to draft plans and
keep records of their oven design process. The students’ understanding of the need to balance fun with being serious and for precise measurements is consistent with PBL studies that evaluated the usefulness of hard scaffolds. Simons and Klein (2007) found that students required to use hard scaffolds demonstrated better note taking skills. Even more consistent with the solar oven project, Belland et al. (2011) determined that hard scaffolds can help students uncover needed information, and find and organize relevant information for problem-solving success.

Scaffolding was a contributing factor leading to students’ sense of accomplishment and control of their learning. The students, of course, felt success when they cooked real food in their solar ovens. They delighted in cooking their own food for the first time. They also felt accomplished in the process of design and construction, when they worked together to gather materials for the ovens and during the exchange of design ideas within and between their small groups. Student reflections about their success also point to them taking ownership of their learning. Education for Sustainable Development (ESD) 2, as discussed by Olsson and Gericke (2016), maintains that sustainability education welcomes diverse viewpoints and works through contradictions, rather than only focusing on facts and knowledge acquisition, and can increase ownership, interest, and academic achievement. Sense of accomplishment and ownership can also engender students feeling more in control of their learning (Ferreira & Trudel, 2012). Evidence collected during solar oven design along with these research literature connections can lead to students’ increased confidence to participate in solving sustainability challenges.
Sense of accomplishment, control, and confidence can contribute to a strong classroom community. Some of Rachel’s students recognized success in peer support and the small group work. Their positive comments about peer-to-peer learning and group work are consistent with Choo et al. (2011) finding that these activities are essential to community building in PBL environments. The students blended diverse ideas for solar oven design within small groups. They investigated which materials had the best insulation properties. They shared insights with each other during informal and formal discussions. They were gaining the same abilities identified by students in Goodnough and Cashion (2006): Increased aptitude in negotiation, research, and presentation.

In summary, the students exhibited understanding of how to follow the engineering design process, apply learning to the real world, and enjoy PBL in order to solve a sustainability problem. They were skillful in attending to details in their designs, increasing their control of their own learning, and successfully cooperating with each other in small groups with the purpose to design build solar ovens. All of these skills and understandings contribute to an experience in which the students developed “a multidisciplinary approach to learning the knowledge, skills, and attitudes necessary to continuously improve the health and well-being of present and future generations, via both personal and collective decisions and actions” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3).

To what extent does PBL affect students’ sustainability consciousness? While quantitative data collection and analysis showed no statistically significant growth in SC, qualitative research activities did reveal particular SC evidence. The evidence points to core and foundational awareness for sustainability, rather than superficial knowledge
gain, with which Rachel’s students navigated decision-making and project work. Indications of SC included student knowingness of sustainability fundamentals, intergenerational impacts of human behavior, the importance of renewable resources, and the difficulty in solving sustainability problems. Students expressed understanding of SC attitudes in terms of caring for each other, future thinking, opening minds, taking immediate action, hard work, and risk taking. Three SC behaviors were identified by students: Protest, speaking up, and organizing.

Rachel’s work to build her pedagogy around the three Es as fundamental to sustainability resulted in evidence of students’ knowingness. The students wrote and spoke about their solar ovens nested in a larger complex system of sustainability design tools and choices. The nascent understanding and expression of the three Es is consistent with Boeve-de Pauw et al. (2015) and their tentative conclusion that integrating the three Es can increase SC knowingness. The students appeared to show more aptitude in SC knowingness than found in Boeve-de Pauw et al. (2015). They displayed in their willingness and emergent ability to discuss the complexity of the three Es. Vare and Scott (2007) along with Olsson and Gericke (2016) found stronger evidence of increased SC knowingness when teachers trained in sustainability education guide students in sustainability PBL. Indeed, Rachel’s higher education training, focus, and intention with sustainability education appeared to increase students’ knowingness.

Even with some evidence of growth in knowingness, struggle in understanding equity was apparent. Olsson et al. (2016) studied sixth and ninth graders and found that they struggled to understand the full scope of sustainability. Rachel’s students were challenged with the equity dimension and that limited their full understanding. It is not
surprising that students were found within the process of growing their knowingness of concepts such as equity. The CCSS for English Language Arts & Literacy state that by following the standards students are in process of learning and will “come to understand other perspectives and cultures” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 7). Further, with process-oriented language, they state that “students will actively seek to understand” and “can vicariously inhabit world and have experiences much different than their own” (p. 7). Awareness and acceptance of different perspectives is just one aspect of social equity. Yet these literature references make clear that it is reasonable to find that all aspects of equity may be challenging for fifth and sixth graders to comprehend.

Future-oriented thinking is an additional complexity that challenges students, and all of us, as we seek to live sustainably. Students discussed their awareness that they were inheriting the planet from their parents, responsible for passing it on to future generations, and obligated to at least sustain the opportunities that they were afforded. At its core, reconstructionism (Brameld, 1955; Rugg, 1939) holds that education engages students in learning for themselves and also for the betterment of society. Adding societal improvement to our educational endeavor inherently includes temporal awareness. If students are participating improving society, there is an assumption that we have problems now that, if solved, will lead to a better tomorrow. Just as the concept of knowingness demands that we consider more than single facts and solutions (Gericke et al., 2018), it also necessitates that we integrate past, present, and especially future concerns. Temporal considerations are also found in the NGSS. The middle school (including sixth grade) level science and engineering practices for “Constructing
Explanations and Designing Solutions” states that students will assume “that theories and laws that describe the natural world operate today as they did in the past and will continue to do the same in the future” (NGSS Lead States, 2013b, p. 48).

One specific example of how we act now that can have implications for the future is if we choose renewable or non-renewable resources. Rachel taught her students about green technology, tools and products made with substantially low or the absence of negative impacts on the environment. Her students cited their awareness of materials that are more or less green, the connections between fossil fuel emissions and climate change, and that the operation of their solar ovens are an example of green technology. These variables noticed by students are just some of the numerous factors that must be accounted for while solving sustainability problems. Encountering varied factors is consistent the definition of knowingness: That sustainable thinking is complex with multiple materials from which to choose and varied solutions based on place and time.

The students’ awareness of renewable resources along with their growing understanding of the three Es demonstrated that they were progressing toward an even more holistic understanding of green technology: One that can “eliminate conflicts between economic growth and environmental health” and recognize that the “operating system of the natural world is an unrivaled model for human design” (McDonough, Braungart, Anastas, & Zimmerman, 2003, p. 437). Further, McDonough et al. (2003) exemplify their holistic description of green engineering in the “Cradle-to-Cradle Framework (C2C)”, the very concept that Rachel introduced her students to at the beginning of the solar oven project.

In summary, the students who participated in this study demonstrated some growth in sustainability knowingness. They showed evidence of being aware of how
important it is to integrate the three Es, equity as a complex concept, temporal considerations, and the role of renewable resources. Their growth in integrating the three Es and struggle with equity demonstrate that they were developing knowingness for sustainability education standard two: “sustainability as a dynamic condition characterized by the interdependency among ecological, economic, and social systems” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). Their knowingness is also apparent by connecting temporal considerations, renewable resource choices, and sustainability education standard one: “meeting present needs without compromising the ability of future generations to meet their needs” (p. 3).

Awareness in students’ sustainability knowingness can lead to attitudes that promote living in a sustainable manner. Rachel and the students identified specific dispositions which are consistent with sustainability consciousness: Care for each other, desire to visualize a better future, aspiration to open minds, acting now for a better world, hard work, and risk taking.

Rachel and one of her students specifically shared that the members of their learning community cared for each other. Common phrases in their comments were that they “truly care” and “support each other”. One subset of research reports in the PBL literature review found some evidence of increased learning due to teachers and differently abled students working collaboratively to design solutions. Learners supporting each other is inherent to PBL (Belland et al., 2009). Given that sustainability problems are complex and that each student problem-solver brings unique skills to the endeavor, it makes sense that members of the learning community take advantage of the opportunity to uphold each other. Supporting each other also necessitates welcoming
varied abilities and diverse ideas. Just as teacher questioning techniques and welcoming varied viewpoints contributed to pluralism (Boeve-de Pauw et al., 2015), a caring attitude between students made it welcoming for students to contribute their unique talents and share their ideas in support of sustainable thinking and problem-solving.

Welcoming alternative viewpoints and recognizing unique individual skills can help open our minds to new solutions and lead to more immediate action. The students who participated in this study realized these possibilities and wrote about it in their teen activism papers. They believed that teen activism opened people’s minds and, more specifically, changed the way they think. To be open-minded and solve problems as soon as possible, one must be receptive to new knowledge. The teen activists studied by the students were often compelled to act without delay because their lives or safety depended on it. PBL as a tool for increasing content knowledge was described in great detail in this research report’s literature review. The students discovered that teen activism is a form problem-solving and requires knowledge and information that can lead to positive change. Sungur et al. (2006) suggested the new knowledge is needed in order to move toward better solutions to the challenges we face. Activism can point out new information that enables people to put novel ideas to use (Wirkala & Kuhn, 2011). Liu et al. (2011) assessed knowledge gain coupled with motivation in the PBL environment. They found some evidence that as students increase their knowledge there is a correlate increase in motivation. Problem-solving via teen activism can also be seen as motivation to be open-minded to alternative solutions. Rachel’s students appeared to identify the importance of being unbiased and responsive while designing solutions.
Opening minds via teen activism is hard work. The students recognized diligence as a strong attitude in the teen activists they studied. While writing about teen activists they used additional synonyms for hard work: Industriousness and persistence. If activism is a PBL related activity, it is not surprising that a hardworking attitude became apparent to the students. Consistent with this research report’s adapted definition of PBL (Wirkala & Kuhn, 2011), it is reasonable to conclude that it requires hard work to design solutions for high stakes, real-world problems without extensive prior study. Industriousness and persistence are found in the CCSS. The ELA standards outline the importance of independence and students becoming “self-directed learners, effectively seeking and using resources” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 7). The students found independent hard-working activists in their research and exhibited their own self-directed behavior while designing and building solar ovens. The Standards for Mathematical Practice offer “perseverance” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010b, p. 9) as a key element of their first standard. Persevering to solve problems demands that students uncover assumptions, plan how they will break up their work to arrive at a solution, compare multiple solutions, and exhibit outcomes in objects and diagrams (p. 10). Science and engineering standards amplify the importance of diligence and perseverance for engineers and activists. People in these roles design solutions, defend conclusions with evidence, critically evaluate the ideas of others, test and revise solutions, and express this work in diverse ways (National Research Council, 2012, pp. 52-53).
Hard-working and independent activism is often perilous. Rachel’s students found that teen activists whose survival was threatened by their culture and society put themselves at risk in order to confront the hazards of injustice and an unsustainable world. They were determined and fearless and, unfortunately, some were physically harmed and even murdered. Sustainability is a concept that can uphold the health of the planet and human survival by making decisions based on the three Es. Luckily, the students, observed and interviewed while building solar ovens, were not in peril and quite safe. They were learning how to reduce risk by participating in a green engineering design project: Building solar ovens. The NGSS and supporting publications clearly present engineering as a study that can reduce risk. “Engineers improve existing technologies or develop new ones to increase their benefits…, to decrease known risks…, and to meet societal demands” (NGSS Lead States, 2013b, p. 46; National Research Council, 2012, p. 213). Willingness to take risks is a position that Rachel’s students recognized in the teen activists they studied and practiced themselves. They learned about other young people who were in dire circumstances and felt they needed to take extreme risks for a better life. They themselves were in a lower stakes environment in which they were trying their own ideas, learning from mistakes, and improving their solar oven designs as a small way to make the world a better place.

In summary, the student subjects of this research identified multiple attitudes in teen activists and themselves that can contribute to increased sustainability. These include care for fellow humans, envisioning a bright future, open-mindedness, acting without hesitation, diligence, and audacity. The attitudes identified by the students can be considered a synthesis of personal and collective responsibility (U.S. Partnership for
Education for Sustainable Development, 2009, pp. 8-9). Personal responsibility attitudes are acting fast, hard work, and fearlessness. Collective attitudes are caring for each other, seeing a better future, and broadmindedness. Sustainability education standard two alludes to both the personal and collective. The standard describes sustainability of education as a study of “interdependency” that can improve “individual and societal well-being” (p. 3). Standard three is even more direct: “Students develop… attitudes necessary to continuously improve… via both personal and collective decisions and actions” for “a world that is sustainable” (p. 3).

Actions for a more sustainability world can be built on sustainability knowingness and attitudes. Rachel’s students recognized sustainable behavior in the teen activists they researched and wrote about. Examples of behavior targeted in the Sustainability Consciousness Questionnaire (SCQ) (Gericke et al., 2018) include choosing to cycle or walk instead of driving, showing respect to all people, and helping poor people. These are important behaviors that can contribute to sustainability yet the SCQ only collects data on intent to act. The students realized how the teen activists transcended intent, doing much more than is outlined in the SCQ. What the students recognized in the activists as actually “doing something” is more audacious. The activist behavior studied is consistent with social reconstructionism (Brameld, 1955; Rugg, 1939) in that activism and academic learning can be integrated. The students isolated protest, speaking out, and organizing as vital activist behaviors that can lead to social improvement.

The students investigated multiple activists who protested to make change. They included Malala Yousafzai, Martin Luther King, Jr., and Greta Thunberg. They recognized harm and oppression in their society in terms of gender, race, and climate
change. Their decisions to protest for social improvement also rests on the foundation of *Pedagogy of the Oppressed* (Freire, 1993). They protested to initiate a creative process of dialogue (Díaz, n.d.). All of the activists were firm in their stance and wanted dialogue that would at least begin the conversation about taking action to improve society. This dialogue is “characterized by respect of the parties toward one another” (Díaz, n.d.). Writing about Paulo Freire and what can be learned from social movements, Susanne Butte (2010) expressed very clearly the point of protesting: “The point was to shake up the internalized perceptions of everyone present.” (p. 167).

Protests are the events that create the opportunity for the spoken word, chants, and songs to motivate the participants and hopefully initiate further respectful dialogue. Rachel’s students found that teen activist spoke out to get the attention of leaders to make a change. They raised their voices in multiple forms including organized speeches and films. As the students were researching the activists and writing about them, they were gaining a deeper understanding of speaking and listening skills. The ELA CCSS grades 6-12 anchor standard for “Comprehension and Collaboration” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010a, p. 48) reads as an alternative description for dialogue: Students “prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others’ ideas and expressing their own clearly and persuasively” (p. 48). The sixth-grade standard for “Presentation of Knowledge and Ideas” (p. 49) points to support for making films to promote respectful discussion. The standard asks students to “include multimedia components… and visual displays in presentations to clarify information” (p.
The conversations, expressions, and multimedia are all examples of discourse: spoken and written language that can challenge social practices (Butte, 2010, p. 168).

Films are made, events scheduled, and protests occur because they have been organized. Rachel’s students found that organizing was characterized by recruitment, fundraising, and purpose. They learned that teen activists created organizations, coordinated events during which they could speak out, and raised millions of dollars for their cause. Organizing is consistent with behavior surveyed in the SCQ. The questionnaire includes survey prompts such as “I work on committees (e.g., the student council, my class committee, the cafeteria committee) at my school” and “I support an aid organization or environmental group” (Gerick et al., 2018, pp. 7-8) related to active participation in formal groups with a purpose.

Committee work and organizational support can, as Freire (1993) believed, change the world. He “highlighted the fact that every single human being has the ability to change the world for the better through their work” (Diaz, n.d.). The work referred to here is that of carpenters, plumbers, custodians, and factory workers. One can reasonably transfer this idea of transforming the world through vocation to the efforts of activist organizations. The student participants in this study realized that changing the world begins with a specific purpose. There are other benefits of focusing on purposeful change whether you are an activist or a student. Sobel suggested that “schools with a social purpose also become schools where students are more academically successful” (Sobel et al., 2014, p. 6). The integration of sustainability, academic content, and at least the study of teen activism can serve to bring education itself back in line with public good (Labaree, 1997) as a purpose of school.
In summary, the sustainable behaviors recognized by students are consistent with the third sustainability education standard: “Continuously improve the health and well-being of present and future generations, via both personal and collective decisions and actions” (U.S. Partnership for Education for Sustainable Development, 2009, p. 3). When youth protest, they think they are carrying out “a personal action that will enhance the quality of life” (p. 8). Youth activists who speak out believe they have analyzed an issue, its patterns and root causes, and potential solutions (pp. 8-9). When activists of any age organize, they are taking collective action, connecting and coordinating multiple people and varied resources. This is one way for them to participate as “active citizens in the democratic process in the interest of sustainability, using the systems approach to make their actions more effective” (p. 9).

**Limitations**

The limitations of this research cannot be overlooked. The study has several limitations that are typical in qualitative and quantitative research. Sources of limitations include a small sample size, self-reported data, anomalous teaching style, and a lack of PBL and sustainability education integrated research.

First, the sample size of one teacher and eleven students is small. Small sample size is often a hindrance in research as with less data it is more challenging to find relationships in the data. Given that this is a mixed-methods study, both quantitative and qualitative challenges must be considered. Only nine of the eleven participating students in Rachel’s class completed the Sustainability Consciousness Survey to provide quantitative data. In comparison, the SCQ the survey was based on was administered to over 2,400 students (Boeve-de Pauw et al., 2015). An n of nine is well below this
example and the standard minimum of n=30 in order to assume a normal distribution and utilize a t-test. Even though WSRT was appropriately used in place of a t-test to analyze pre- and post-survey data, the nine students may not represent fifth and sixth grade students in the whole population. Therefore, it is challenging to compare this study’s findings to prior SC research and limit generalizability. Low participant numbers are less of a challenge for the qualitative data collection and analysis portions of this study. Rachel’s class, however, is atypical to common elementary class sizes usually at approximately twenty students. That too can limit the application of research results to a broader population.

Second, all qualitative data were self-reported in interviews, researcher observations, and artifacts generated by participating teachers and students. Self-reported data is limiting in that it cannot be independently verified. To improve data collection and analysis, this study followed a mixed-method design to attempt to overcome the limits of self-reporting data. This research attempted to follow the example of pre- and post-assessments as described in research reports featured in the literature review.

Third, Finley Elementary School’s mission is meant to be implemented school-wide. Rachel communicated that the levels of sustainability education in the school vary and her class presented as somewhat of an anomaly within the school. That she teaches in a significantly different way as compared to her colleagues and students look forward to that difference as they progress through the grades may be the more significant reasons that her PBL and sustainability education activities appear to work.

Last, there is a lack of PBL and sustainability education combined research literature on which to build new research activities. Literature review search terms were
chosen specifically to discover studies that combined PBL and sustainability education. Only one study (Dovros & Makrakis, 2012) fit this description. While this gap in existing research limits the ability to build a foundation for research activities, it also presents an opportunity to take research, in this case on PBL, in a new direction. There appears to be a gap in the literature in terms of investigating PBL in real-world PreK-12 contexts such as sustainability education.

Conclusions

The concluding section of this dissertation includes three segments. First, a summary of research discoveries is presented given the findings and discussion provided here. Second, recommendations are provided based on results and interpretations. Lastly, how this study contributes to existing knowledge is briefly outlined. The literature review and research objectives were carried out using specific methods and data analysis techniques to furnish a foundation on which to draw conclusions.

Research objectives. The review of literature revealed noteworthy findings. Sustainability consciousness is a recently formulated concept regarding awareness of sustainability issues and actions with significant use and study in Sweden. Researchers in Sweden (Boeve-de Pauw, et al., 2015; Gericke et al., 2018; Gericke & Rundgren, 2016; Olsson & Gericke, 2016; Olsson & Gericke, 2017) have established a strong model of measuring SC using the Sustainability Consciousness Questionnaire (SCQ) (Gericke et al., 2018). The SCQ was adapted for use with the students at Finley Elementary School and titled as the Sustainability Consciousness Survey (SCS). This research supplies some evidence that an intentional pedagogy based on the three Es points to evidence that more schools in Sweden and the United States can successfully follow this model. The increase
in schools adopting a sustainability education curriculum is in contrast to fewer and more isolated schools across the world being the only organization taking the opportunity to implement the model.

Taking advantage of that opportunity can lead to students actively participating in shaping a more sustainable world. This study sought to examine the relationship between sustainability education and PBL as an overarching instructional strategy as a small group of students and their teacher designed and built solar ovens. Prior research suggests strong connections between sustainability education and PBL. The study of Finley Elementary School fifth and sixth grade students was most connected with three of the five themes identified in this segment of literature review: 1) Increased knowledge for action; 2) collaborating in small groups; and 3) recognizing interdependency. Students solidified and increased comprehension in multiple subject areas by integrating their understanding within the concept of sustainability. More specifically, they demonstrated increased sustainability awareness and knowledge of activism in their teen activism papers. Their small group work on solar ovens was consistent with literature review findings that identified successes in problem-solving and design solutions linked with interpersonal collaboration. Further, the students participated in and were able to articulate the importance of interdependency within and between small groups as integral to meaningful learning and efficacious project work.

The sustainability education standards produced by the U.S. Partnership for Education for Sustainable Development (2009) were used as a tool by which to evaluate PBL research. The standards promote systems thinking as a fundamental understanding for a sustainable world (p. 3). They specifically reference “interdependency” and
“interconnected systems” (p. 3) as important concepts for sustainability education. In turn, Rachel followed a systems-oriented approach to implement her pedagogy of sustainable thinking during the solar oven project and throughout her teaching practice. How she perceived her instructional practice was an example of conceptual system that guided the pedagogy. Her practice reflected the interconnection of multiple concepts: Three Es (environment, economy, equity), learning outcomes (curriculum standards), the field of engineering, and questioning techniques. Rachel displayed a second system, one that served to rouse students’ sustainability understanding and action. She excited learning and action via intentional design and use of her classroom, exploration of the schoolyard, extension of learning to the community, facilitation of joy during project work, and responsiveness in order to tailor learning experiences to students’ needs.

Students responded to the teacher’s systems-oriented pedagogy of sustainable thinking with willing participation and expressions of learning. Guided by Rachel to construct solar ovens, they immersed themselves in the engineering design process. The design process elements that best exemplify this immersion were students’ imagining and reimagining designs, creatively building the ovens, and understanding the process as complex and iterative. Numerous design sketches and oven reconstructions demonstrate their imaginations. The wide range of insulators gathered and used in the ovens exhibited the group’s creativity. Students’ willingness to return to the planning phase and adapt their models after testing were signs that students recognized problem-solving as a non-linear process.

Rachel’s effort to bring joy to project work may have helped students navigate the challenging non-linear design process. She modeled how to balance fun and work during
solar oven design and construction. The students enjoyed their experience. The most unexpected finding regarding how students enjoyed the project was that they found satisfaction in concentrated and detailed work just as much as through sharing joyful stories and telling each other jokes. Joy was a consistent characteristic throughout the project rather than a fleeting emotion. Students’ sense of accomplishment grew from consistent enjoyment even while overcoming frustrating setbacks and the successful construction of working solar ovens.

Investigating the effect of the students’ accomplishments on their sustainability consciousness yielded an additional unexpected result. The hypothesis of the quantitative portion of this research was that by participating in the solar oven project, students’ SC survey scores would rise. However, pre- and post-test results showed no statistically significant growth. Further reflection and interpretation led to an important realization. In this study, the SC survey was used to measure SC before and after the solar oven project, an effort that lasted approximately two months. Absence of growth in that time frame was not surprising once it was known that these same students had been participating in sustainability education at Finley Elementary School for seven to eight years. Coupled with this realization, student participants did demonstrate some sophisticated awareness of sustainability knowingness, attitude, and behavior in their writing and interview responses regarding teen activism. SC was used as a tool with which to analyze teen activism data. Students’ sophisticated awareness was best exemplified by their writing and comments on teen activists being willing to risk their lives to make a difference. Their focus on this characteristic of activism extends the idea of sustainability behavior much further than the SC survey measures and demonstrated the importance Rachel’s
students and the teen activists apply to gender equity, reducing waste in the environment, and an economy that pays people fairly.

**Recommendations.** The review of literature, specific research methods, quantitative and qualitative data analysis led to clear research recommendations. The recommendations below are divided into two categories: Suggestions specific to the evidence of this study and proposals for future research.

The evidence gathered and analyzed from Finley Elementary School point to specific recommendations related to: School mission statements, teachers’ core passion, intentional use of the third teacher (O'Donnell, Wicklund, Pigozzi, & Peterson, Architects Inc., VS Furniture., & Bruce Mau Design, 2010), and collaboration to design solutions.

1. This research suggests that schools consistently revisit their mission in order to ensure that curriculum, instruction, and assessment is directly supporting that mission. In this case, the school changed its mission in 2011 to align with the definition of sustainability education. Wiggins and McTighe (2007) wrote at length about the importance of attending to school mission statements. The primary message of their book can be summarized in one sentence: “Reform must be guided by a constant focus on the meaning of school mission and the analysis of that mission into aligned policies, structures, and practices.” (p. 3)

2. Similar to the importance of a school’s mission statement, it is important to recognize what motivates a teacher and unifies their professional practice. Rachel is inspired and driven by sustainability education. She shared that drive with her students in order to guide them to develop
sustainability thinking and meet curriculum standards. Seeking to find out what motivates educators in relationship building between teachers, school leaders, district administrators, policy makers, and consultants can further promote meaningful learning experiences for students.

3. This study indicates that the intentional use of both the indoor classroom and schoolyard and wider community as a context for learning can promote deeper and more meaningful learning. Rachel spoke in detail about the design of her classroom, how she used and what she observed in children on the school grounds, and the role of the community landscape beyond the school property lines. Most teachers are deliberate about how they organize tables, chairs, and learning stations in their room. They take periodic field trips as well based on available funding for bus transportation. More teachers, though, will benefit from expanding their perception of and intention for where learning happens.

4. The sustainability education standards promote both individual and collective action and learning for a more sustainable world (U.S. Partnership for Education for Sustainable Development, 2009, pp. 8-9). Many teachers guide learning with students in small groups and at learning stations at which they collaborate. This practice can be strengthened even further by linking this mode of learning not just to meeting curriculum standards but also to teaching a vital cooperative skill needed to design solutions to sustainability challenges.
The evidence gathered and interpretations formulated in this research also point to opportunities for future related research. Possible areas for further investigation include additional research that links PBL and real-world problems such as those related to sustainability, replicating the case study approach in sustainability education classrooms, applying the research model practiced in Sweden (Boeve-de Pauw, et al., 2015; Gericke et al., 2018; Gericke & Rundgren, 2016; Olsson & Gericke, 2016; Olsson & Gericke, 2017), and studying a group of students over a longer period of time.

1. Of the twenty-nine studies presented in the literature review, one integrated PBL and sustainability education. More research is needed that examines PBL in real-world contexts, especially related to sustainability as this research and a prior study (Bocko, 2018) suggest.

2. The case study design can be applied to additional schools and classrooms that intentionally teach sustainability in their curriculum even with the limitations exhibited in this research. Case study as a method and the accumulation of data that portrays sustainability education will provide a focused portrait and further reveal inherent successes and challenges of this model. The mixed method approach using the SC survey may be avoided unless there is clearer pre- and post-evaluation opportunity.

3. The SCQ can be further utilized in the field if applied in the U.S more in line with its use in Europe. There are two ways to accomplish this. First, administer the SCQ, or a further adapted U.S. version, with larger numbers of students. Increased sample sizes may improve reliability and validity of results as a compliment to qualitative case studies. A strength
of the many studies described in the literature review was their mixed
method design integrating qualitative data with quantitative pre- and post-
assessment data. Those mixed methods can be applied to PBL research in
a sustainability education context. Second, conduct SCQ studies with
larger samples sizes to compare students who attend sustainability
education schools and those who learn in conventional settings. These
studies can be compared to research conducted in Sweden and begin to
build a foundation of U.S. data.

4. Study a group of students participating in sustainability education over a
longer period of time. There are few schools and even fewer school
districts that based curriculum, instruction, and assessment on
sustainability education. Researching a group of students from when they
enter a sustainability focused school until they leave using qualitative
methods and quantitative measures can provide a more detailed picture of
the extent to which instructional strategies and resulting student
understanding and skills increase sustainability consciousness.

Contributions to knowledge. In addition to providing avenues for future
research, this study has made multiple contributions to the literature on PBL and
sustainability education, given that research into PreK-12 PBL and sustainability is
limited. The contributions fall into the categories of adding to research literature,
connecting an instructional model to real world learning, highlighting the importance of
learning experiences designed to meet a school’s mission, and increasing the use of a new
survey instrument.
PreK-12 PBL research has been reported to be a limited yet growing field (Belland, Glazewski, & Richardson, 2011; Ertmer & Simons, 2006; Goodnough & Cashion, 2006; Hmelo-Silver, 2004; Hung, 2011). The findings of this study add to the growing body of research and offer some affirmation for outcomes documented in prior research. In particular, the results further contribute to PBL research related to group collaboration, interdependency, and reflection. Rachel specifically taught students how to design sustainability solutions collaboratively on teams through PBL (Goodnough & Cashion, 2006; Simons et al., 2004; U.S. Partnership for Education for Sustainable Development, 2009). The students demonstrated strength and understanding for intragroup interdependency (Simons & Klein, 2007) and intergroup cooperation. Rachel consistently paused for reflection during the solar oven project and related learning experiences. She facilitated numerous reflective discussions (Dovros & Makrakis, 2012) during construction and design and coached students to write about a deeper understanding of activism (Song et al., 2006) as a way to reflect on how to improve the world around them.

More than adding to the PreK-12 PBL literature in general, this research generates understanding for the link between PreK-12 PBL and one example of real-world application: sustainability education. The U.S Partnership (2009) sustainability education standards are provided in a 16 page document. The text includes the word problem 16 times, the word design 11 times, and solution 14 times. The document is clearly sending a message that students must learn how to design solutions for sustainability problems. The focus on problem solving and students helping improve our world is a manifestation of problem-posing (Freire, 1993) and social reconstructionism (Brameld, 1955; Rugg,
This research builds on a longer version of the PBL literature review previously published as a chapter (Bocko, 2017) in an edited book. In a review of the book, the reviewer highlighted this chapter as the most impactful for her. She wrote, “the chapter most helpful to my work at Mundo Verde Bilingual Public Charter School was chapter 8: ‘Synergy Between Problem-Based Learning and Educating for Sustainability: A Review of the Literature’” (McNerney, 2017). She further added that “having the academic research so well summarized … will be a helpful tool for communicating the reasoning behind our mission” as a “sustainably-focused public school” (McNerney, 2017).

The Finley Elementary School sustainably-focused mission, renewed and adopted in 2011, also figures prominently in this research. The unexpected finding that the student participants in the study were the first group to complete their entire PreK-6 experience guided by a sustainability education mission affirms a core argument in Schooling by Design (Wiggins & McTighe, 2007): That a school’s mission must be the primary guide for curriculum, instruction, and assessment decisions and activities. Finley Elementary School’s intentional academic programming designed as sustainability education is an example of a school mission that was “honored” during “day-to-day planning, teaching, and assessing” (p. 32).

The SCQ (Gericke et al., 2018) was first used in Sweden to assess middle and high school students’ sustainability knowingness, attitudes, and behavior in schools with a mission to educate for sustainable development. Although some researchers have employed the SCQ in other countries, the subjects of those studies were pre-service teachers’ sustainability consciousness in Thailand (Sunthonkanokpong & Murphy, 2019) and Spain (Marcos-Merino, Corbacho-Cuello, & Hernandez-Barco, 2020). Applying the
instrument in the U.S. with PreK-12 students is rare. Administering an adapted SCQ in this mixed-methods study at Finley Elementary School is an early application in the U.S. As a result, the findings in this study may serve to enhance our knowledge of students’ sustainability consciousness, particularly for upper elementary aged students.

Sustainability education, measured in just one way by the SCQ, is the meaningful framework that enables students to actively participate to better themselves and reconstruct society while they learn (Brameld, 1955; Rugg, 1939). Paraphrasing Orr (Jickling & Sterling, 2017), with the above literature, findings, and interpretations in mind, we must learn how to guide students through formal schooling so that they emerge as caring, competent, and decent stewards of our earth and society (p. x).
APPENDICES
Sustainability Consciousness Survey

Sustainability Consciousness Survey 3.0
This survey consists of a series of claims which you respond to by clicking on the choice you make. Go back carefully over the survey before you click 'submit'. Make sure you have not left out any questions. Thank you for taking the survey.

* Required

Basic Information

Please answer the following questions by writing the answer or choosing the best choice.

1. What is your name? *

2. What grade are you in? *
Mark only one oval.

   - 5th Grade
   - 6th Grade

3. Have you heard of sustainability? *
Mark only one oval.

   - Yes
   - No
   - Maybe

Sustainability Statements

For each statement below, mark the choice that best matches your understanding.
Knowingness Items

4. Part 1 - You can mark your choice on a scale from "1 - Strongly Disagree" to "5 - Strongly Agree". If you do not agree nor disagree, then choose #3. If you do not know how to respond to the statement, then choose "Don't Know".

1 = Strongly Disagree 5 = Strongly Agree
Mark only one oval per row.

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
<th>Don’t Know</th>
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<tbody>
<tr>
<td>I know that lowering water use is needed for sustainability.</td>
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<td>I know that protecting many different living creatures is needed</td>
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<td>for sustainability.</td>
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<td>I know that sustainability requires that we switch to using renewable</td>
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<td>resources (like wind power and solar energy).</td>
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<td>I know that solving conflicts by talking peacefully is needed for</td>
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<td>sustainability.</td>
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<td>I know that respecting human rights is needed for sustainability.</td>
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<td>I know that all people must be able to get a good education so the world</td>
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<td>can be sustainable.</td>
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<td>I know that to be sustainable, businesses must treat workers,</td>
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<td>customers, and suppliers fairly.</td>
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<td>I know that people need to know how the economy works to be</td>
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<td>sustainable.</td>
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<td>I know that ending poverty in the world is needed for sustainability.</td>
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Attitude Items

5. Part 2 - You can mark your choice on a scale from "1 - Strongly Disagree" to "5 - Strongly Agree". If you do not agree nor disagree, then choose #3. If you do not know how to respond to the statement, then choose "Don't Know". *

1 = Strongly Disagree  5 = Strongly Agree
Mark only one oval per row.

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<tr>
<td>I think that using more natural resources than we need does NOT threaten the well-being of people in the future.</td>
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<td>I think that we need more strict rules to protect the environment.</td>
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<td>I think that harming one part of an ecosystem can harm other parts as well.</td>
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<td>I think that we need to make sure people in the future have the same quality of life as we do now.</td>
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<td>I think that everyone should be given the chance to solve sustainability problems.</td>
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<td>I think that women and men in the world must be given the same chances for education and employment.</td>
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<td>I think businesses should use less packaging and sell more reusable things.</td>
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<td>I think that there is a difference between needs and wants.</td>
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<td>I think that workers in rich countries and poor countries should work in safe conditions.</td>
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### Behavior Items

6. Part 3 - You can mark your choice on a scale from "1 - Strongly Disagree" to "5 - Strongly Agree". If you do not agree nor disagree, then choose #3. If you do not know how to respond to the statement, then choose "Don't Know".

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<tr>
<td>I recycle as much as I can.</td>
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<td>I always separate food waste before throwing things out when I have a chance.</td>
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<td>I do things to lower waste (e.g. throw away less food or use less paper).</td>
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<td>I treat people with respect when I work and talk with them, no matter their cultural background or who they are.</td>
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<td>I listen to other people’s ideas, so we can come up with the best solutions.</td>
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<td>I often make lifestyle choices which are NOT good for my health.</td>
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<td>I do things to help people in need.</td>
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<td>I encourage my family to buy second-hand things in a shop or on the internet.</td>
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<td>I encourage my family to avoid buying things from businesses who mistreat workers and harm the environment.</td>
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