THE EFFECTS OF PROJECT BASED LEARNING ON STUDENT OUTCOMES IN A GEOEMTRY CLASSROOM

by

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ABSTRACT

Students engaged in Project Based Learning as a way to deepen and apply their knowledge of trigonometry, improve their perceptions of the content, connect with the world around them, and engage in practices commonly utilized in science and engineering. The project was centered around the re-design and relocation of a historic barn on the campus of Kimball Union Academy in Meriden, NH, and students were asked to consider how the barn might be modernized to include passive and active solar technologies. Pre- and post- intervention content assessments, Likert surveys, student worksheets, and written reflections were used as data collection instruments. Data were processed using both quantitative and qualitative analysis strategies. The results suggested that students made gains in their subject-matter proficiency, attitude toward math, ability to make connections, and engagement with applicable science and engineering practices.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

I teach math at Kimball Union Academy. (KUA), an independent boarding school in Meriden, NH. The school is composed of grades 6-12, with a student body of approximately 340 students and an average class size of 11. KUA is a college preparatory school, and as such, our students come from a wide variety of middle and elementary schools throughout the state, nation, and world. They are diverse in their interests, aptitudes, and backgrounds—hailing from 22 different countries during the 2021-2022 school year (Kimball Union Academy, 2021).

KUA is continually working to adapt its educational practices to meet the needs of its student body, and in the summer of 2021, the mission statement of the school was reframed to prioritize “intentionally designed” educational experiences with the stated goal of developing a deep sense of belonging for all students (T. Lewis, personal communication, August 2021). In addition, an educational framework called KUA Design was developed that invites teachers to design their lessons in such a way that historically lower achieving students are equally engaged as their higher achieving counterparts. This is referred to as “teaching to the margins,” and teachers are continually given support and tools so that they can be successful in this aim. Project Based Learning (PBL) has been presented as one such tool that teachers might consider as they work to provide appropriate challenge for all students, since it has been well documented that thoughtfully designed and carefully implemented PBL encourages collaboration, improves problem solving ability, promotes curiosity, and empowers students to expand their learning beyond the walls of the classroom (The Buck Institute for Education, 2021). With this in mind, more of the faculty at KUA, including those in the math department, have begun to pivot their instructional methods to include PBL and other teaching pedagogies that foster connection, engagement, and belonging.

The geometry class at KUA has been passed from teacher to teacher quite a bit in recent years, with me being the most recent person tasked with shaping a curriculum that meets the learning needs of our students. Though I had used projects in my math classrooms before, I had never really been fully satisfied with the outcomes. It seemed like the learning that was occurring was limited in scope and that I was not as successful as I could be in engaging students' curiosity. So, when I joined KUA as a new faculty member in the Fall of 2021, a fresh start meant another chance to design a comprehensive, meaningful, and rigorous PBL experience for my geometry students. The architectural design process provides rich fodder when it comes to applying geometric concepts such as area, volume, scale, and trigonometry. Since several building projects were already underway at KUA, I reached out to our Chief Operations Officer to brainstorm potential ways to engage students in the reimagining of facilities on KUA's campus.

The Kimball Barn is a small building on KUA property purported to be one of the oldest buildings in Meriden, NH (T. Lewis, personal communication, November 2021) (Figure 1). Though the barn is of historical importance, it's location in the Fall of 2021 was not compatible with the plans to construct a new quad on campus, and thus a new home for the barn was needed. It was decided that the barn would be moved down to the athletic fields and that it would be reimagined to serve as a locker room space for visiting teams. Though a general site plan had been made, many of the details for the interior of the barn, solar panel array, and heating/cooling systems had not yet been finalized. This seemed like a perfect opportunity for my geometry students to apply and deepen their geometry skills, and so I set to work creating a PBL experience that I hoped would suit the needs of my students, leave a positive mark on the Academy, and serve as the culminating learning experience for my geometry class.

Figure 1. Images of the exterior (left) and interior (right) of Kimball Barn as it stood on the KUA campus in December 2021 shortly before deconstruction began.

Focus Statement/ Question

My focus question was, What are the effects of PBL on student outcomes in a geometry classroom?

My sub-questions include the following:

1. What is the impact of PBL on students' attitude toward math and their ability to make connections to their own lives?
2. What is the impact of PBL on students' subject-matter proficiency?
3. Can PBL serve as an effective tool for developing students' ability to engage with and utilize applicable Science and Engineering Practices (SEPs)?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Overview and History

The idea of "learning by doing" is not new, and over the years, Project Based Learning (PBL) is one approach within this broader educational philosophy that has proven to be effective (Thomas, 2000). Prominent educational philosopher John Dewey touted the benefits of experiential learning nearly a century ago in his book *Experience in Education* (Dewey, 1938). However, as Dewey and others have cautioned, not all experiential educational experiences are equally valuable. In fact, some may even suppress or hamper learning (Dewey, 1938; Kanter, 2010). Kilpatrick (1918) suggested that projects could be used to weave experiential learning into curricula, while also improving student performance in key areas. It has since been well documented that students engaged in intentionally designed PBL have increased basic academic subject proficiency (Boaler, 1999; Geier et al., 2008; Kanter, 2010; Schneider et al., 2002), critical thinking, creativity, and comfort collaborating with others as compared to their traditionally educated peers (Boaler, 1999; Thomas, 2000). Built on the foundation laid by educational scholars such as Dewey and Kilpatrick, contemporary PBL is an approach that uses classroom projects to foster deep, relevant, and long-lasting learning (Thomas, 2000).

PBL, when properly executed, is a student-driven way to navigate the learning process. Through PBL, teachers serve as facilitators while their students develop driving questions that spark their curiosity, pursue knowledge needed to answer their questions, and illustrate their discoveries by creating projects to share with an audience (Bell, 2010; Larmer & Mergendoller, 2010; Thomas, 2000). Students engage with issues and questions that are, and will continue to be, relevant to their lives while also building skills that will prepare them for post-secondary education, the workplace, and their roles as global citizens (Thomas, 2000). Over the past few decades, scholars have suggested that there are a few hallmarks of quality PBL that teachers should consider as they design projects for their classrooms (Bell, 2010; Larmer & Mergendoller, 2010; Thomas, 2000). Though many variations of this list exist (Thomas, 2000), indicators of meaningful PBL may include (a) a genuine desire to understand, (b) a key question that helps to focus the inquiry, (c) student input as to how and what they will learn, (d) integration of real-world skills, (e) innovation and the creation of new knowledge, (f) individualized feedback and a rigorous revision process, and (g) a final product presented to an invested audience (Larmer & Mergendoller, 2010). In designing "Gold Standard" PBL experiences for their students, teachers may intentionally build projects that incorporate each of these indicators (Larmer & Mergendoller, 2010). For most classroom teachers, however, simply choosing to improve an existing project by uplifting one or more of these indicators can be a good place to start and may significantly improve the student experience.

Impacts of PBL

Student attitudes and emotions have been shown to significantly impact their ability to comprehend new mathematical concepts (Evans, 2006). As such, when considering a new teaching strategy like PBL, it is important to understand how that method might impact student perceptions and openness to the subject-matter. In one study, high school math students in Great Britain who were exposed to a Project-Based curriculum were more likely to be able to adapt what they had learned to fit new situations and problems and consider what they were learning to be useful and applicable in the world around them (Boaler, 1999). Students engaged in PBL have also been shown to demonstrate increased enthusiasm, engagement, and interest as compared to their traditionally educated peers. In a 2006 study exploring the feasibility and outcomes of PBL in a 12th grade classroom, for example, 18 of the 20 students in the study reported that they liked learning through PBL. Their reasons for liking PBL ranged from relishing the opportunity to be engaged in active learning to being part of a different type of learning experience (Goodnough & Cashion, 2006). These studies offer valuable evidence that PBL can have a positive impact on student attitudes toward the subject matter, which is an important consideration given that without a positive and constructive mindset, there is little likelihood of meaningful learning (Evans, 2006).

And so, with PBL shown to positively impact student perceptions and outlooks, the natural next question must be "How does PBL improve student mastery of the subject-matter?" Several studies have shown that well-designed and thoughtfully implemented PBL units reward teachers by generating meaningful gains in learning (Boaler, 1998; Geier et al., 2008; Kanter, 2010; Schneider et. al., 2002). Various standardized tests are designed to measure mathematics proficiency, and in one study by Holmes and Hwang (2016), eighth and ninth grade students engaged in PBL in their math classrooms showed roughly equal mastery of mathematics content as their non-PBL counterparts at another school as suggested by their performance on a state-adopted standardized math exam. Perhaps more interestingly, however, the scores of the students engaged in PBL showed smaller variance than those of students at the non-PBL school, suggesting that the PBL students were brought along together in their learning regardless of race or other socioeconomic factors (Holmes & Hwang, 2016). Some studies have gone even further to suggest that students who learn math in PBL centered, rather than lecture-based, math classrooms make bigger strides in both their conceptual and procedural knowledge as compared to their more traditionally educated counterparts (Boaler, 1998).

In recent years, it has become increasingly popular to create interdisciplinary learning opportunities for students, particularly in the science, technology, engineering, and mathematics fields (STEM) (Li et. al., 2020). Studies suggest that such educational experiences better prepare student to function in the modern workplace where a diverse array of skills and knowledge may be required on a daily basis (Wan Husin et al., 2016). As such, the National Science Teaching Association (NSTA) has put forth a set of Science and Engineering Practices (SEPs) that describe behaviors that scientists and engineers engage in as they investigate problems, construct models, and design solutions so that teachers can integrate these practices into their daily instruction (National Science Teaching Association, 2014). Because a strong foundation in mathematics is critical to success in STEM in school and beyond, it may be of interest to mathematics teachers considering Project Based Learning to better understand the impact of PBL on students' ability to engage with and utilize applicable SEPs. Though studies have suggested that PBL can bolster gains in skills such as critical thinking, creativity, collaboration, communication, information literacy, and flexibility (all of which are central to the NGSS SEPs) (Boaler, 1999; Thomas, 2000), there has not been much research done that explicitly examines the impact of PBL on student fluency with the NGSS SEPs. That said, this has been identified as an area ripe for further investigation (Miller et al., 2019).

Implementation of PBL

In designing PBL experiences for their students, it is imperative that teachers consider how they will scaffold the process to foster meaningful gains in student development. All too often, teachers unfamiliar with best practices in PBL conflate a high-quality final product such as a poster or PowerPoint presentation with impactful learning. In fact, the knowledge gained and real-world skills developed through such a project might be minimal or non-existent (Kanter, 2010; Larmer & Mergendoller, 2010). As educators hoping to avoid such pitfalls consider, design, and implement PBL in their classrooms, there are a few areas that require particular focus. It is crucial to (a) support students as they transform into active critical thinkers, (b) guide learners in developing effective group management strategies, (c) scaffold inquiry for those unfamiliar with the process, and (d) provide adequate feedback throughout the PBL experience (Barron et al., 1998; Krajcik et al., 1994; Larmer & Mergendoller, 2010; Ngeow and Kong, 2001). Without attention to these areas, learning outcomes may fall short of teacher hopes and expectations. Because designing learning experiences that adequately address student needs in each of these areas is not an easy or straightforward task, it has been suggested that teachers who are planning to incorporate PBL into their curriculums are most successful when they have the support of their administration and significant professional development focused on designing PBL experiences for their students (Krajcik et al., 1994). Such investments on the front end are sure to pay off as students benefit from thoughtfully created and well implemented PBL initiatives.

CHAPTER THREE

METHODOLOGY

Demographics

The purpose of this study was to determine the effects of Project Based Learning (PBL) on learning outcomes in a geometry classroom at Kimball Union Academy (KUA), a mid-sized private boarding school in Meriden, New Hampshire. The student body at KUA is comprised of approximately 340 students who come from a wide range of backgrounds and geographic locations around the world (kua.org). Traditionally, our geometry curriculum culminates with the application of students' geometry skillsets, honed throughout the course, to the study of trigonometry, area, and volume. Concepts related to trigonometry, area, and volume can be readily related to architecture and design, and the school was interested to involve students in several architectural projects currently underway, so it seemed natural to deploy PBL during this unit of study.

My project was conducted in an honors geometry classroom (N=12). Though the students in that class came from a wide variety of geographical and educational backgrounds, they were without exception bright, curious, and eager to apply their knowledge in ways that engaged their creativity and critical thinking. Seven of the students in the class identified as female and five identified as male, two students had diagnosed learning differences and received educational accommodations for those differences, and one student came from Shanghai, China and spoke English as their second language. The class was comprised mostly of ninth graders, with three tenth graders and one twelfth grader. From the outset of my project planning process, I was excited to carry out my research with this diverse, well-rounded, and engaged group of students.

Intervention

My focus questions for this investigation were: (1) What is the impact of PBL on students' attitude toward math and the ability to make connections to their own lives? (2) What is the impact of PBL on students' subject-matter proficiency? Finally, (3) Can PBL serve as an effective tool for developing students' ability to engage with and utilize applicable Science and Engineering Practices (SEPs)? To collect data that would help me address these questions, I documented student learning and progress through Pre- and Post- Intervention Likert Surveys and Content Assessments, as well as through Student Worksheets and Post- Intervention Reflections. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

This architectural design project served as the culminating experience in my semester-long honors geometry class in lieu of the usual final exam. In the weeks leading up to the project, students were exposed to the basics of various geometric principles including points, lines, and planes; area and volume; parallel and perpendicular lines; congruence and similarity; and trigonometry. The project was conducted in the final three weeks of the course which fell immediately after the holiday break—we had ten 75-minute instructional periods to dedicate to this exploration.

Up until the project, my students and I had spent much of our class time engaged in a predictable pattern of student-led conversation about independent practice problems, brief blocks of direct instruction about new topics, and collaborative problem-solving sessions to cement new learning. Each unit culminated in a traditional quiz-based assessment of relevant skills, and then we moved on to new content and the familiar cycle was repeated once more. Though this style of learning worked well for the students in my class, as indicated on numerous surveys throughout the semester, by the time the holiday break came around students and teacher alike were ready to apply our learning in new ways and to experience a change of pace.

Upon returning to campus after the break, the students completed both a Pre- Intervention Likert Survey (Appendix B), and a Pre-Intervention Content Assessment (Appendix C). These pre-treatment instruments were used to understand their baseline knowledge of concepts such as trigonometry, area, and volume as well as their attitudes toward math and the ability to make connections to their daily lives.

After the students had completed the Likert Survey and the Content Assessment, we began an on-campus architectural design project by engaging with two guests. One of the guests was the school's Chief Operations Officer (an architect by training) and the other was a Project Manager at Norwich Solar Technologies, a local solar installation company. The guests shared a bit about their dream of moving, restoring, and eventually revisioning, a small barn on KUA property purported to be the oldest building in Meriden, NH. They described that the barn was slated to be disassembled and relocated in the coming weeks (Figure 2), and though the new site and purpose had been identified, many details such as the final interior layout, solar array compatibility, and heating/cooling needs had not yet been ironed out. Project constraints such as budget, size, location, timeline, and architectural preferences were shared with the class, and before the panel departed, students were given the opportunity to ask clarifying questions about the goals, scope, and specifics of the proposed project.

Figure 2. Images of the Kimball Barn during the deconstruction process.

Over the course of the next two-and-a-half weeks, students worked together in small groups to collect and analyze data in order to research sustainable building and architectural principles, experiment with the mathematics needed to properly align a solar panel array, and finally, generate a proposed site plan and interior layout for the barn based on their newfound knowledge. The project culminated when the students presented their proposals for feedback to Ms. Julie Haskell (Dean of Faculty at KUA), Mr. Donoghue (Norwich Solar Technologies), and Mr. Hunter Ulf (COO at KUA) (Figure 3). My hope was that this project would provide students with a meaningful educational experience while solidifying their grasp on the mathematical concepts covered over the semester and deepening their connection to place and community.

Figure 3. Students engaging with the panelists (left) and writing thank you notes to their guests (right).

Data Collection and Analysis Strategies

Data Collection Methods

Throughout the process, students documented their learning through Student Worksheets (Appendix D), and once the proposals were presented to a panel for feedback, we wrapped up with a Post-Intervention Likert Survey and Content Assessment, which were the same as the pre-treatment instruments. Finally, all students completed a Written Reflection (Appendix E). The data collection instruments and focus questions are organized below (Table 1).

Table 1. Data Triangulation Matrix.

	Focus Questions		
Data Collection Instruments	What is the impact of PBL on students' attitude toward math and their ability to make connections to their own lives?	What is the impact of PBL on students' subject-matter proficiency?	Can PBL serve as an effective tool for developing students' ability to engage with and utilize applicable SEPs?
Pre- and Post-Intervention Likert Survey	X		X
Pre- and Post-Intervention Content Assessment		X	
Student Worksheets	X	X	X
Written Reflection	X	X	X

Pre- and Post-Intervention Likert Survey. Likert surveys are a commonly used tool in qualitative social sciences research. They are particularly common in educational research and can offer important insight into student thinking, experience, and conceptual patterns. In the original Likert scale, participants are asked to show their level of agreement (usually from *strongly disagree* to *strongly agree* on a 5-point scale that includes a neutral option) with the list of statements (items) (Joshi et al., 2015). A Likert survey is a suitable way to measure student attitudes in my Action Research study because it is a methodology well aligned with my goal to better understand the attitudes, perceptions, thoughts, and experiences of my students (Horst et al., 2018).

A Pre- and Post-Intervention Likert survey (Appendix B) was given twice, once before the intervention and once after the intervention had concluded. The goals of this instrument were twofold. First, I wanted to establish a baseline understanding of my students' attitudes toward math, their ability to make connections to their own lives, and confidence with select Science and Engineering Practices (SEPs). Second, I sought to understand any changes in these areas that may have occurred over the course of the PBL unit.

Pre- and Post-Intervention Content Assessment. Though it is widely accepted among educational researchers that the traditional assessment model of teach then test is imperfect and perhaps outdated, tests designed to evaluate student understanding of the content or material covered during a unit of study are incredibly common in many educational settings (Fook & Sidhu, 2010). Though one could argue that to be as objective as possible in my data collection and analysis, I should have included only questions that had clear and unique answers on my Pre- and Post-Intervention Assessments, this would have been a major departure from the style of many of the tests and quizzes that I usually gave my students. For this reason, I felt that it was more important to utilize an assessment that was consistent with my usual teaching methods, even if that allowed for a wide range of student expression, than to generate the type of perfectly objective data that could result from a more standard multiple-choice assessment.

The Pre- and Post- Intervention Content Assessment (Appendix C) was given twice, once before the intervention and once after the intervention had concluded. I wanted to establish a baseline understanding of my students' subject-matter proficiency with geometric concepts such as trigonometry, area, and volume. I also hoped that by administering the assessment before and after the intervention, I might gain an understanding of how my students' subject-matter proficiency changed over the course of the PBL unit.

Student Worksheets. Journals have been used to provide insight into student learning in many educational studies (Bagley & Gallenberger, 1992). In mathematics classrooms specifically, they have also proven to be important tools to improve student attitudes and self-perceptions related to the subject matter (Bagley & Gallenberger, 1992; Page & Clark, 2014). Importantly, journaling has been noted to be a particularly fruitful way to gauge student learning and engagement in PBL (Dunlap, 2006).

Throughout the intervention, learning and processes were documented in Student Worksheets that were meant to serve as a proxy for the journals that have proven to be so worthwhile in previous PBL research (Appendix D). The Student Worksheets were collected daily, reviewed, and used as a springboard for conversation and direction throughout the intervention. I had three goals in mind when I used this instrument. First, I wanted to gather data that would better help me understand students' progress in their ability to engage with applicable SEPs. The SEPs I focused on were: (1) developing and using models, (2) using mathematics and quantitative thinking, (3) constructing explanations and designing solutions, and (4) obtaining, evaluating, and communicating information (National Science Teaching Association, 2014). Second, I hoped to document students' changing attitudes toward math and their ability to make connections to their own lives. Third, by including periodic checks for understanding with the applicable trigonometry, area, and volume content, I was able to give students frequent feedback on their subject-matter proficiency.

Written Reflection. Qualitative research involving interviews or written reflection is usually driven by the goal of better understanding how individuals interact with and make meaning of their world (Merriam, 2002). Collecting and analyzing qualitative data generated from student interviews or written reflections gives researchers perspective as to *how* and *why* the scores improved by giving those who are studied a chance to speak for themselves (Sherman & Webb, 2005). Though the data generated from written reflections or interviews may be more open-ended, broader, and more holistic than data collected through other research instruments, their value is undeniable in anthropological, sociological, medical, and educational settings because of their ability to help researchers contextualize and interpret their research settings (Merriam, 2002).

Upon the culmination of the intervention, students were invited to share their impressions of the intervention through a Written Reflection (Appendix E). In implementing this instrument, I had several goals in mind. I sought to better understand students' post-intervention attitudes toward mathematics, their ability to make connections to their own lives, their subject matter proficiency (or at least receptivity to and general comfort with trigonometry, area, and volume), and their ability to engage with and utilize SEPs.

Analysis Strategies

Addressing my research questions required analysis of both qualitative and quantitative data. Quantitative research involves systematic investigation through the collection and analysis of numerical data (Coghlan & Brydon-Miller, 2014). In conjunction with qualitative research, quantitative research is frequently utilized as part of educational research designs because (a) results from a variety of individuals can be summarized and used to develop a single explanatory model, (b) statistical analysis, though not free of subjectivity, is typically independent of the researchers personal beliefs and biases, and (c) since validity and reliability are strictly defined within widely recognized statistical parameters, limited training is required to collect and analyze basic quantitative data sets (Libarkin & Kurdziel, 2002). In this study, I compared Pre- and Post-Intervention Content Assessment scores using mean as a measure of central tendency and examined variability by calculating standard deviation for both data sets. Analyzing the dataset for normalized gains (Hake, 1998), gave me additional insight as to whether measurable learning had occurred because of my experiment.

In addition to the quantitative data generated from the Pre- and Post- Intervention Content Assessment, qualitative data was generated from the Pre- and Post- Intervention Likert Surveys, Student Worksheets, and Written Reflections. Questions on my Likert surveys were scaled (*strongly disagree, disagree, neither agree nor disagree, agree, strongly agree*) stand-alone (not related to each other and thus not analyzed together) items, so I used analysis methods such as modes and frequencies to understand trends in the data set. Qualitative data generated from the Student Worksheets, such as quotes and examples of student work, was used to inform the scope, direction, and pacing of the intervention. Data generated from the Written Reflections was "binned" based on key words, analyzed for themes, and then used as evidence to support other findings (Williams, 2012).

CHAPTER FOUR

DATA AND ANALYSIS

Impact of PBL on Students' Subject-Matter Proficiency

The Pre- and Post- Intervention contentment assessments assessed proficiency in three areas: ability to use the properties of special right triangles, find trigonometric ratios using right triangles, and use trigonometric ratios to find angle measures in right triangles. The results indicated that the average percent increase in learning in each of those areas from before the Project Based Learning (PBL) unit to after was 23.3%, 22.5%, and 27.5% (*N*=12). Overall average gains from the pre to the post assessment were 24.4%. Though the median score increased 26.7 percentage points between the two assessments, it is also interesting to note that the score distribution tightened slightly from the first assessment to the second, with the standard deviation decreasing from 7 to 6.4 percentage points from the Pre- to the Post- Intervention Assessment. With outliers considered, however, this trend is no longer apparent, as can be seen below (Figure 4).

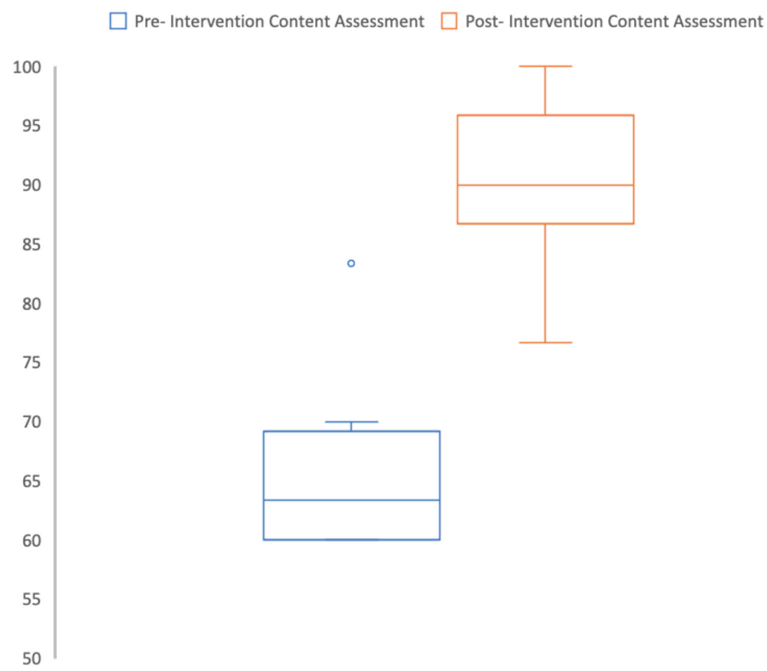


Figure 4. Score distributions of the Pre- and Post- Intervention Content Assessment, (*N*=12).

To gain further insight into the change in these assessment scores, normalized gains were calculated. The average normalized gain for the assessment was 38%, meaning that on average, the intervention caused the students to understand 38% more of that which they did not originally understand about trigonometry and right triangles at the outset of the PBL exploration. According to Hake (1998), this corresponds to medium percent learning gains.

Normalized gains were also calculated for each of the three content areas. Students gained the most knowledge about the use of trigonometric ratios to find angle measurements in right triangles (45% normalized gain), but their knowledge gains in the use of properties of right triangles and finding trigonometric ratios using right triangles followed closely behind (35% and 37% normalized gains, respectively). These learning gains were also reflected in the Post-Intervention Survey. As one student shared, “I learned mostly how to use trigonometry to find the angles of the sun and side lengths of triangles.” Another student added “This project helped me learn the most about trigonometry because I used it all the time to find lengths and measurements. Especially the tree heights and the passive solar overhang!" Based on the data generated from the Pre- and Post- Intervention Content Assessments, as well as the Post-Intervention Survey, it is clear that students made real progress in their knowledge of the mathematics fundamental to the project.

Impact of PBL on Students' Attitude Toward Math and Ability to Make Connections

In addition to assessing changes in student proficiency with the relevant subject matter, it was also important to me to understand how the students' abilities to make connections to their own lives were impacted by the PBL intervention. The results of the Post-Intervention Survey indicated a strong sense among the students that the project brought trigonometry to life. When asked "How did the Kimball Barn Project help you to learn about area, volume, and trigonometry?" all the students surveyed were able to outline specific applications for these mathematical concepts in the real-world. One student shared that "In addition to reviewing and practicing these skills, applying our knowledge in making our calculations and seeing the impact that this had was inspiring and helped in solidifying my understanding of the subject and its applications." Another student added that "This project helped me understand how to use trigonometry in the real world—it made a lot more sense when it corresponded to something tangible." The student quotes shared in the Post- Intervention Survey seemed to make a clear case for gains in student appreciation for the importance and applicability of trigonometry.

This trend- gains in students' ability to make real-world connections- was also seen in the data generated from the Pre- and Post- Intervention Likert survey. Five questions on the Likert survey addressed real-world applications of the subject matter, and the results of these questions are depicted graphically below (Figure 5). Pre- intervention responses are shown to the left of post- intervention responses for each question, and results are organized by the percent of responses for each response: *strongly disagree, disagree, neutral, agree,* and *strongly agree*. As can be determined from the charts, a few marked shifts in the student responses from the Pre- to Post- Intervention Likert Surveys were realized. For example, more students *agreed* or *strongly agreed* with the statements on the survey after the intervention (n=61) as compared to before the intervention (n=54). These trends generally support the findings from the Post- Intervention Survey: the PBL intervention resulted in gains in students' ability to make connections between the subject matter and the world around them.

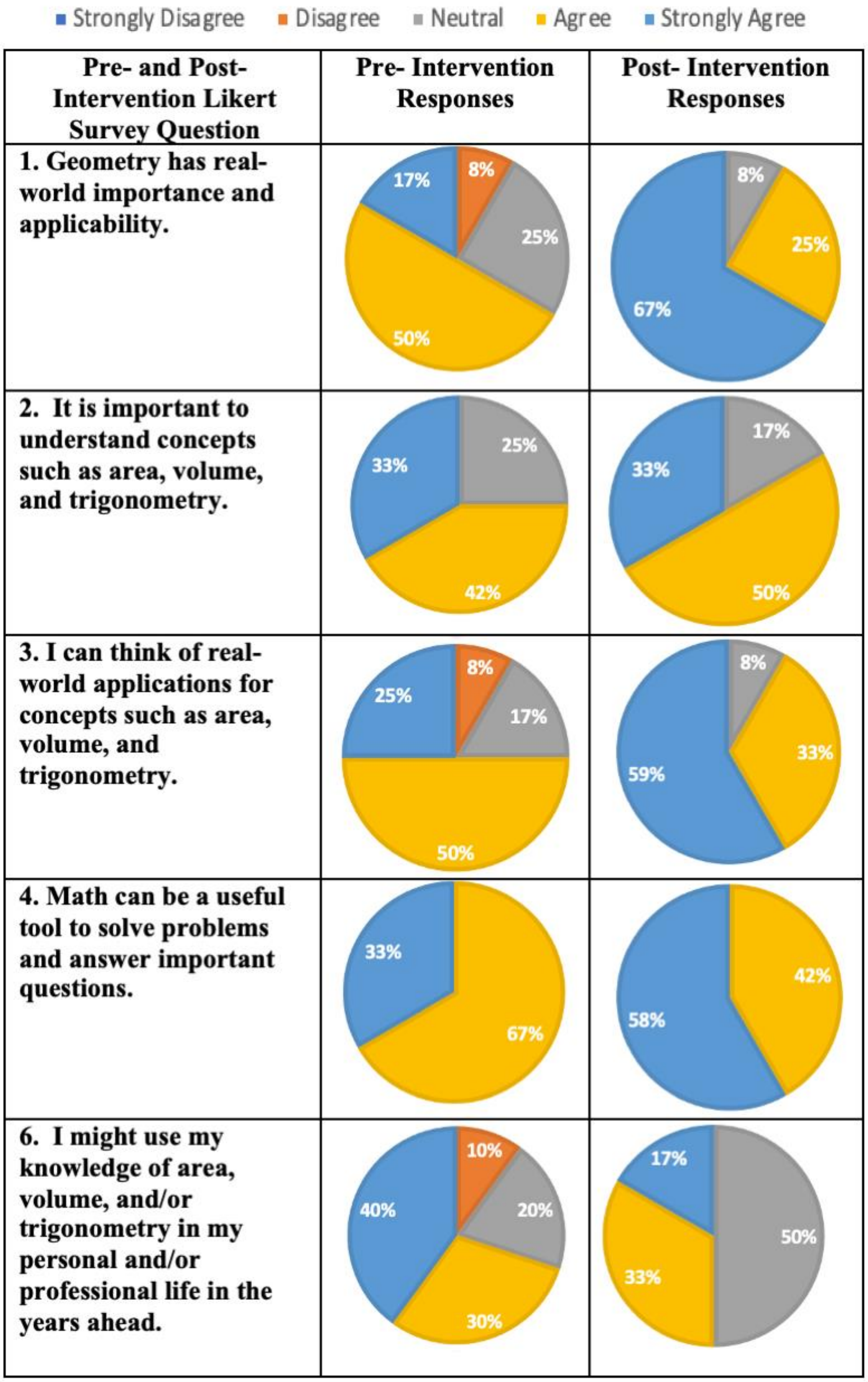


Figure 5. Results of the Pre- and Post-Intervention Likert Survey questions 1-4 and 6, (*N=12)*.

In addition to indicating a positive effect on students' ability to forge connections between the content and the world around them, the Post- Intervention Survey also suggested that there was a positive impact on students' attitude toward mathematics. When asked "Overall, would you rate your experience with the project as positive or negative?" all the students but one rated their experience as positive. The one student who rated the experience as negative wrote "Meh. It was fun at some points, but bad at others. I think it would be better with a little more time." Notably, this student was quarantining due to COVID-19 for much of the project and was forced to join class remotely. Another student whose response was much more typical of the group wrote "Throughout this project, my overall experience was very positive. Working in groups to apply our knowledge to the real world changed my perspective of the importance of the material and the relevance that it has." Another student shared that the experience was "Positive—I think it was a good learning experience compared to sitting and taking an exam," while her peer wrote "I enjoyed finding real life uses for geometry and actually having an effect on others and the environment." Overall, based on the results of the Post- Intervention Survey, the PBL experience had a positive impact on students' attitudes toward math.

Though the student quotes generated from the post-intervention survey suggested that students had enjoyed the learning process and perceived their experience in a positive light, this trend was not as easy to pull out of the data generated from the Pre- and Post- Intervention Likert surveys. One question asked for students to respond to the statement "In general, I like math." The responses to this question are shown below (Figure 6). As with the previous chart, pre-intervention responses are shown to the left of post-intervention responses, and results are organized by the percent of responses for each response: *strongly disagree, disagree, neutral,* *agree, and strongly agree*. As can be seen in the charts, though indeed no students *disagreed* or *strongly disagreed* with the statement "In general, I like math" by the end of the intervention, the positive impact of the PBL experience on student perceptions of and attitudes toward mathematics was not as clearly conveyed in the Pre- and Post- Intervention Likert data as it was in the data generated by the Post- Intervention survey

■ Strongly Disagree ■ Disagree ■ Neutral ■ Agree ■ Strongly Agree

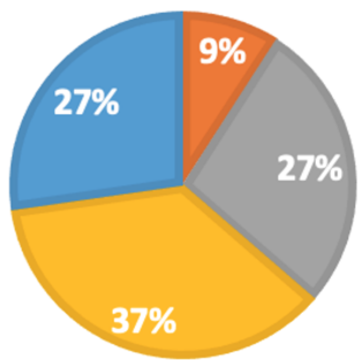
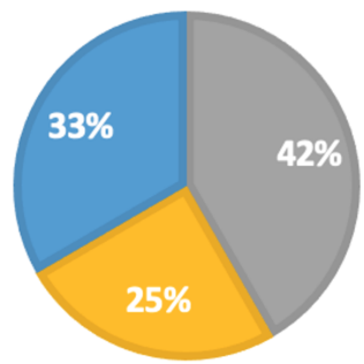
Pre- and Post- Intervention Likert Survey Question	**Pre- Intervention Responses**	**Post- Intervention Responses**
5. In general, I like math.		

Figure 6. Results of the Pre- and Post-Intervention Likert Survey question 5, (*N=12).*

<u>Impact of PBL on Students' Ability to Engage with and Utilize Applicable Science and Engineering Practices</u>

I was also interested to learn how Project Based Learning impacted student understanding of and ability to engage with applicable Science and Engineering Practices (SEPs). As part of the Post- Intervention Survey, students were asked in which area they felt they had made the most progress and the least progress. They chose between (a) developing and using models, (b) using mathematics and quantitative thinking, (c) constructing explanations and designing solutions, and (d) obtaining, evaluating, and communicating information, all of which were SEPs that I identified as relevant to the project before the outset of the intervention. Student responses to these questions are shown below in two pie charts, displayed side by side (Figure 7).

As can be seen from the pie charts above (Figure 7), students reported the most progress in (a) using mathematics and quantitative thinking and (b) constructing explanations and designing solutions (20.8% of the responses fell to both options). In addition to choosing between the list of SEPs to indicate their progress, students also shared their thoughts on their growth in writing. For example, one student described that "I made the most progress with my quantitative thinking. I didn't know how to do anything like this before this project." Another student shared that "I got a lot better at constructing explanations and designing solutions because of the written question practice. Writing made me display an increased understanding." Overall, the results of the Post- Intervention Survey indicated that students made positive gains in their abilities to use mathematics, think quantitatively, construct explanations, and design solutions.

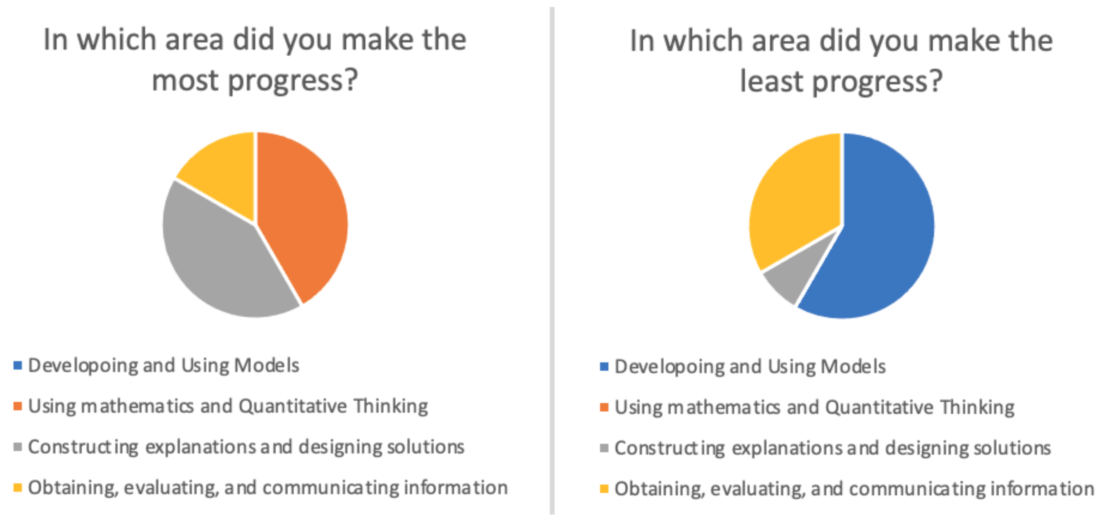


Figure 7. Results of the Post- Intervention Survey question "In which area did you make the most progress? The least progress?", (*N*=12).

A strong trend was seen in responses to the Post- Intervention Survey question "In which area did you make the least progress?" Overwhelmingly, students described that they had made the least progress in their abilities to develop and utilize models (58.3% of responses were in this category). When asked to justify their response, several students commented about their lack of progress with modeling. As one student wrote, "I did more looking at the models rather than making them." Another student added, "I really don't think my ability to use models changed. I didn't do much or progress in this area." Yet another student elaborated that "modeling was not super applicable to my group's part of the final presentation."

While the data generated from the Post- Intervention Survey was informative and displayed clear trends regarding students' perceptions of their progress with SEPs, this was not the case with the Likert data. As can be seen in the series of pie charts below (Figure 8), with pre-intervention responses shown to the left of post-intervention responses and results organized by the percent of responses for each response, most students *agreed* or *strongly agreed* with the statements regarding their comfort with SEPs both before and after the intervention. Thus, no discernable trend in student engagement with SEPs could be determined.

■ Strongly Disagree ■ Disagree ■ Neutral ■ Agree ■ Strongly Agree

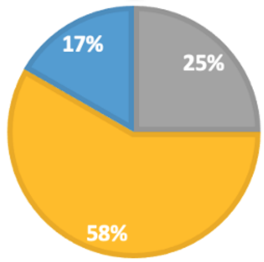
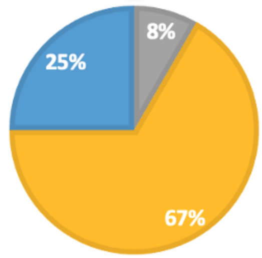
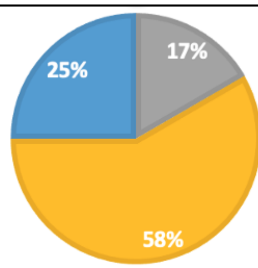
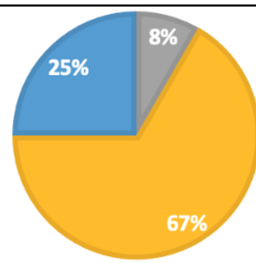
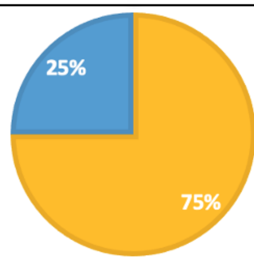
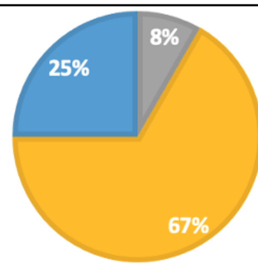
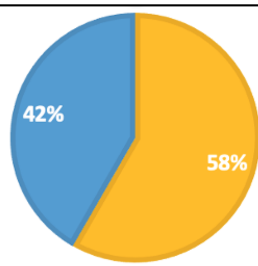
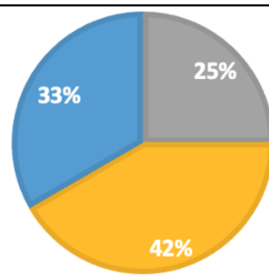
Pre- and Post-Intervention Likert Survey Question	Pre- Intervention Responses	Post- Intervention Responses
7. I can develop and use models to solve problems.		
8. I can use mathematics and think use numbers to reason about situations.		
9. I can use mathematics to construct explain things and solve problems.		
10. I can obtain, evaluate, and communicate information related to mathematics.		

Figure 8. Results of the Pre- and Post-Intervention Likert Survey questions 7-10 regarding student ability to utilize and engage with applicable SEPs, (*N=12).*

CHAPTER FIVE

CLAIMS, EVIDENCE, AND REASONING

Claims From the Study

There are three main claims that can be made regarding the findings from this study including that (a) Project-Based Learning (PBL) has a positive effect on students' subject-matter proficiency, (b) PBL has potential to improve students' attitudes and ability to make connections to their own lives, and (c) PBL can serve as an effective tool for developing students' ability to engage with and utilize applicable Science and Engineering Practices (SEPs) in the math classroom. As discussed below, each of these claims is well-supported by the data collected in this study, is consistent with the findings of other researchers, offers valuable insights to me as an educator, and will change the way I approach my courses in the future.

Subject-Matter Proficiency

The normalized gains in learning, as evidenced by the Pre- and Post-Intervention Content Assessments, suggested medium gains in all three content areas assessed. Additionally, in the reflections shared as part of the Post-Intervention Survey, the students described specific areas in which their knowledge had improved over the course of the study. My interpretation of these data is that they paint a compelling picture of student learning gains.

Value of the Study and Consideration for Future Research. Many studies have suggested that well-designed and thoughtfully implemented PBL units reward teachers by generating meaningful gains in discipline-specific learning as well as conceptual understanding—sometimes even more so than can be achieved in a more traditional classroom setting (Boaler, 1998; Geier et al., 2008; Kanter, 2010; Schneider et. al., 2002). Though I cannot compare my students' performance on my Post- Intervention Assessment to that of a more traditionally educated control group, I can attest that they mastered the material at a level similar to, or even above, what I would expect had we explored trigonometry in a more traditional classroom setting. While this may not be a ground-breaking contribution to the PBL research community, this finding did shift my own perceptions about the potential of PBL in geometry—which is a valuable impact in and of itself.

While overall, I was heartened with the consistent gains in learning over the course of this project, I am still not sure how deep and long-lasting the learning was. Questions that have surfaced, as a result of the findings that merit further exploration are: (1) If I were to readminister the same assessment three months later, would there still be evidence of learning? (2) Was student learning more durable as a result of PBL than it would have been had I taught the material in a more traditional way? Research does suggest that knowledge gained through Problem-Based Learning (a close cousin of Project Based Learning) is deeper and longer-lasting than learning achieved through lecture or other traditional methods (Beer & Bowden, 2005), but it would be interesting to know whether similar results can be obtained in high school geometry classrooms such as those at Kimball Union Academy.

Attitudes and Connections

The data generated from the Post- Intervention Survey showed that student attitudes were positively impacted by the intervention, with all but one student rating their overall experience as positive, rather than negative. Student quotes such as "I had a positive experience. I worked with people I like and it was challenging but not overwhelming. We learned a lot and pushed each other but had fun while we were doing it," are hard to ignore and speak volumes about the positive perceptions students held about PBL in the math classroom. Additionally, when asked to outline specific applications for the skills they had learned on the Post- Intervention Survey, all of the students were able to identify specific applications for, or connections to, the material learned throughout the PBL exploration. As one student put it, "This project showed me that math is more than just a school subject. Through the project I was able to understand more how you can use trig in real life." Overall, whether students connected their learning to passive solar architectural principles, solar panel installation considerations, to-scale architectural renderings, or construction site plans, it was clear that they knew how trigonometry could be applied to solve problems and appreciated how it could be used to answer questions in the world around them.

Value of the Study and Consideration for Future Research. Previous research has shown that students engaged with PBL are more likely to demonstrate increased enthusiasm, engagement, interest, and most importantly, consider what they were learning to be useful and applicable in the real-world (Boaler, 1999; Goodnough & Cashion, 2006). It has been well established that student attitudes and emotions significantly impact students' ability to comprehend new mathematical concepts (Evans, 2006), and studies have suggested that PBL can be a good tool to positively impact students in these areas (Goodnough & Cashion, 2006). My study supported this notion. Not only did my students report that they enjoyed learning through PBL, but they indicated that they would like to learn through PBL in their future coursework. As one student put it "Hands on experience teaches students better than sitting and taking a test. Plus they like it better." Another shared that "Other math teachers should do projects. It makes the end of the semester have much better memories and ties everything together." Based on what my students shared, especially in their Post- Intervention Surveys, I feel that one of the strongest findings of my study was that my students really appreciated and enjoyed the process of learning by doing in math class. For me, the photos I took of my students working during the PBL unit, tell a clear story of student engagement, motivation, and enthusiasm (Figure 9). Future study could examine the effects of incorporating small-scale PBL initiatives into the weekly or monthly plan in a Geometry classroom. So many of the topics in a traditional Geometry curriculum can be applied in the "real world," and based on my limited experience, these broader connections really helped to engage my students with the subject-matter and become more productive stewards of their own learning.

Figure 9. Photos of students taken over the course of the Project Based Learning experience.

Science and Engineering Practices

The data generated from the Post- Intervention Survey showed that students perceived gains in two main areas: using mathematics and quantitative thinking and constructing explanations and designing solutions. Student remarks such as “I didn’t know how to use math to do anything like this before this project” and “constructing explanations was tricky, but this helped me make progress” suggest progress and growth with these Science and Engineering

Practices. In my view, this indicates that PBL is an effective way to build student fluency with important skills that scientists and engineers use every day.

Value of the Study and Consideration for Future Research. Studies have suggested that PBL can bolster gains in skills such as critical thinking, creativity, collaboration, communication, information literacy, and flexibility (all of which are central to the NGSS SEPs) (Boaler, 1999; Thomas, 2000). Since there has not been much research done that explicitly examines the impact of PBL on student fluency with the NGSS SEPs specifically (Miller et al., 2019), my study does establish a valuable starting point for future research in this area, at least with regard to student perceptions of their gains in areas such as constructing explanations and designing solutions, using mathematics and quantitative thinking, and obtaining, evaluating, and communicating information. I can also say that as I watched them problem solve, collaborate, think creatively, and finally share their knowledge with the public I saw their SEPs being honed—my instincts as a teacher tell me that important knowledge was gained in these areas. That said, future study could better obtain clearer evidence of actual gains in these important skills. Where were the students at with their SEP skillsets before the PBL exploration? How could I have better quantified their progress? Both of these questions merit further exploration. Certainly, if a math curriculum were to engage regularly with PBL throughout the school year, it would be important to more rigorously measure student progress with SEPs.

Impact of Action Research on the Author

At the outset of my experiment, my main goal was to design a student experience that was rigorous enough to meet the demands of my curriculum while also encouraging students to explore, make connections, and engage with their curiosity about the world around them. Based on the evidence collected over the course of this experience, I feel strongly that this PBL exploration met those goals. And so, this study, in which I implemented a Project-Based Learning (PBL) unit in my Honors' Geometry classroom with the goal of deepening their appreciation for and understanding of mathematical concepts, impacted my teaching in several ways and will change the way I approach my planning in future years.

First, I am interested in continuing to find ways to build PBL experiences into my geometry curriculum that occur more frequently and on a smaller scale than this exploration. This exploration took nearly three weeks to complete and required a complete shift away from the day-to-day routines of my classroom. In the future, I might prefer to find smaller, but still authentic questions that my students can explore in the space of one or two class periods per unit of study. Not only would this add a level of dynamism to the entire curriculum rather than just one unit, but it would also likely foster a sense among the students that real-world applications exist for most of the mathematical topics we explore—not just trigonometry.

Second, I am interested in learning more about alternative assessment strategies in mathematics. Watching my students interact with the panelists as they presented their ideas for the new Kimball Barn was, hands down, the most rewarding teaching experience I have had to date. After watching their dress rehearsal and giving them quite a bit of feedback, I was very concerned that they would not rise to the occasion, but they did! The students came dressed to impress, had notecards to keep them on track, seamlessly transitioned from one presenter to the next, and shared their knowledge and proposal for the Kimball Barn with confidence and clarity. Even better, they were able to answer tough, probing, and varied questions asked by the panel, which suggested deep learning and knowledge of the subject matter. My challenge in assessing their final presentation came in assigning individual grades. Because so much of the work completed over the course of the project was collaborative, it was difficult to distinguish between the students, and so the whole class earned an “A” for their contributions. Were I to repeat this project, I’d like to find a way to more clearly differentiate between my students in how I assessed their learning. I did grade the students’ worksheets independently along the way, but in the future I could give them more time to work independently and more formally give them feedback on their work before allowing them to collaborate with their peers. This would give me a more complete picture of individual student learning, effort, and growth. Another way that I could better understand individual student progress would be to record the presentation, rewatch it later, and score each student independently on the content and delivery of their part of the presentation.

Third, I would be interested to explore professional development opportunities related to PBL in the math classroom. Developing my own project was extremely time consuming and stressful since I constantly needed to adjust to the needs of my students on a day-to-day basis while also juggling my other teaching assignments and duties. This workload would not be tenable for me long-term! I can imagine, however, that using projects developed by other educators and tweaking them to suit the needs of my students rather than building projects from scratch could be a much more sustainable way to incorporate PBL into my teaching on a more regular basis.

Overall, this was a rewarding experience that helped me to reflect on my identity and actions as a teacher. Though there would certainly be things I would change if I were to try something similar again in the future, the overall gains in student mastery of the subject-matter, perceptions of and attitudes about mathematics, and development of Science and Engineering Practices were enough to convince me of the value of PBL in the math classroom.

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APPENDICES

APPENDIX A

MONTANA STATE UNIVERSITY'S INSTITUTION REVIEW BOARD COMPLIANCE

Thank you for your application. This email acknowledges receipt of the request for IRB Review and serves as the Approval Letter for your research. Your new **IRB Exempt Protocol # is NR121421-EX**.

Study Title: **The effects of project base learning on student outcomes in a geometry classroom**

As the PI, it is your responsibility to facilitate subject understanding by informing subjects of all aspects of the project, providing an opportunity to ask questions, and describing risks and benefits of participation. Submit any new changes to the research protocol to the IRB via Amendment Form prior to implementing.

The research described in your submission is exempt from the requirement of additional review by the Institutional Review Board in accordance with 45 CFR 690.104(d). The specific paragraph which applies to your research is:

(1) Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

APPENDIX B

PRE- AND POST- INTERVENTION LIKERT SURVEY

Please answer the following questions. Data collected from this survey is anonymous, and participation in this research is voluntary. Participation or non-participation will not affect your grade or class standing in any way.

1. **Geometry has real-world importance and applicability.**
   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

2. **It is important to understand concepts such as area, volume, and trigonometry.**
   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

3. **I can think of real-world applications for concepts such as area, volume, and trigonometry.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

4. **Math can be a useful tool to solve problems and answer important questions.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

5. **In general, I like math.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

6. **I might use my knowledge of area, volume, and/or trigonometry in my personal and/or professional life in the years ahead.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

7. **I can develop and use models to solve problems.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

8. **I can use mathematics and numbers to reason about situations.**

   Strongly Agree Agree Neutral Disagree Disagree Strongly
   1……….…………….2…..…………3…………...…4……………..5

9. I can use mathematics to construct explain things and solve problems.

Strongly Agree   Agree   Neutral   Disagree   Disagree Strongly
1……….…………….2…..…………3…………...…4……………..5

10. I can obtain, evaluate, and communicate information related to mathematics.

Strongly Agree   Agree   Neutral   Disagree   Disagree Strongly
1……….…………….2…..…………3…………...…4……………..5

APPENDIX C

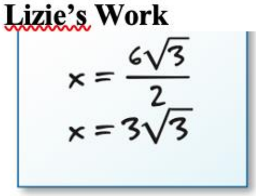
PRE- AND POST- INTERVENTION CONTENT ASSESSMENT

Geometry Honors Quiz 8.3-8.4
Ms. Lynd **Name ________________**

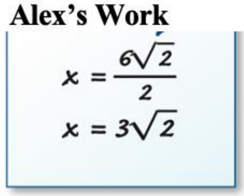
Directions: Remember to write neatly in pencil, show all your work so you can give you credit for your thinking, and clearly indicate your final answers (circle them if necessary).

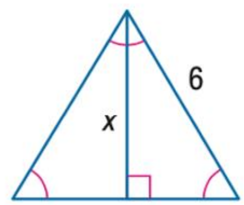
1. Alex and Lizie want to find x in the triangle shown. Is either of them correct? If one of them is wrong, what mistake do you think they made? Explain.

Lizie's Work

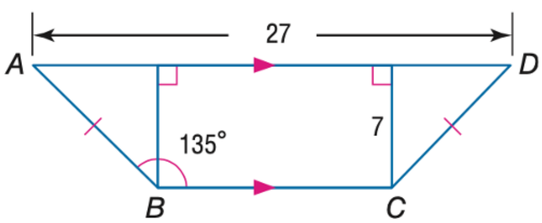


Alex's Work



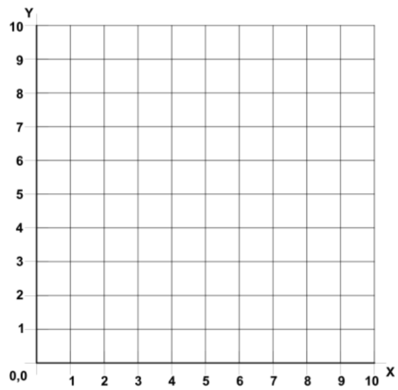


2. Find the perimeter of quadrilateral ABCD. Round to the nearest whole number. Show your work.



3. Draw a rectangle that has a diagonal twice as long as its width. Then write an equation to find the length of the rectangle.

4. Let A = (3, 1), B = (9, 5), and C = (4, 6). Your protractor suggests that angle CAB is approximately 45 degrees. Using what you know about special right triangles and distance in the coordinate plane, explain why angle CAB is in fact exactly 45 degrees.



5. Standing 50 meters from the base of a fir tree, Richard used a protractor to measure an angle of elevation of 33◦ to the top of the tree.
   a. Draw a diagram to represent the scenario.

   b. How tall was the tree? Show your calculations. Round to the nearest meter.

6. Simon lets out 120 meters of kite string, then wonders how high the kite has risen. He can calculate the answer after using a protractor to measure the 63-degree angle of elevation that the string makes with the ground.
   a. Draw a diagram to represent the scenario

   b. How high is the kite? Show your calculations. Round to the nearest meter.

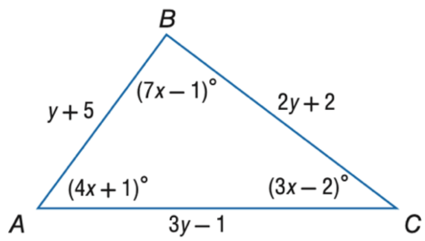
   c. What (unrealistic) assumption did you have to make to solve this problem?

   d. A gust of wind takes the kite up to a height of 115m! What is the angle of elevation now (the string is still 120m long). Please draw a picture as part of your explanation. Round to the nearest whole degree.

7. Emilia, who is roughly 5 ft tall, casts an eight-foot shadow.
   a. Draw a diagram to represent the situation.

   b. How high is the sun in the sky? This question is not asking for a distance, by the way.

8. Solve triangle ABC. Round to the nearest whole number.
   a. Find x and y.



   b. Use your values of x and y to find all the angle measurements and all the side lengths. Label them on the diagram provided.

9. Out for a walk in Manhattan, Brynn measures the angle of elevation to the distant Empire State Building and gets 3.6 degrees. After walking one km directly toward the building, she finds that the angle of elevation has increased to 4.2 degrees.
   a. Draw a diagram to represent the scenario.

   b. What is the height of the Empire State Building to the nearest **meter**? Show your calculations.

   c. How far is Brynn from the Empire State Building after her 1 km walk? Show your calculations.

Name: ______________________

Rubric *(to be filled out by Ms. Lynd)*

Applicable Problem(s)	**Skill Assessed**	**Score (5-10)**
1-4	I can use the properties of special right triangles.	
5, 6, 8, 9	I can find trigonometric ratios using right triangles.	
6d, 7	I can use trigonometric ratios to find angle measures in right triangles.	

Overall Score: __________

APPENDIX D

STUDENT WORKSHEETS

Worksheet 1: NREL Solar Energy Scavenger Hunt

Goal: The goal of this activity is to familiarize ourselves with the basics of solar energy before our visit from Terry Donoghue, a Solar Project Manager at Norwich Technologies.

Directions: Please go to the National Research Energy Laboratory website to learn more about the basics of solar energy. Follow the instructions below, click through the various resources, and answer the prompts.

Rubric: This is a graded assignment. I'll grade it using the rubric below. You do not need to fill out the rubric– I'll take care of that!

3 = Not quite yet 4 = Emerging 5 = Proficient 6= Advanced

Score	Standard
	The student fully *complete*d the assignment by the *due date* and followed all *directions*.
	The student wrote in *complete sentences* and took care to *proofread* for clarity and grammar.
	The student utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*.

Total: ______________/ 18
1 sentence explanation of score:

1. Begin by watching this video and answer these questions.
    a. What key moments in the history of harnessing solar energy for electricity were mentioned in the video?

2. Next, watch this video to learn how solar panels work
    a. Imagine a non-geometer friend asks you how a solar panel works. What would you tell them? Use your own words and simple language!

    b. What challenges and barriers exist? Use Google to find an article to learn more about barriers to widespread use of solar energy to produce electricity and share a bit about what you learned. Include a link to your resource.

    c. Can solar energy power the world? Why or why not? Use Google to find an article that provides more information about this and share a bit about what you learned. Include a link to your resource.

3. Click on the link to learn more about Solar Photovoltaic Technology Basics
    a. Four types of solar photovoltaic technologies are described on this page. Choose ONE that interests you. Read through some of the information provided about the technology, and, in a paragraph, summarize the possibilities, progress, and challenges that relate to the technology. You can use Google to search for additional resources, just include links to your sources.

4. Click on the link to learn more about Passive Solar Technology Basics
    a. Read through the resources linked on this page, then describe TWO ways that passive solar technology could be used in the new Kimball Barn. Be specific!

5. Based on what you learned in the scavenger hunt, list at least THREE important things that you think we should consider as we plan to harness the energy from the sun to power the new Kimball Barn.

6. Lastly, please list at least two thoughtful, relevant, and specific questions to ask Mr. Donoghue when he visits our class. Keep in mind that he has previously taught math at KUA, has had two children attend The Academy, and was involved in the installation of our current KUA solar arrays!

Worksheet 2: Getting Ready for the Kimball Barn Solar Project

Goal: The goal of this activity is to think about ways to use similar triangles and trigonometry to estimate the height of a tall object such as a tree or building.

Directions: Follow the instructions below to thoughtfully respond to the prompts.

Rubric: This is a graded assignment. I'll grade it using the rubric below. You do not need to fill out the rubric– I'll take care of that!

3 = Not quite yet 4 = Emerging 5 = Proficient 6= Advanced

Score	Standard
	The student *fully complete*d the assignment by the *due date* and followed all *directions*.
	The student wrote in *complete sentences* and took care to *proofread* for clarity and grammar.
	The student utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*.

Total: _____________/ 18
1 sentence explanation of score:

1. Imagine you had a piece of string (any length), a partner, and a meter stick. It is not sunny out. Without doing anything unsafe or climbing to high heights, how could you use those materials to estimate the height of a nearby tree or building? Hint: Think about similar triangles and trigonometry…

2. Imagine that you have a partner and a meter stick and that it *is* sunny out. Without doing anything unsafe, how could you use those materials to estimate the height of a nearby tree or building? Hint: Think about similar triangles and trigonometry…

3. To understand how much power we can hope to generate from a solar array atop Kimball Barn, there are several measurements we will need to obtain. Mr. Ulf has provided us with scale drawings, but we can also go to the barn or the site where the barn will be to determine any missing measurements.

   Here are the <u>sitemap</u>, <u>front elevation diagrams</u>, and proposed <u>floor plans</u> for your reference.

Next class, you will work with your group to answer the question: “How much power can we hope to generate from a solar array atop Kimball Barn?” To prepare, you should think a bit about how you might obtain each of the following measurements. You will be able to go outside or work in the classroom with Mr. Ulf’s drawings, as needed.

- The height of trees and buildings near Kimball Barn (can’t climb)
- The height of Kimball Barn (can’t climb)
- The width of Kimball Barn
- The roof pitch of Kimball Barn (can’t climb)
- The surface area of the Kimball Barn roof (can’t climb)
- How close (in degrees) is the South(ish) facing roof of the planned Kimball Barn to an actual North/South orientation?

For each of the bulleted items, describe specifically how you could find the needed information. You don’t have to be exactly right, but your group mates are depending on you to have given this some solid consideration!

Trees:

Height of Barn:

Width of Barn:

Pitch of Roof:

Roof area:

Orientation of Building:

Worksheet 3: An Exploration of Solar Shading

Goals:
There are two initial goals for this activity. They are:
- To find a method to estimate the heights of various buildings and trees that may shade our solar panels.
- To use your method to estimate the height of those objects
- To provide mathematical validation for your method– why does it work?

By the end of this project, you will use your data:
- To determine whether those objects will (currently or in the future) shade the solar panels.
- Create a proposal based on your findings. Is the Kimball Barn a good site for the panels? If so, why? If not, where would be a better location?

Directions:
Follow the instructions below to thoughtfully respond to the prompts. You will work in groups, and everyone needs to contribute.

Rubric:
This is a graded assignment. I'll grade it using the rubric below. You do not need to fill out the rubric– I'll take care of that!

3 = Not quite yet 4 = Emerging 5 = Proficient 6= Advanced

Score	Standard
	COMPLETION: The students *fully complete*d the assignment by the *due date* and followed all *directions*.
	WRITING: The students wrote in *complete sentences* or *bullet points* as directed and took care to *proofread* for clarity and grammar.
	CALCULATIONS: The students' calculations are *mathematically sound* and *well-organized*
	VOICE: The students utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*.
	COLLABORATION: Each group member contributed in equally meaningful ways to show evidence of collaborative *group* work.
	REFLECTION: The students reflected thoughtfully and accurately on their progress.

Total: ______________/ 36

Procedure:

1) In groups, your findings and thoughts from the brainstorming assignment. Record notes on the conversation in the space below (bullet points are fine here).

   How can we estimate the height of a tree or building if it is sunny?

   How can we estimate the height of a tree or building if it is NOT sunny?

2) Decide on ONE procedure to use from your conversation above. If your method seems overly complicated and requires more than a meter stick, consider watching this helpful video for a simple idea. Describe, in detail and step by step, your plans to estimate the height of at least **three** objects that *may* shade the solar panel. How will you collect your data? What measurements will you need to take? Which trees/buildings will you be measuring? What materials will you need?

Data:

Record your data in the space below. Your method will determine the best way to organize your data, but a table will likely be helpful no matter your approach. You can make changes, as needed, to the structure of this table.

Calculations:

In the space provided below, show how you calculated the height of your three objects based on the data you collected. Again, your method may determine how you organize your calculations. You may insert a photo of a notebook page here.

Please define the following terms IN SIMPLE WORDS to prepare yourself for the next part of this assignment.

Vernal Equinox

Autumnal Equinox

Summer Solstice

Winter Solstice

Azimuth

Angle of Elevation

Solar Noon

Using the heights of your three objects, determine whether they will cast a shadow on the south roof of Kimball Barn at Solar Noon on four different dates during the year: The Summer Solstice, Winter Solstice, Vernal Equinox, and Autumnal Equinox. Lastly, you should experiment a bit to determine the number of days per year that you expect the panels to be shaded at solar noon.

You may insert a photo of a notebook page here. This online calculator will be tremendously helpful!

Data Analysis, Conclusions, and Reflections:
Based on your calculations, do you think that the Kimball Barn is an appropriate site for a solar array? Why or why not? If not, you will need to suggest an alternate location and provide justification (like the calculations we did above). If so, are there any changes to the site that you would recommend?

Worksheet 4: How Much Solar Power Can We Generate?

Goal: There are two goals of this activity:
1. To find out the size and orientation of the solar array atop Kimball Barn
2. To find out how much electricity we can generate with the solar array

Rubric:
This is a graded assignment. I'll grade it using the rubric below. You do not need to fill out the rubric– I'll take care of that!

3 = Not quite yet 4 = Emerging 5 = Proficient 6= Advanced

Score	Standard
	COMPLETION: The students *fully complet*ed the assignment by the *due date* and followed all *directions*.
	WRITING: The students wrote in *complete sentences* or *bullet points* as directed and took care to *proofread* for clarity and grammar.
	CALCULATIONS: The students' calculations are *mathematically sound* and *well-organized*
	VOICE: The students utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*.
	COLLABORATION: Each group member contributed in equally meaningful ways to show evidence of collaborative *group* work.
	REFLECTION: The students reflected thoughtfully and accurately on their progress.

Total: _____________/ 36

Part 1: How big will the array be and how will it be oriented?
1) What is the area of the S. facing roof of Kimball Barn? Show your calculations and explain how you got your answer. Please include a sketch.

2) The solar panels used by Norwich Solar are 40x80 inches. The required setback is 1 ft from all edges. How many panels can fit on the roof? They can be oriented vertically, horizontally, or a mixture of both orientations. Show your calculations and explain how you got your answer. Please include a sketch.

3) What is a Watt? Use your own words to explain. If each Norwich Solar panel is a 400-Watt panel, what does this mean? How many kW do you expect your system to generate? This is the DC system size (you'll use this in the calculator).

4) What is the roof pitch of Kimball Barn? Show your calculations and explain how you got your answer. Please include a sketch.

5) The azimuth angle is the angle clockwise from true north describing the direction that the array faces. An azimuth angle of 180° is for a south-facing array, and an azimuth angle of zero degrees is for a north-facing array.

   The default value is an azimuth angle of 180° (south-facing) for locations in the northern hemisphere and 0° (north-facing) for locations in the southern hemisphere. These values typically maximize electricity production over the year. For the northern hemisphere, increasing the azimuth angle slightly above 180° favors afternoon energy production, and decreasing the azimuth angle favors morning energy production. The opposite is true for the southern hemisphere.

   What is the Azimuth of Kimball Barn? Show your calculations and explain how you got your answer.

Part II: How much electricity will we produce?
Please go to the National Research Energy Laboratory PVWatts Calculator and follow the instructions provided (both below and as part of the calculator). Use your findings from part 1 to answer the prompts in the calculator.

1) On the first page of the calculator, enter our location as 03770, you will be able to adjust it a bit. Hit Next.
2) On the second page, move the rid pin on the map to the Kimball Barn Site. You can keep NREL international as the default climatology resource. Hit Next.
3) If prompted, reenter our location as 03770. Hit Next.
4) Draw your system on the mini map provided.
5) Enter the DC system size, array type (fixed roof), tilt, and azimuth that you calculated above. Leave the default values for module type and system losses. Don't worry about any of the advanced parameters. Hit Next.
6) What is the expected system output for Kimball Barn? How much money would KUA save annually on their electricity bill? Take a screenshot of the readout (including the month-to-month data and paste it here.

7) The average American home uses ~30 kWh per day, but the average American home relies on fossil fuels, not electricity, for heating.

   We hope that the Kimball Barn will utilize heat pumps, so the kWh per day that it is in use might be closer to ~60 kWh. As Mr. Ulf, mentioned, KUA is curious whether the building can be "Net Zero."

Assuming that the barn is in use only during the spring and fall sports seasons, how many kWh will it use annually? Is this more or less than the panels will generate? Show your calculations and explain how you got your answer.

Worksheet 5: Passive Solar

Goals:
There are two goals for this activity. They are:
- To research one or more passive solar design elements
- To create a detailed and mathematically justified plan as to how that passive solar element could be incorporated into the existing plans for Kimball Barn

Directions:
Follow the instructions below to thoughtfully respond to the prompts. You will work in groups, and everyone needs to contribute. Part 1 should be completed individually. Part 2 should be completed as a group during class.

Rubric:
This is a graded assignment. I'll grade it using the rubric below. You do not need to fill out the rubric– I'll take care of that!

3 = Not quite yet 4 = Emerging 5 = Proficient 6= Advanced

Score	Standard
	COMPLETION: The students *fully complet*ed the assignment by the *due date* and followed all *directions*.
	WRITING: The students wrote in *complete sentences* or *bullet points* as directed and took care to *proofread* for clarity and grammar.
	CALCULATIONS: The students' calculations are *mathematically sound* and *well-organized*
	VOICE: The students utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*.
	COLLABORATION: Each group member contributed in equally meaningful ways to show evidence of collaborative *group* work.
	REFLECTION: The students reflected thoughtfully and accurately on their progress.

Total: ______________/ 36

Part 1:
1) Each group has been assigned a list of passive solar design elements. At a minimum, your group must implement all the design elements in your list in your floorplan/ landscape plan, but you can also <u>add</u> other elements that interest you from other lists.

    - Emilia, Teegan, Lizie, Sophia: <u>Roof overhang</u> plus quality/ well positioned <u>windows</u>
    - Angus, Brynn, Lu, Sasha: <u>Sunroom</u>, <u>blinds</u>, plus <u>landscaping</u>

- Alex, Richard, Simon, Matthew: Thermal Mass, windows, blinds, and distribution mechanisms

2) Begin researching possibilities by clicking on the links provided. These are meant to get you started. Each group member should take notes in the space provided below. Attribute information by including links to your resources. Be sure to indicate who took what notes (initials or first name at beginning of notes)!

3) Based on your research, what ideas do you have for Kimball Barn? Each group member should record their ideas in the space provided. Be as specific as possible!

Part 2:

4) As a group, read and share what everyone learned about passive solar design. Then, decide on your final design and describe it in the space provided.

5) Please show any calculations/ diagrams in the space below. A photo of a notebook page will suffice.

APPENDIX E

STUDENT REFLECTIONS

Reflection Questions

Disclaimer read to students: Participation in this research is voluntary. Participation or non-participation will not affect your grade or class standing in any way.

1. Overall, would you rate your experience with the project as positive or negative? Can you explain your rating?

2. What was your favorite part of the project?

3. What was your least favorite part of the project?

4. Was your experience with the area and volume unit different than your experience in the other units? Why or why not?

5. How did the architecture unit help you to learn about area, volume, and trigonometry?

6. In your mind, what is the most important knowledge or skill that you will take with you from this project?

7. Would you recommend that other math teachers utilize projects in their courses? Why or why not?

8. In which of the following SEPs would you say you made the most progress? The least progress? Can you explain?
    a. Developing and using models
    b. Using mathematics and quantitative thinking
    c. Constructing explanations and designing solutions
    d. Obtaining, evaluating, and communicating information

9. Is there anything else that you would like me to know about your experience?

APPENDIX F

FINAL PRESENTATION GUIDELINES

Final Kimball Barn Proposal Presentation Guidelines

Goals:
The goal of this activity is to prepare a final presentation that clearly conveys our class' collective learning and design ideas with our panelists (Ms. Haskell, Ms. Lynd, Mr. Ulf, and Mr. Donoghue). Remember, though you and your classmates are experts at this point, you should make sure that you are targeting a NON-TECHNICAL audience. We shouldn't get lost in the weeds with technical jargon and detailed calculations! This is purely a simplified summary of our learning.

Directions:
The presentation has been divided into parts, and each group will be responsible for presenting a few key pieces. You will follow the prompts below to create your slides.

1) Here is a list of the slides in the presentation. They have been color coded to help you identify which slides you are responsible for. As a group, look at the slides you have been assigned and divide up the work in an equitable manner.

    - The Kimball Barn Project: An Overview
        - i) What is known about the history of Kimball Barn?
        - ii) Where is it being moved and what will it be used for? What is the timeline?
    - Solar Panels: The Basics
        - i) How has the solar industry changed in the past few decades?
        - ii) How do solar panels work?
        - iii) What are some important considerations when installing solar panels?
    - Shading Calculations: A How To
        - i) How can you figure out if your site is compatible with a solar array (generally)?
    - Shading: Our Findings and Recommendations
        - i) Where will the Kimball Barn solar array be located?
        - ii) Are there trees that shade the Kimball Barn solar array?
        - iii) How should the site be changed, if at all to better accommodate the panels?
    - How Much Electricity can a Solar Array Generate?
        - i) How can you figure out how much electricity your panels will generate (generally)? What are important considerations
    - What can we Expect from the Kimball Barn Array?
        - i) How much electricity will the Kimball Barn use/ generate? Can it be Net Zero?
    - Passive Solar Design: Basic Principles and Examples

    i) What are the basic principles of passive solar design?
    ii) How is this related to the greenhouse effect (generally)?
  - How to Design a Roof Overhang
    i) How can a roof overhang help cool a building in the summer and heat it in the winter (general principles here)?
  - Passive Solar Design and Kimball Barn
    i) What passive solar design elements do you recommend be incorporated into Kimball Barn?
  - Thank you for Listening! Any Questions?
  - Works Cited
    i) Anyone who uses a resource should put the link on this slide. The link should be preceded by text such as “Slide 1 Diagram:” so that it is clear which link goes with what information.

Key: Everyone, Angus, Brynn, Lu, Sasha, Emilia, Sophia, Teegan, Lizie, Matthew, Simon, Alex, Richard

2) Use your resources (mainly the worksheets we’ve been working on!) to begin constructing your slides. I’ve included a few additional items below
   - Here is a link to the presentation template that we will all use.
   - Here is a link to a folder containing helpful images, diagrams, and sketches that you may want to use. No image, sketch, or diagram should appear twice in the presentation! Remember a picture says a thousand words. You should feel free to use other photos and diagrams that you find as well. Every slide should have at least one photo or diagram. **Each bullet point should contain only 5-10 words**. No full sentences allowed!

Rubric:
The project will count as 15% of your final grade in this class. Each group will be assessed using the following rubric.
Please note that there will be an option for us to reflect on the process, both independently and as a group, following the presentation. If labor was not divided equitably, it is possible that not all group members will receive the same grade.

You do not need to fill out the rubric– I’ll take care of that! You should, however, read through the rubric and make sure that you have met all the criteria.

3 = Not quite yet   4 = Emerging   5 = Proficient   6= Advanced

Score	Standard
	COMPLETION: The students *fully complete*d all parts of the assignment by the *due date* and followed all *directions.* ● *Did you share your NREL Solar Scavenger Hunt, Getting Ready: Kimball Barn Solar Project, Solar Shading: An Exploration, How Much Solar Power Can We Generate, and Passive Solar Worksheets with Ms. Lynd?* ● *Were your slides ready to go on the day of the presentation?*
	WRITING: The students wrote in *complete sentences* or *bullet points* as directed and took care to *proofread* for clarity and grammar. ● *Is the writing on your Solar Shading: An Exploration, How Much Solar Power Can We Generate, and Passive Solar Worksheets polished?* ● *Are the bullet points on your slides between 5-10 words each? Are your bullet points clear and easy to follow?*
	VISUALS: The students included *visuals* such as diagrams, photos, and sketches that made their presentation engaging and easy to follow ● *Are your slides arranged in a clear and aesthetic manner?* ● *Do your images support the text and help to convey your message?* ● *Did you refer to your images during the presentation?*
	CALCULATIONS: The students' calculations are *mathematically sound* and *well-organized* ● *Are the calculations on your Solar Shading: An Exploration, How Much Solar Power Can We Generate, and Passive Solar Worksheets correct and easy to follow?* ● *If you included sample calculations in the presentation, are those calculations correct and easy to follow for a <u>non-technical audience</u>?*
	VOICE: The students utilized their own *voice*, provided unique *examples*, thoughtfully explained *concepts*, and/or asked nuanced *questions*. ● *Were you thorough and clear in your explanations, both written and verbal?* ● *Was your speech during the presentation well-rehearsed and polished?*
	COLLABORATION: Each group member contributed in equally meaningful ways to show evidence of collaborative *group* work. ● *Did all members do their best (under the circumstances with COVID) to contribute?* ● *Did everyone participate in the final presentation in a meaningful way?*
	REFLECTION: The students reflected thoughtfully and accurately on their progress. ● *Did everyone stay after the presentation to reflect on the process and project?*

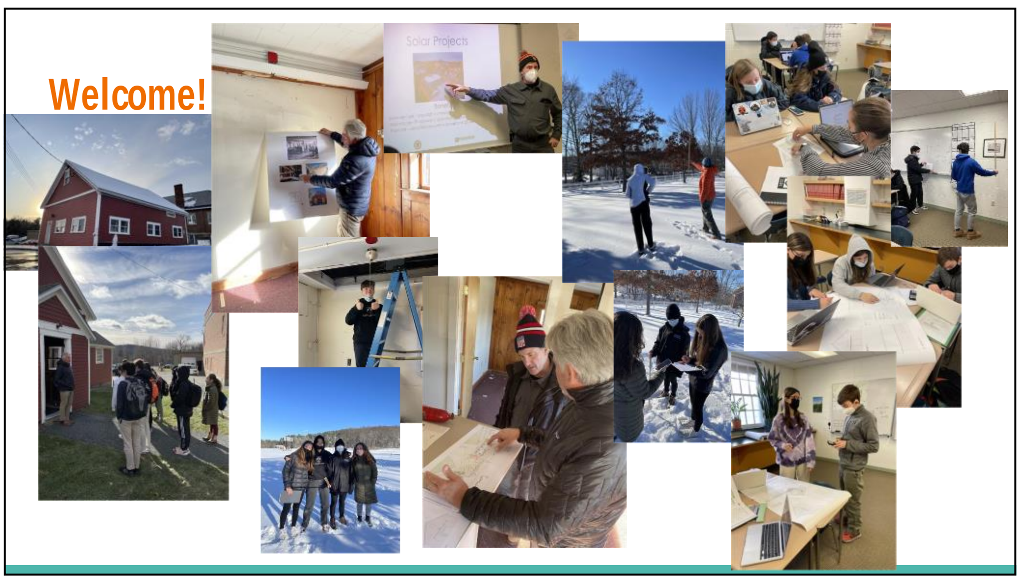
APPENDIX G

STUDENT PRESENTATION SLIDES

Kimball Barn Proposal

Honors Geometry

1

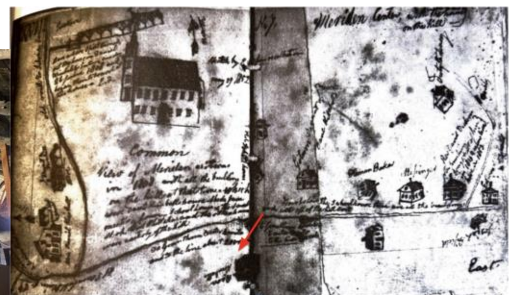


2

The Kimball Barn Project: An Overview

Built in 1770's-1790's

Preserve the Beams
And valuable timber

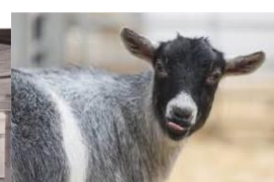


1808 Map of Meriden

3

The Kimball Barn Project: An Overview

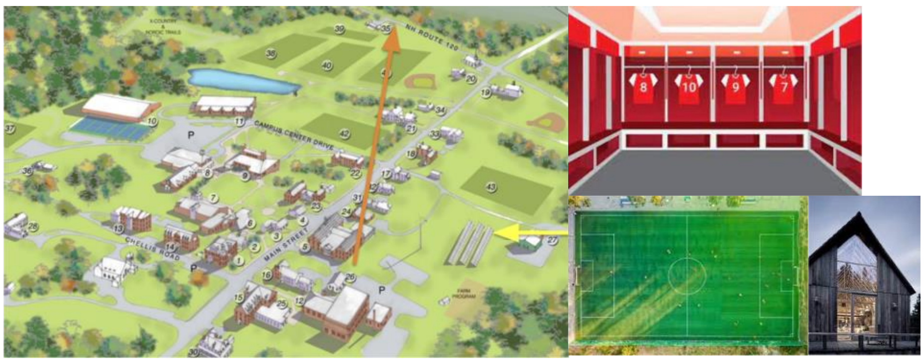
Previous Uses



4

The Kimball Barn Project: An Overview

What's happening to it?



5

The Kimball Barn Project: An Overview

What happening pt 2 with the design

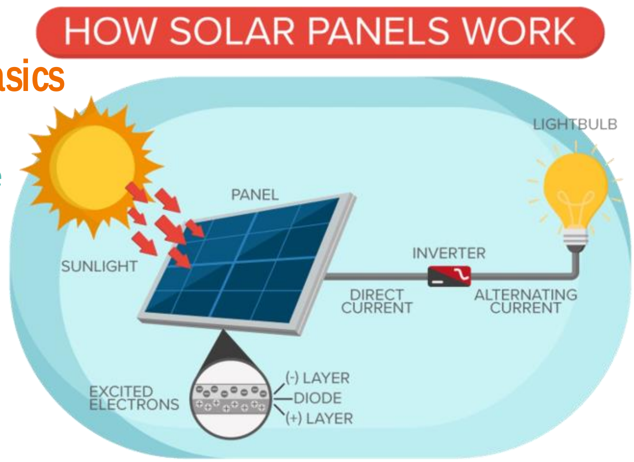
Preserve but make new

6

Solar Panels: The Basics

How do solar panels work?

- ★ Sunlight activates the panels
- ★ It displaces electrons
- ★ They produce electrical current
- ★ The electrical energy is converted

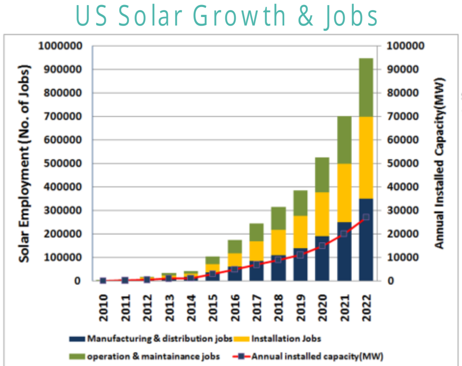


7

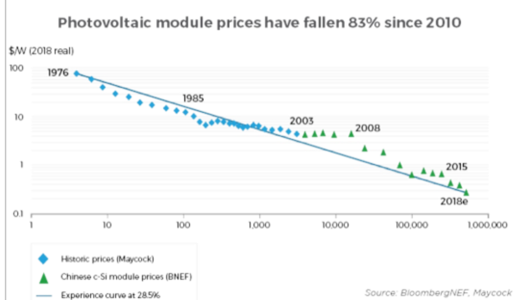
Solar Panels: The Basics

How has the solar industry changed in the past few decades?

US Solar Growth & Jobs



Cost Reduction

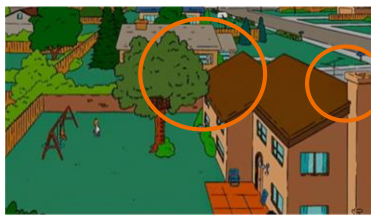


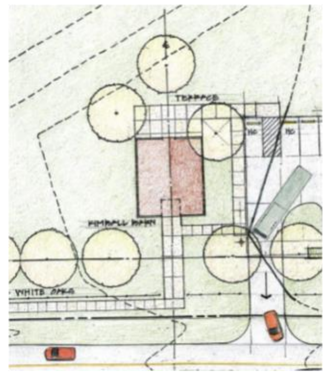
8

Solar Panels: The Basics

What are some important considerations when installing solar panels?

- ★ Electrical Needs
- ★ Sunlight exposure
- ★ Climate
- ★ Placement
- ★ Location





9

Shading Calculations: A How To

Materials: a meter stick, and yourself

Step 1:

Step 2:

Step 3:

Step 4:

Final Steps: (literally!)

10

Shading: Our Findings and Recommendations

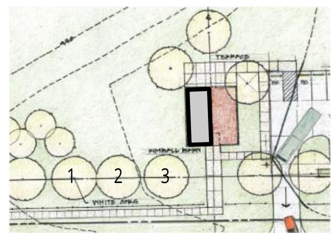
Are there trees that would shade the solar array?

- Equinoxes: shadows would not have significant impact
- Winter: shadows have large impact
- Summer: shadows would make no difference

Are there modifications that we would need to make to the site?

- Currently, we do not suggest any drastic changes
- In the future, re-evaluation may be necessary based on tree growth

Tree #	Shadow Length @ Equinoxes
Tree #1	24.1 ft
Tree #2	26 ft
Tree #3	21.2



11

How Much Electricity can a Solar Array Generate?

44 x 23=1012 ft2 but when we cut off 1 ft from each of the edges, our new equation will be 42ft x 21ft = 882 ft2

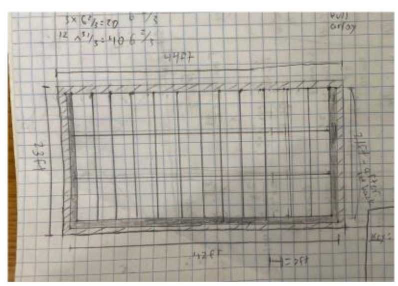
42ft x 12 = 504in

21ft x 12 = 252in

504in ✚ 40in = 12 panels (with wiggle room)

252in ✚ 80in = 3 panels

3 x 12 panels would equal a total array of 36 total panels



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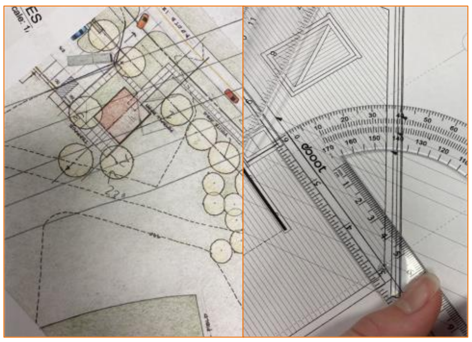
How Much Electricity can a Solar Array Generate?



- Azimuth angle of the sun was about 180 degrees.
- The azimuth angle of the Kimball Barn was 157 degrees.
- The roof pitch was about 35°

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How Much Electricity can a Solar Array Generate?

- One solar panel can produce 400 watts in an hour. Since we have 36 panels, a solar array can generate 14.4 kW per hour.
- Using about 45 kWh a day year round

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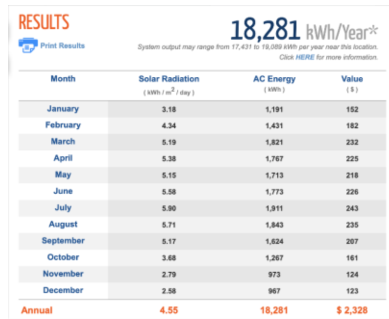
What can we Expect From the Kimball Barn Array?

- The Kimball Barn Array can generate 18281 kWh/year
- Saving $2328 per year!
- The barn will use 9165 kWh in a year.
- Producing 9116 kWh of extra energy.



RESULTS

Print Results

18,281 kWh/Year*

System output may range from 17,431 to 19,089 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	3.18	1,191	152
February	4.34	1,431	182
March	5.19	1,821	232
April	5.38	1,767	225
May	5.15	1,713	218
June	5.58	1,773	226
July	5.90	1,911	243
August	5.71	1,843	235
September	5.17	1,624	207
October	3.68	1,267	161
November	2.79	973	124
December	2.58	967	123
Annual	4.55	18,281	$ 2,328

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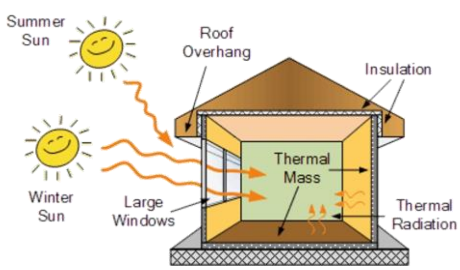
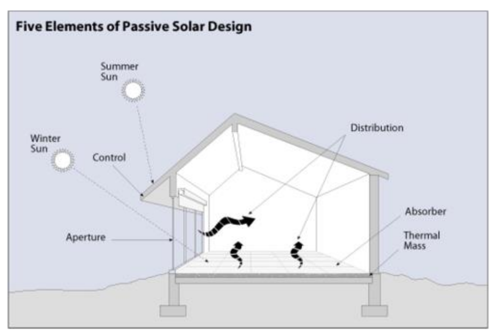
Passive Solar Design: Basic Principles and Examples

- Absorbing/storing heat during winter, keeping the building cool during summer
- Overhangs blocking windows, greenhouse, sunrooms
- Heat and cooling from passive technologies not fossil fuels
- Depending on the design, heat is stored or kept from entering





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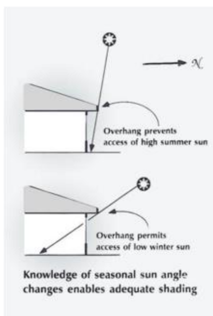
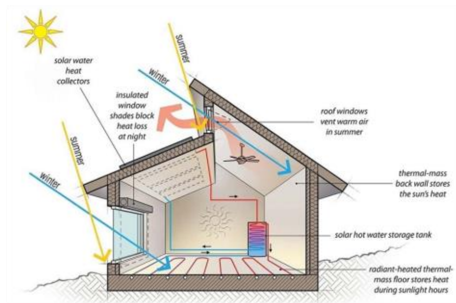
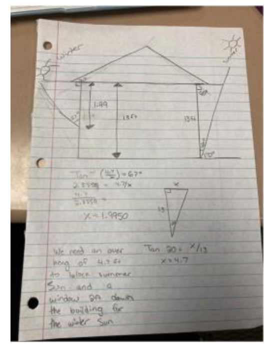
How to Design a Roof Overhang

- Block the sun during the summer to keep buildings cool
- Let in the sun during the winter for heating
- Depends on how long the overhang is/how big are windows
- Also can be a series of overhangs with window directly below







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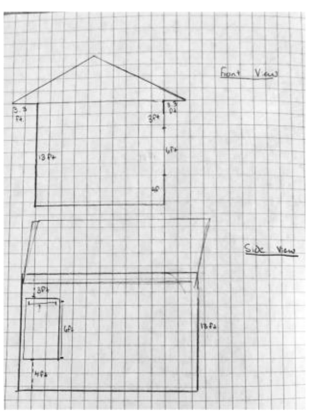
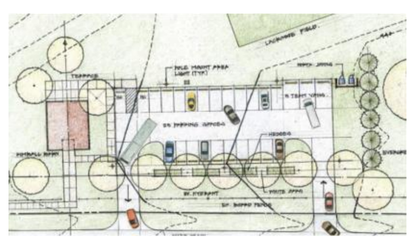
Passive Solar Design and Kimball Barn



Our suggested design elements:

- Windows along south-side of building
- Overhang on both sides
- 3ft below overhang, 4ft from ground
- 6 ft in height
- Windows in event space
- ¼ of total side space



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