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The Effect of Science, Technology, Engineering and Mathematics (STEM) Project Based Learning (PBL) on Students' Achievement in Four Mathematics Topics

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ABSTRACT

The integration of project-based learning in Science, Technology, Engineering, and Mathematics activities has received much attention because of its potential in engaging students with real–world problem solving. This study was designed to examine the effectiveness of Science, Technology, Engineering, and Mathematics project-based learning lessons on students' achievement in algebra, geometry, probability and problem solving. The achievements of two groups of students who participated in the study were compared longitudinally in 2008, 2009, and 2010. The results showed that lessons integrating Science, Technology, Engineering, and Mathematics project-based learning improved students' scores in mathematics in general (d= 1.311), algebra (d=1.500), geometry (d=1.837), and probability (d=.487), but not in problem solving (d=.343). In addition, students in Science, Technology, Engineering, and Mathematics project-based learning schools showed higher scores in geometry, probability, and problem solving than those in non Science, Technology, Engineering, and Mathematics project-based learning schools. Implications for reforming instructional approaches and suggestions for further study were discussed.

Keywords: Project-based Learning; Science, Technology, Engineering and Mathematics (STEM).

INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) are critical fields to ensure a country's development. For this reason, increasing the STEM workforce has been regarded as an urgent assignment. In order to encourage more students to pursue STEM majors in colleges and to obtain careers in STEM fields, it is important to support them in learning about and exploring STEM disciplines (Han, 2015). To attain this goal, diverse pedagogical strategies such as project-based learning (PBL) have been attempted and the curriculum for mathematics and science subjects has been revised (Capraro & Nite, 2014).

Despite efforts, students have demonstrated less interest in STEM disciplines and received lower scores on standardized national tests (National Center for Education Statistics, 2003; Hennessey, 2007; Mann, 2009). In addition, Marino (2010) argued many students with

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learning and other disabilities have been struggling in inclusive STEM classrooms and few of these students have pursued their studies in advanced STEM courses. This situation is alarming and negatively affects student enrollment jn post-secondary institutions, which results in low numbers transitioning into in STEM fields.

To resolve the problems associated with STEM fields in schools, project-based learning (PBL) has been developed as a targeted strategy and pedagogical practice by integrating knowledge of science, technology, engineering and mathematics as cohesive components for solving real-world problems (Breiner, Harkness, Johnson, & Koehler, 2012). Capraro and Slough (2013) stated PBL is broader than problem-based learning consisting of several activities/tasks utilizing contextualized and authentic experiential problems to scaffold student's learning in STEM concepts. STEM PBL is a student-centered methodology using "an ill-defined task within a well-defined outcome" to spark interest and to tap prior knowledge in building new concepts and understandings (Capraro & Slough, 2013, p. 2). The combination of appropriate pedagogy, technology and STEM content during a PBL activity can support student construction of knowledge (Marino, Black, Hayes & Beecher, 2010). Previous research findings have shown some positive inherent outcomes when implementing PBL STEM approaches in expanding students' knowledge of science and mathematics and deepening their understanding of interdisciplinary relationships among principles, concepts, and skills across engineering and technology domains (Barron et al., 1998; Han, Capraro, & Capraro, 2014; Lou, Liu, Shih, Chuang, & Tseng, 2011; Marino et al., 2010).

STEM education has become part of the school curriculum especially in the United States; thus, many PBL activities based on engineering and technology applications have been designed and implemented by teachers to engage students in learning (Breiner et al., 2012). For instance, the engineering components in STEM PBL lessons provide students with real-world contexts, promote interest, and improve student problem solving and communication skills. While students explore the projects in classrooms using STEM PBL, they are engaged in solving problems within the project individually and in groups. This allows students to arouse their curiosity and critical thinking skills while engaging in scientific inquiry through doing and learning. However, these potential benefits from utilizing STEM PBL cannot guarantee that students will learn the necessary skills included in the National Council of Teachers of Mathematics [NCTM, 2000] principles or state's standards (e.g. Texas Essential Knowledge and Skills [TEKS]). Studies are necessary to identify factors influencing the effects of implementing STEM PBL activities especially on students' academic achievement longitudinally.

Previous research studies have shown a number of researchers have explored student academic achievement and attitude towards STEM at the same time. However, there seems to be few empirical studies examining the effectiveness of STEM PBL in relation to students' academic achievement alone. Multiple studies suggested STEM PBL had strongly influenced student cognitive development during problem solving activities (e.g., Barron et al., 1998; Lou et al., 2011; Marino et al., 2010). In fact, Barron et al. (1998) contented meaningful learning happened when students actively and collaboratively solved real world problems wherein eventually affecting their academic performance. Similarly, Lou et al. (2011) found that the select students in their study not only gained profound knowledge in science and mathematics, but also can apply engineering and science knowledge during exploration activities. Along these same lines, Marino et al. (2010) argued that students with reading difficulties had demonstrated significant differential performance on STEM achievement after participating in a technology-enhanced astronomy curriculum, but their academic achievement was affected by several factors. This evidenced the consistent assimilarion of factors such as integrated technology-enhanced STEM curricular materials, which contributed to students with disabilities' performance in STEM.

Studies have also focused on the impact of STEM PBL on students' attitude and behavior toward STEM fields that indirectly affected their academic performance (Awang & Ramly, 2008; Blumenfeld, Fishman, Krajcik, Marx & Soloway, 2000; Wah & Chu, 2009). STEM PBLs contain diverse hand-on activities along with communication and collaboration with peers. The group-focused activities help students develop more positive attitudes and reduce anxiety toward science and mathematics (Blumenfeld et al., 2000). However, students' academic success through STEM PBL classes can only be evaluated in the presence of teachers' fidelity to the program (Stearns, Morgan, Capraro, & Capraro, 2012) environment, and students' ability. That is why further diverse research on students' academic improvement through STEM PBL is necessary.

The purpose of this study was to examine how STEM PBL lessons affect student achievement in terms of four mathematical topic areas (i.e. algebra, geometry, probability and problem solving) and to compare the student achievement of two groups (i.e. students who participated in the STEM PBL lessons versus students in schools where teachers have not utilized STEM PBL in lessons) longitudinally for three years (2008, 2009, and 2010). This longitudinal study is an in depth analysis revealing the individual level of change based on participant involvement in a three year STEM PBL program. It is also practically significant to draw a causal relationship between the STEM PBL program and student achievement in four areas of mathematics contents.

STEM PBL has been focused as a reformed instructional approach to improve students' interests and academic achievement in STEM fields. Previous studies regarding the impact of STEM PBL on students' affect and cognition have revealed that a lesson integrating STEM PBL encouraged students' positive attitude toward STEM fields and improved students' academic achievement in mathematics. However, it has not been investigated how STEM PBL positively influenced student academic achievement in mathematics, or what specific sub topic areas of mathematics were influenced by STEM PBL. Therefore, the present study is focused on the following research questions:

1. Are there differences in students' academic achievement in each sub topic area of mathematics (e.g., algebra, geometry, probability, and problem solving) between Year 1 and Year 2 and between Year 2 and Year 3?

2. Are there differences in students' academic achievement in each sub topic area of mathematics (e.g., algebra, geometry, probability, and problem solving) between STEM PBL and non-STEM PBL schools for three years (Year 1, 2, & 3)?

METHODOLOGY

a) Participants

The participants were diverse students enrolled in six small, urban, low socio-economic high schools. Three of the six schools provided teachers with an opportunity to participate in a sustained (30 days, 7 hours per day) professional development provided by one STEM center. As a result of the professional development, the teachers were required to implement a STEM PBL series of activities in their classes. Students were continually involved in STEM PBL activities implemented by their teachers in science and mathematics classes from 2008 to 2010. On the other hand, the other three schools were in the same region but had no opportunities for teacher training in the STEM PBL instructional approach. In this study, these six schools were called either STEM PBL schools or non-STEM PBL schools depending on whether teachers in the school were offered professional development in STEM PBL.

Specifically for the current study, we selected only students who had lower scores than the median to examine the effect of STEM PBL on student achievement because STEM PBL is an appropriate instructional approach for students who were low academic achievers (Han et al., 2014). Demographics of the participating students in this study are reported in Table 1.

Table 1. *Demographics of the Participating Students in the Initial Year*

	STEM PBL schools (N=661)	Non STEM PBL schools (N=526)
Gender/Sex		
Female	332 (50.2%)	268 (51%)
Male	329 (49.8%)	258 (49%)
Ethnicity		
Hispanic	336 (50.8%)	272 (51.7%)
African American	204 (30.9%)	227 (43.2%)
Others	121 (18.3%)	27 (5.1%)
Economically Disadvantaged		
Yes	625 (94.5%)	472 (89.7%)
No	36 (5.4%)	54 (10.3%)
At-Risk		
Yes	486 (73.5%)	405 (77%)
No	175 (26.5%)	121 (23%)

Note. Others include White, American Indian, and Asian. According to Texas Education Agency (2011), "at-risk" refers to students who had limited English proficiency, and/or were in the care of a state agency.

b) STEM PBL Pedagogical Approach

Teachers in STEM PBL schools were involved in a professional development provided by a research university in the U.S. from 2007 through 2010. While the professional development was being delivered, the teachers and university researchers collaborated in developing STEM PBL lesson plans. An example of the STEM PBL lesson plan is shown in the Appendix section. Once the lesson plans were designed, the teachers utilized the lessons integrating STEM PBL in their mathematics or science classrooms. In general, a STEM PBL lesson was usually implemented for 3 to 5 days and sometimes up to 2 weeks. On the first day, an interdisciplinary project including real-world problems was introduced to students. The teachers were advised that the project should include ill-defined tasks. Also, mathematics or science curriculum standards connected to the projects were provided. In the introduction phase, it was critical to have students understand learning objectives (i.e., well-defined outcomes) and ill-defined tasks. While exploring the project, students could collaborate with peers to perform the tasks. If students were having difficulties accomplishing the tasks, the teacher advised them and helped these students as a facilitator and supporter. When students sometimes had difficulties in solving a problem, teachers provided an explanation lecture teaching basic content knowledge. At the end of the project, students were generally required to present their experiences, outcomes, and artifacts from the project. The Appendix section displays the lesson plan that focusing on a project of designing and building an irrigation system. In specific, this irrigation system project is used as real-life problem to scaffold students' science knowledge construction when learning about the dynamics of water, water conservation, kinetic energy, and fluid dynamics.

c) Data Sources

The state accountability instrument, Texas Assessment of Knowledge and Skills (TAKS) provided empirical data (2008 to 2010). The reason this test was used is because its subscales measured the same topics taught by the teachers using STEM PBL and was a sufficient estimate of how STEM PBL activities influenced students' achievement in the mathematical areas: algebra, geometry, probability, and problem solving. Students took this mandated test once a year. The test included 52-60 items and 10 mathematics objectives. The numbers of items tested in Year 1, 2, and 3 measuring mathematics achievements for each objective are reported in Table 2.

Table 2. *Objectives and Number of Items for Each Objective*

Objective	Year 1	Year 2	Year 3
1. Functional Relationships	5	5	5
2. Properties and Attributes of Functions	5	5	5
3. Linear Functions	5	5	5
4. Linear Equations and Inequalities	5	5	5
5. Quadratic and Other Nonlinear Functions	4	5	5
6. Geometric Relationships and Spatial Reasoning	4	5	7
7. Two- and Three-Dimensional Representations	4	5	7
8. Measurement and Similarity	6	7	7
9. Percents/Proportions/Probability/Statistics	5	5	5
10. Mathematical Processes and Tools	9	9	9

The ten objectives were categorized into four topic areas such as Algebra, Geometry, Probability, and Problem Solving. That is, objective 1 through 5 were focused on diverse functions and their properties. Therefore we classified the five objectives as a topic area named "Algebra." Objectives 6, 7, and 8 covered geometric relationships and spatial reasoning, dimensional representations, and measurement. Therefore, we classified these three objectives as "Geometry". Lastly, a single objective 9 and 10 represented "Probability" and "Problem Solving" respectively. To calculate students' scores for these topic areas, we summed the scores of the objectives provided by the Texas Education Agency [TEA] and used the composite scores as dependent variables.

d) Data Analysis

As the first phase, descriptive statistics (e.g., mean and standard deviation) of the dependent variable were calculated. In addition, the 95% confidence intervals were computed to estimate the population means to lie between the intervals' upper and lower limits, which were captured 95% of the time using SPSS 18.0.

To answer the first research question, one-way analysis of variance (ANOVA) was used to compare the means of four mathematical topic areas across three years. In this analysis, the independent variables used were years of STEM PBL instruction. Two kinds of Post Hoc tests, Tukey and Scheffe, were used to examine statistically significant differences. Before using ANOVA, the required assumptions were checked. The dependent variable was continuous and the independent variable (i.e., years of STEM PBL) was ordinal. Therefore, an ANOVA analysis was applicable for the first research question.

In answering the second research question, *t*-tests were used. A *t*-test was executed to determine whether there were any statistically significant differences between STEM PBL and non-STEM PBL schools in terms of the means of students' scores in the four mathematical topic areas. Similar to the ANOVA test, three assumptions were checked. First, the dependent variables were students' scores in mathematics and four sub-areas of mathematics, and they were all continuous variables. Second, there was an independent variable (i.e., PBL—indicating whether teachers in a school were involved in STEM PBL professional development) employed in the current study. This independent variable consisted of two categorical, independent groups. Last, the dependent variable was approximately normally distributed for each group of the independent variable. Therefore, the data for this study did not fail the assumptions, and a *t*-test was applicable. To illustrate the trajectories of students' scores in the four topic areas across three years, graphs of broken lines were drawn.

FINDINGS

Table 3 presents the descriptive statistics including means, standard deviations, and confidence intervals (lower and upper limits) for three years followed by the results for the first and second research questions.

a) Comparing Across Years

Results from ANOVA analyses indicated that there were statistically significant differences for student achievement in each mathematics sub-area across years. The ANOVA analyses were conducted separately for students in STEM PBL and non-STEM PBL schools (see Table 4). The results from ANOVA analyses were similar between STEM PBL and non-STEM PBL schools except in the area of problem solving. For the topic areas of algebra and geometry, the differences of students' scores between Year 1 and 2 and between Year 2 and 3 were statistically significant. For the area of probability, the difference between Year 1 and 2 was not statistically significant whereas the difference between Year 2 and 3 was statistically significant. For the area of problem solving, STEM PBL and non-STEM PBL schools demonstrated different results. Students in STEM PBL schools showed improved scores in problem solving across the three years whereas students in non-STEM PBL schools had a significant improvement from Year 1 to 2 but not from Year 2 to 3.

b) Comparing STEM PBL Schools with Non-STEM PBL Schools

T-tests were conducted to examine whether there were statistically significant differences between students in STEM PBL and those in non-STEM PBL schools in terms of the scores in mathematical topic areas during the three years (see Table 5). The results from the *t*-tests demonstrated students in STEM PBL and non-STEM PBL schools did not have statistically significant differences on scores for each mathematical topic area in Year 1 and 2. However, in Year 3, students in STEM PBL schools showed higher scores than those in non-STEM PBL schools in the topic areas of geometry, probability, and problem solving.

Table 3. *Differences of Students' Scores in Four Mathematics Topic Areas Across Years*

		Year 1				Year 2				Year 3					
	Area	*Mean*	*SD*	*CI Lower*	*CI Upper*	*Mean*	*SD*	*CI Lower*	*CI Upper*	*Mean*	*SD*	*CI Lower*	*CI Upper*	*d pre-pst*	*d T-C*
STEM PBL Schools	Mathematics	23.203	6.847	22.68	23.73	26.963	9.073	25.96	27.96	34.843	10.501	33.48	36.21	1.311	.288
	Algebra	10.744	3.649	10.466	11.023	12.325	4.015	11.877	12.773	16.469	3.979	15.945	16.993	1.500	.067
	Geometry	6.207	2.317	6.030	6.384	8.550	2.835	8.234	8.866	11.862	3.685	11.376	12.347	1.837	.228
	Probability	2.319	1.194	2.23	2.41	2.331	1.211	2.20	2.47	2.902	1.201	2.74	3.06	.487	.098
	Problem Solving	3.932	1.791	3.80	4.07	4.537	1.820	4.33	4.74	4.545	1.877	4.30	4.79	.334	.343
Non-STEM PBL Schools	Mathematics	23.61	6.337	23.07	24.15	27.472	9.206	26.39	28.55	32.565	10.801	31.21	33.92		
	Algebra	10.947	3.433	10.653	11.241	12.895	4.301	12.387	13.404	15.950	4.386	15.391	16.509		
	Geometry	6.413	2.248	6.220	6.605	8.339	2.888	7.9977	8.681	10.946	3.834	10.457	11.434		
	Probability	2.41	1.119	2.31	2.50	2.289	1.289	2.14	2.44	2.636	1.246	2.48	2.79		
	Problem Solving	3.84	1.753	3.69	3.99	4.444	1.816	4.23	4.66	3.987	1.804	3.76	4.22		

Note. SD=Standard Deviation. Pre-pst is the Cohen's d effect size for the STEM PBL group year 3 gains over year 1. T-C is the net effect-comparing year 3 for the STEM and non STEM PBL groups.

Table 4. *Differences of Students' Scores in Four Mathematics Topic Areas Across Years*

Schools	Area	F value	*p* value	Tukey Year 1-Year 2		Tukey Year 2-Year 3	
				MD	Std. Error (*p* value)	MD	Std. Error (*p* value)
STEM PBL	Mathematics	97.619	<0.001	-3.861	0.617 (*p*<0.001)	-0.593	0.729 (*p*<0.001)
	Algebra	135.620	<0.001	-1.949	0.290 (*p*<0.001)	-3.054	0.345 (*p*<0.001)
	Geometry	210.766	<0.001	-1.927	0.212 (*p*<0.001)	-2.606	0.252 (*p*<0.001)
	Probability	5.561	<0.001	0.120	0.089 (*p*=0.367)	-0.347	0.106 (*p*=0.003)
	Problem-Solving	10.461	<0.001	-0.602	0.132 (*p*<0.001)	0.457	0.157 (*p*=0.011)
Non STEM PBL	Mathematics	170.361	<0.001	-3.760	0.563 (*p*<0.001)	-7.881	0.714 (*p*<0.001)
	Algebra	189.018	<0.001	-1.580	0.262 (*p*<0.001)	-4.144	0.334 (*p*<0.001)
	Geometry	364.584	<0.001	-2.343	0.190 (*p*<0.001)	-3.312	0.242 (*p*<0.001)
	Probability	21.177	<0.001	-0.012	0.083 (*p*=0.988)	-0.571	0.105 (*p*<0.001)
	Problem-Solving	16.602	<0.001	-0.605	0.125 (*p*<0.001)	-0.008	0.159 (*p*=0.999)

Note. MD=Mean difference

Table 5. *Comparing Between STEM PBL and Non-STEM PBL Schools*

Area	Year 1 *t*	*df*	*P*	Year 2 *t*	*df*	*P*	Year 3 *t*	*df*	*p*
Mathematics	-1.062	1158.346	0.293	-0682	600	0.495	2.331	474	0.020
Algebra	-0.975	1185	0.330	-1.663	586	0.097	1.331	461	0.184
Geometry	-1.536	1185	0.125	0.891	586	0.373	2.618	461	0.009
Probability	-1.319	1185	0.187	0.411	586	0.681	2.334	461	0.020
Problem Solving	0.865	1185	0.387	0.619	586	0.536	3.257	461	0.001

To compare the trajectories of students' scores in STEM PBL and non-STEM PBL schools, graphs were drawn (see Figure 1). The trajectories connecting the mean scores of the three years indicate that students in STEM PBL schools outperformed those in non-STEM PBL schools for algebra after the second year. For geometry, students in STEM PBL schools showed higher scores than those in non-STEM PBL schools after the first year. For probability, students in non-STEM PBL schools had lower scores in the second year than in the first year. However, in the last year students in both types of schools demonstrated higher scores than in the first and second years. For problem solving, the mean scores of students in STEM PBL and non-STEM PBL schools were increasing from the first to the second year. After the second year, the scores of students in non-STEM PBL schools dropped, whereas students in STEM PBL schools showed even mean scores. For the four mathematical topic areas, students in STEM PBL schools commonly demonstrated higher mean scores in the last year even though there were not statistically significant differences in the initial year.

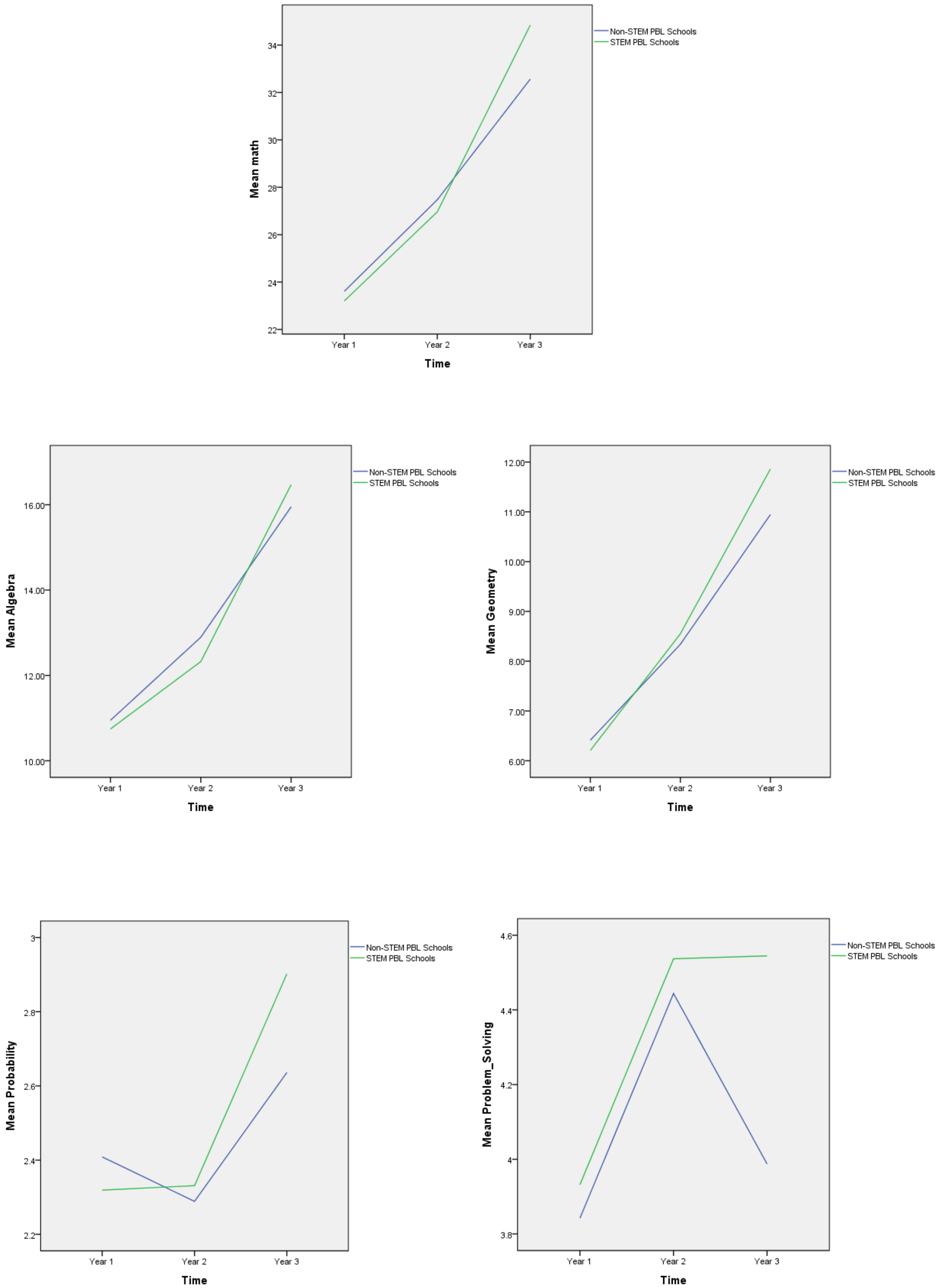

Figure 1. *Trajectories of Students' Mean Scores Across Three Years.*

DISCUSSION, CONCLUSION and IMPLICATIONS

The instructional use of STEM PBL has been examined as an appropriate instructional approach to improve students' mathematics scores, especially for low achievers (Han et al., 2014). In the present study, the impact of STEM PBL on student academic achievement in mathematics was investigated using a fine-grained strategy with respect to algebra, geometry, probability, and problem solving included in the curriculum of K-12 school mathematics. The findings for this study revealed that students in STEM PBL schools showed higher scores on geometry, probability, and problem solving than those in non-STEM PBL schools during the third year.

The current study expands the results regarding the impact of STEM PBL (i.e., Barron et al., 1998; Capraro et al., 2015; Han et al., 2014; Lou et al., 2011), on student achievement in mathematics. Students' scores in algebra, geometry, and probability showed similar trends using graphs of broken lines for students in STEM PBL and non-STEM PBL schools. However, problem solving showed no positive effects. This indicates that STEM PBL activities are likely to affect student knowledge connected to mathematical topics differently. Because STEM PBL has been regarded as a reformed instructional approach to improve students' problem solving skills (Capraro, Capraro, & Morgan, 2013), the results indicating there was no positive impact of STEM PBL on students' problem solving were not what was expected. As a reason for this unexpected result, the authors assumed that the term, "problem solving" or "problem" as measured by the test might be different from the construct defined by researchers. Problem solving was defined as finding "a way where no way is known, off-hand…out of a difficulty…around an obstacle" (Polya, 1945, p. 1) and capability to "engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen" (Programme for International Student Assessment, 2012, p. 30). According to these definitions, a problem must be non-routine to encourage students' problem solving skills. Unfortunately, most problems included on the test were word problems, but they did not all meet the bar for non-routine problems.

Students who demonstrate deep catalyzing understanding of integrated STEM develop profound understanding of the underlying content. From the results, student gained more than one might expect for just one year of year growth. When comparing to the control group, they gained on average about a quarter of a standard deviation for the best subjects and about a fifth of a standard deviation overall. The overall implications of the results is that sustained engagement with STEM PBL has a greater impact on student learning than did business as usual (no STEM PBL) group.

The findings of the study imply that lessons integrating STEM PBL should include diverse contents and contexts so students experience STEM PBL as an integrated whole. In the present study, students in STEM PBL and non-STEM PBL schools did not differ statistically on algebra performance. STEM PBL includes real world components, which are more likely to be integrated with geometry, probability, or problem solving because contextual situations based on a real world context might be more easily integrated.

Despite of the critical findings from the current study, there were two limitations that should be considered. Students' gender and the number of STEM PBLs students experienced could have had an effect on performance. Gender could have influenced the level of participation or functioned as a mediator for engagement. In particular, the STEM PBLs taught in science could have significantly contributed to their mathematics achievement. Therefore, the authors would strongly suggest further studies investigating the impact of STEM PBL on students' academic achievement in the subtopics of mathematics when considering student's individual, teaching and learning environments, and curriculum and standards factors. Another limitation that might be pointed out was that the results from this study could not be generalized to any students in other areas or countries. Depending on various regions and countries, instructional approaches for the mathematics topic areas might be different and they could affect students' scores in mathematics. Therefore, further studies need to examine the results from the current study with other students in other regions or countries.

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APPENDIX-1

15. THE WATER FLOWS THROUGH IT: DESIGN AND BUILD AN IRRIGATION SYSTEM

AUTHOR: JENNIFER WHITFIELD

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement – Present scenario.	Discuss features and benefits of irrigation systems. Analyze professional sprinkler designs.	Discussion on water conservation and irrigation's role in conservation.	Research key topics.	Investigate the functionality of an actual irrigation system.

Day 6	Days 7-8	Days 9-10	Day 11
Create a blueprint of the house and plastic containers.	Draw the design of the irrigation system on	Build irrigation system.	Give presentations.

WELL-DEFINED OUTCOME

Students must design and build a scaled-down version of an irrigation (lawn sprinkler) system that equally distributes water to different containers meant to represent grass on a yard, so the water depth in each container is 1.25 inches.

TEACHER INTRODUCTION

This PBL is designed for an on-level or above-level high school student. It uses a real world event to give students the opportunity to apply their knowledge of two-dimensional and three-dimensional measurements, operations on decimals, spatial reasoning, estimation, and properties of basic angles (45°, 90°, and 180°). Prior to attempting this project students should know how to operate on decimals, calculate the area of basic two-dimensional geometric shapes (circles, rectangles, triangles, etc.), calculate the volume of basic three-dimensional objects (cylinders, rectangular prisms, etc.), use tape measures to precisely measure lengths, and convert fractions to decimals. This PBL can be used as a major project for students to demonstrate understanding and ability to problem solve and think critically.

In this project, the teacher will give each group of students a shallow plastic tub that contains a small house constructed from Lego© and other plastic containers that are fixed to the box. The Lego© house should be constructed so students can easily measure its dimensions. The plastic containers represent the sections of a grass lawn that need to be watered, and the plastic containers will also hold the water that is dispensed from the irrigation system that students build. The plastic containers must be carefully chosen because students need to measure the dimensions and calculate the volume of the containers. Figure 1 shows a possible configuration of the house and the plastic containers.

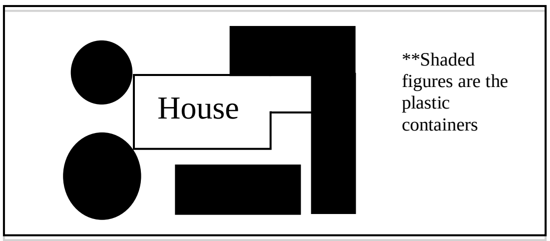


Figure 1. Sample configuration of Lego house and plastic containers.

One of the features of an irrigation system is that it spreads water uniformly across a given plot of land. In an attempt to duplicate this feature of irrigation systems in this PBL, students will build an irrigation system, with actual PVC pipe, that distributes water as uniformly as possible to each of the different containers. Students may only use hydrostatic pressure and the earth's gravitational pull as the force to move the water through the PVC pipe; students cannot make any adjustments to the plastic containers in the given box. Students must use only materials on the "Materials List" to build the irrigation system, and they will record the cost of building the irrigation system. The cost of the system will help them generate an invoice used to bill the customer.

Students must design the irrigation system so the water depth in each container is 1.25 inches. Students will have a main water source that will hold all the water used for one cycle of the irrigation system.

When students run the irrigation system through the cycle, they will fill the water main with a pre-calculated amount of water (i.e., enough water to fill each container with 1.25 inches of water). Then they will turn the valve so that the water runs through the system and consequently fills each water container. Students must record how long it takes the irrigation system to run through one cycle and try to minimize the amount of time it takes to uniformly disperse the water.

Once students have finished their irrigation systems (i.e. designed, built, tested, and refined the system), they will present their irrigation designs to an irrigation contractor and justify their designs. With the irrigation contractor present, students will run their irrigation systems through one cycle. Once the cycle is complete, students will measure the water level (height) for each container and report to the contractor how accurately the irrigation systems dispersed the water.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

Apply mathematics to problems arising in everyday life, society, and the workplace.
Use a problem-solving model that incorporates eighbour given information, formulating a plan or strategy, determining a solution, justifying the solution, and evaluating the problem-solving process and the reasonableness of the solution.
Communicate mathematical ideas, reasoning, and their implications using multiple representations, including symbols, diagrams, graphs, and language as appropriate.
Display, explain, and justify mathematical ideas and arguments using precise mathematical language in written or oral communication.
Apply the formulas for the volume of three-dimensional figures.
Explain flow rates and compare flow rates among their peers.

Science – The student is expect to:

Identify source, use, quality, management, and conservation of water.
Recognize and demonstrate that objects and substances in motion have kinetic energy.
Learn the dynamics of water.
Demonstrate basic principles of fluid dynamics, including hydrostatic pressure, density, salinity, and buoyancy.

English – The student is expected to:

Use appropriate strategies for rehearsing and presenting speeches.
Use appropriate interpersonal communication strategies in professional and social contexts.
State new vocabulary terms and use them in both written and verbal forms.
Determine the meaning of grade-level technical academic English words in multiple content areas.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

Water flow – Explain how flow rate can be measured in gallons per minute and liters per minute.
Hydrostatic Pressure.
Water conservation.
Inner workings of valves and other pipe fittings.

Technology

Learn how technology has advanced irrigation installation and learn about the innovative irrigation products available on the market to help conserve water.

Engineering

Apply design concepts to problems in physical and mechanical systems.
Use consistent units for all measurements and computations.
Engage in design and prototype development.
Use teamwork to solve problems.
Complete work according to established criteria.
Develop a plan for implementation of an individual product.

Mathematics

Add, subtract, multiply and divide decimals.
Analyze ratio, proportions, and measurement scales.
Calculate volume of solids.
Calculate area of common shapes (e.g., squares, rectangles, circles, and triangles).
Measure objects with precision.
Use special reasoning to devise a sprinkler plan.

STUDENT INTRODUCTION

In this PBL you will use graph paper to design a model irrigation system for a scaled down replica of a model home. The design will serve as the blueprint of the house and will need to be as detailed as possible, especially with measurements. Once you have the blueprint of the home, you will use PVC pipe and pipefittings to construct the model irrigation system you designed. You will have a main water source that will hold the water used for the irrigation system. When you are ready to run your irrigation system, you will turn the valve to release the water from the main water source and watch your irrigation system water the "lawn" of the model home. Your goal is to have a water level of 1.25 inches in each of the water containers surrounding your model home.

MATERIALS USED

For the Model Home

Large, shallow plastic tub
Structure to represent the house (a house built from Legos works nicely)
Water Containers of various sizes and shapes
Hot glue gun to secure the house and water containers in the plastic bin

For the Irrigation Design

Graph Paper
Colored Pencils and/or Markers
Scotch Tape
Ruler
Compass

To Build the Irrigation System

Pipe cutters
Pipe Glue (May be used by teacher only)
PVC Pipe Fittings (ells, cross, corner ells, couplers, caps, tees)
Hand Drill with various drill bits (May be used by teacher only)
Buckets of Water for testing system
Safety Goggles
½” PVC pipe
1”, 2”, and 3” PVC pipe
Reducers: 3” to 1½”, 2” to 1”, 1½” to ½”, and others as needed
Sharpie Markers
Towels for Clean-up
1” and ½” Ball Valves

For Assessments

Strips of colored paper
Copies of Formative Assessment #1
Copies of Final Rubric

DAY 1 (20 MINUTES)

Read the following scenario to the students.

It is May and school is almost out! You start thinking about how great it is going to be to stay up late every night and sleep-in every morning. You just can’t wait until the first day of summer when your life does not revolve around a schedule. You can go to bed when you want; you can eat what you want and when you want; you can play when you want; and you can get up when you want. Boy! That is the life! Wait….get up whenever you want…Oh no…that is not going to happen! Suddenly, you remember that last summer every Tuesday, Thursday, and Saturday you had to wake up at 4am to water the yard. Yes, your parents made you spend 2 hours, three days a week, early in the morning, moving hoses and water sprinklers around the lawn. Your parents are sticklers for water conservation and saving money. They have found that the best hours of the day to run a sprinkler system is from 4am-6am. So, they required you to water the lawn during these identified hours. You begin to remember how miserable you were waking up at 4am. You think about how wonderful it would be to have an automatic sprinkler system installed at your house. After all, last summer you saw the eighbour’s sprinkler turn on and off automatically while everyone in the house slept peacefully. Wouldn’t it be wonderful if a sprinkler system automatically turned on at 4am, went through each watering cycle, and then turned off automatically? You don’t know how your parents will react to the proposition of installing a sprinkler system, but you decide to go ahead and try to convince them of the benefits of having an automatic sprinkler system. The next night before bed you discuss this with your parents. You tell them how miserable you were last summer, state the benefits of having an automatic sprinkler, and share with them how many of the neighbors have an automatic sprinkler system. Much to your surprise your parents say they are open to the idea of getting an automatic sprinkler system installed. You can hardly believe it! They actually listened to you! The discussion continues for a few more minutes and then finally, they agree to have the system installed! How fantastic! Oh, but wait, they tell you this is contingent on a few things and you will find out about specifics of the plan in the morning. Specifics in the morning! Oh no….they have always been sticklers about details! You begin to wonder if getting up at 4am may be a better option. Nonetheless, you doze off to sleep. When you awake the next morning you notice an envelope with your name on the front. You grab the envelope, open it and begin to read.

At this point the teacher gives each student an envelope that contains the letter to the child (see Appendix for sample letter). Let the students either take the letter home to read or read the letter in class.

DAY 2 (50 MINUTES)

Start by showing the class the following images:
http://www.missouribotanicalgarden.org/Portals/0/Gardening/Gardening%20Help/images/Pests/Pest2460.jpg
http://www.outsidepride.com/blog/wp-content/uploads/2013/03/lawnUCVerde.jpg
Ask students to identify similarities and differences among the pictures. Students should notice one lawn is covered in green grass and the other has spots of brown and green. Conduct a discussion on how a sprinkler system can affect the appearance of a lawn and how the design of the system is a large factor in maintaining a lawn that looks nice. The discussion should bring out important concepts like:

The placement of the sprinkler pipe in the yard
The placement of the sprinkler heads in the yard
The number of sprinkler heads used in the system
How much water is released from each sprinkler head
You could have the students discuss where they think the pipe and heads would be placed in the pictures previously shown. You could show different pictures of lawns and see where the pipe is laid and where the sprinkler heads are placed. You could also show pictures of a sprinkler system that is watering a lawn and ask students if they can figure out where the pipe is laid. The whole discussion must focus on the importance of the design of the sprinkler system. If more motivation is needed during the discussion, show them this video: https://www.youtube.com/watch?v=uBKCDHnxJZw#t=28 (3:08).

Next put the students in groups and give each group of students a professional sprinkler design. Some sample sprinkler designs are given in the Appendix section, but there are also examples on the Internet. Have the students discuss, as a group, why the sprinkler pipe and sprinkler heads are placed as they are on the plan. Once each group has discussed the irrigation plan, distribute Formative Assessment #1 and have the students turn it in before they leave the classroom. A handout for Formative Assessment #1 is given in the Evaluation section of this PBL.

DAY 3 (50 MINUTES)

Conduct a discussion on the conservation of water and the role lawn irrigation systems play in the conservation of water. The discussion should surface concepts like the control of water flow (i.e. you don't want too much pressure or too little pressure), the strategic positioning of the sprinkler heads, and the time of day at which the automatic system can run. Follow this up by showing students the following two videos to help motive the idea of lawn irrigation and the details of designing an irrigation system.
https://www.youtube.com/watch?v=2UVoDRXx66Q (1:56)
http://www.youtube.com/watch?v=mhZrzIomNSo#t=257 (start at beginning but stop at 5:10)

After watching the videos have students break into groups. In their groups have the students list three roles that sprinkler systems play in the conservation of water. Give each group of students a different colored strip of paper and have the students neatly write the results of their discussion on the strip. They should write one idea per strip of paper. When the discussion period is over, have the students post their strips on a wall in the back of the classroom. Once all strips are posted, have a class discussion to share the ideas written on the strips of paper and sort the strips of papers so those that have the same theme are grouped together.

DAY 4 (50 MINUTES)

Allow students to research key topics online. There are at least two key concepts students should understand.

The basic concept of hydrostatic pressure and the role that it plays in this PBL. Students need to know how hydrostatic pressure will help push the water through their irrigation system. Students should do a web search of simple videos that explain fluids and hydrostatic pressure. Here is a website in the event students are having a difficult time finding simple explanations of pressure due to fluids. http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/water-pressure/

The features and purposes of each of the different pipefittings. Students need to research irrigation design. What parts are they going to use and how will each of these parts affect the flow of water within their irrigation systems? It will be helpful for them to go to a home improvement store (i.e., Lowe's, Home Depot) and look at the fittings. Alternatively, you could have some of the fittings and small pieces of PVC pipe available in the classroom for students to play with and see how they fit together. A list of necessary fittings is given in the materials list that is located in the Appendix section of this PBL.

DAY 5 (50 MINUTES)

During this time students will explore the functionality of a real sprinkler system. To do this you could invite a sprinkler contractor to class as a guest speaker and allow some time for students to ask questions. Ideally, this would be the same sprinkler contractor that will listen to the presentations of the students at the end of the PBL. If possible, the class could take a field trip to a job site where the contractor is installing an irrigation system. This would allow the students to see how the system is installed and ask the contractor questions. If a field trip is not possible, try to get some video footage of an actual sprinkler system being installed.

DAY 6 (50 MINUTES)

Once students have had the opportunity to research irrigation design and are familiar with the physical parts that make up the system, it is time for students to begin designing their irrigation systems. In this process students need to create a blueprint of the model houses they selected. The blueprints should be precise scale drawings of their model houses. Have students draw their blueprint on grid paper. Tip: Grid paper that has one-inch squares subdivided into a 10x10 grid work nicely. The blueprint should include the following:

A drawing of the house and of each water container. Students need to measure the dimensions of the house and of each water container, paying close attention to the location of the water containers relative to the house.

Labels of the dimensions of the house and of the water container.

The location of the main water source.

A legend that identifies icons used on the blueprint as well as scale factors (i.e. 1 square = 1 inch).

DAY 7-8 (50 MINUTES EACH DAY)

After the students have the model houses drawn on the blueprints, it is time for the students to draw the designs of the irrigation systems. During this stage, students need to consider the following items:

Students should consider the irrigation fittings that are available. The supplies students will use can be found on the supplies page (see Appendix). Notice that most of the fittings allow only for 90 degree or 180 degree turns in the system. Students must consider these angles during the design stage.

Students must be sure they plan for the pipe to stay on the exterior of the house. It is unreasonable, for example, to have pipe go over the house. In a real situation, sprinkler contractors do not bore pipe under the house. Sprinkler contractors bore under driveways and other small concrete objects, but not under an entire home. The pipe needs to remain outside the perimeter of the house and on the ground.

Students need to think about how much water needs to flow to each water container. Some of the bigger water containers will hold more water (at a 1.25 inch depth) than others and will consequently need more water flow. Water flow can be managed by the size of PVC pipe used and the number of turns in the system. If the students design a linear system (i.e. no tees) then the water flow will be different at the start of the linear design (closest to the water source) than at the end.

During the design stage, students need to plan where each water orifice will be placed and how many orifices will supply each water container. Discussion should also take place about the size (in diameter) of each orifice and the distance between each orifice, especially if there will be more than one orifice feeding one water container.

Students need to think about where they are going to put the pipe relative to the water container. Are they going to design the pipe to go through the center of the water container or are they going to place it more toward the edge?

Once students have an idea of their irrigation designs and all the intricacies of the designs, they need to draw the irrigation designs on the blueprints. Students should use some icon to show where all the orifices will be located on the irrigation system and also label the linear measurements of the system. In the sample blueprint different colors are used to represent a different aspect of the design. For example, black lines could represent the borders of the house, green lines the borders of the water containers, and blue lines the location of the pipes that will be carrying the water. The blueprint also contains a unique name for each water container and displays the volume of water each container will hold if the water level is 1.25 inches.

Once students have the designs of the system completed, they need to calculate the following and add to their blueprints.

The total amount of pipe they will need (in linear feet).

The total number of fittings they will need to construct the system.

The total cost of the system (based upon the prices in the supply list that is provided to them). Students will use the Irrigation PBL Customer Invoice sheet to help them calculate the total cost of their system. See Evaluation section of this PBL for Invoice handout.

The total amount of water (in cups) they will need to start with to ensure each container has 1.25 vertical inches of water in each container. This will involve a conversion from cubic inches to cups (students can figure this conversion factor on their own).

When students are finished with all aspects of the blueprint they should take their blueprint and the Checklist For Blueprint (see Appendix section) to at least 2 other groups for evaluation. Each group should have the blueprint peer reviewed – via the checklist – by at least 2 other groups.

DAY 9-10 (50 MINUTES EACH DAY)

Students will build the systems they designed in the blueprints. For this portion of the PBL it is important students have access to all the materials listed at the beginning of this PBL. Students will measure and cut the PVC pipe as indicated on the blueprints. Students should go through several iterations of measuring pipe, cutting pipe, and then making sure that they can lay the pipe over the containers and the Lego© house to ensure their construction is practical. Some adjustments may need to be made during this phase so their configuration of pipes matches the configuration of the Lego© house and containers. The students should wait to glue the final products together in the event changes are necessary to make the products operational. Once the final products are glued together, students can put the holes in the PVC pipes as planned on the blueprint.

DAY 11

After the students have designed their irrigation systems it is time to put them to the test. Each group – one at a time - will take the plastic bin that contains their Lego home and lay their irrigation system over the containers that will hold the water. Then the group will measure out the amount of water that was previously calculated to run one cycle of the system and put the water in the main water source. Once all water is in the main water source, the group will turn the value and let the system run through its cycle. When the system has finished running the cycle, the teacher will measure the water depth in each water container and record it for each group. Ideally, the irrigation contractor should be at this presentation to make a final rating on the design and demonstration of operation of the system.

EXTENSION

There are a number of different extensions you can provide for students.

For most students , they should use ½" pipe for their whole project. ButHowever, for students who are more advanced, you can allow them to mix the sizes of pipe for their project. This will require students to think about how water will flow in the different sized pipes and what happens to the flow of water when the pipe size changes (i.e. what happens if they change from 1" pipe to ½" pipe, how the change affects the water flow).

For most students, the teacher should have the water main constructed for them so they can focus on the sprinkler design. But, for students who are more advanced, you could have the students construct their own main water source.

Advanced students could figure the scale factor of their models and then figure the amount of materials needed for the large-scale designs. Additionally, they could construct the full "bid" for the sprinkler system and use the computer software a contractor uses to design their systems. IRRICAD is an example (http://www.irricad.com/).

Students could research the effects of friction on water flow through the pipes. After the research they could discuss how the concept of friction was involved in their designs.

Students can research how pressure affects the rate of flow within the system.

EVALUATION

Final Product Rubric

CATEGORY	4	3	2	1
Resembles the Design	90%-100% of the final product follows the design of the blueprint.	80%-89% of the final product follows the design of the blueprint.	70%-79% of the final product follows the design of the blueprint.	69% or less of the final product follows the design of the blueprint.
Materials	For the entire project, appropriate materials were selected.	For most of the project, appropriate materials were selected.	For some of the project, appropriate materials were selected.	For most of the project, inappropriate materials were used.

Care During Construction	Great care was taken in the construction process so that the structure is neat and follows plans accurately.	Construction was careful and accurate for the most part, but 1-2 details could have been refined to improve the product.	Construction accurately followed the plans, but 3-4 details could have been refined to improve product.	Construction appears careless or haphazard. Many details need refinement.
Accuracy of Measurements	The total amount of pipe used is the same amount calculated on the blueprint.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by 10%.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by 20%.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by more than 20%.

Functionality of the Final Product Rubric

CATEGORY	4	3	2	1
System Accesses all Water Containers	The system distributes water to all of the water containers.	The system distributes water to all BUT one of the water containers.	The system distributes water to all BUT two of the water containers.	The system did not distribute water to three or more of the water containers.
Water Level of Each Water Container	The system distributed 1.25" of water to all of the water containers.	The system distributed 1.25" of water to all BUT one of the water containers.	The system distributed 1.25" of water to all BUT two of the water containers.	The system did not distribute 1.25" of water to three or more of the water containers.
Amount of Water at the Water Main	The system had the exact amount of water in the water main to run the system.		The system had too little or too much water in the water main to run the system.	
Amount of Time to Run One Cycle of System	The amount of time it took for the system to run through one cycle was very reasonable.	The amount of time it took for the system to run through one cycle was reasonable. One adjustment could have made the system run more efficiently.	The amount of time it took for the system to run through one cycle was somewhat reasonable. Two adjustments could have made the system run more efficiently.	The amount of time it took the system to run through one cycle was not reasonable. Major improvements are required for the system to run efficiently.

Design of the System Rubric

CATEGORY	4	3	2	1
The Blueprint	Lines are clear and not smudged. There are almost no erasures or stray marks on the paper. Color is used carefully to enhance the drawing. Overall, the quality of the drawing is excellent.	There are a few erasures, smudged lines or stray marks on the paper, but they do not greatly detract from the drawing. Color is used carefully to enhance the drawing. Overall, the drawing is good.	There are a few erasures, smudged lines or stray marks on the paper, which detract from the drawing OR color is not used carefully. Overall, the quality of the drawing is fair.	There are several erasures, smudged lines or stray marks on the paper, which detract from the drawing. Overall, the quality of the drawing is poor.
Checklist for Blueprint	3 other groups completed the Checklist for Blueprint.	2 other groups completed the Checklist for Blueprint.	1 other group completed the Checklist for Blueprint.	No other groups completed the Checklist for Blueprint.

Modification/Testing	Clear evidence of troubleshooting, testing, and refinements based on data or scientific principles.	Clear evidence of troubleshooting, testing and refinements.	Some evidence of troubleshooting, testing and refinements.	Little evidence of troubleshooting, testing or refinement.

Formative Assessment #1

After you have listened to another group's presentation list three reasons why the sprinkler pipes and heads were placed as they were on the irrigation plan.

1.

2.

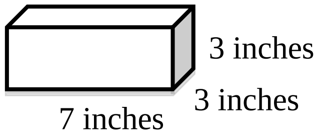
3.

Multiple Choice Problems

1) Sally had a sprinkler pipe that was 3.5 feet long. She wants to cut this piece of pipe into four equal pieces. Where should she make the first cut on the pipe?

   A) The first cut should be made at 7/8 of a foot.
   B) The first cut should be made at 7/16 of a foot.
   C) The first cut should be made at exactly 1 foot.
   D) The first cut should be made at 1/4 of a foot.

2) Find the volume of the three-dimensional container below.



   A) 21 cubic inches
   B) 63 cubic inches
   C) 13 inches
   D) 9 cubic inches

3) Which of the following are ways in which automatic sprinkler systems help with water conservation?

   A) Water in 2-3 short cycles rather than a single long period of time.
   B) There are numerous accessories (rain sensor, smart controller, etc.) that can be added onto sprinkler systems to help prevent the system from running when unnecessary.
   C) Program the system to run in the early hours of the morning.
   D) All of the above.

4) A rectangular block of length 8 cm and width 4 cm has a volume of 96 cm^3. What is the height of the block?
   A) 32 cm
   B) 3 cm
   C) 8 cm
   D) 54 cm

5) For every 33 feet (10.06 meters) you go under water, the pressure ____________ by 14.5 pounds per square inch (1 bar).
   A) Decreases
   B) Increases

Correct Answers: 1-A 2-B 3-D 4-B 5-A

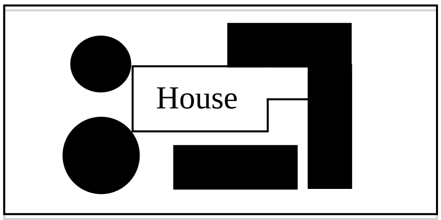
APPENDIX-2

Letter to Child

To our dear and sweet child;

We are thrilled that you have approached us with the idea of installing an automatic sprinkler system. This could be a great thing for all of us involved. For us to finalize this deal, however, we want you to use this as a learning opportunity. We want you to design and build a model of an irrigation system for a scale-model of a house. Here is how it will work:

We will give you a box that contains a Lego©-constructed house and other containers that are fixed to the box. These containers represent the sections of the lawn that need to be watered and will hold the water that is dispensed from the irrigation system. Here is a possible configuration of the house and containers you may see.



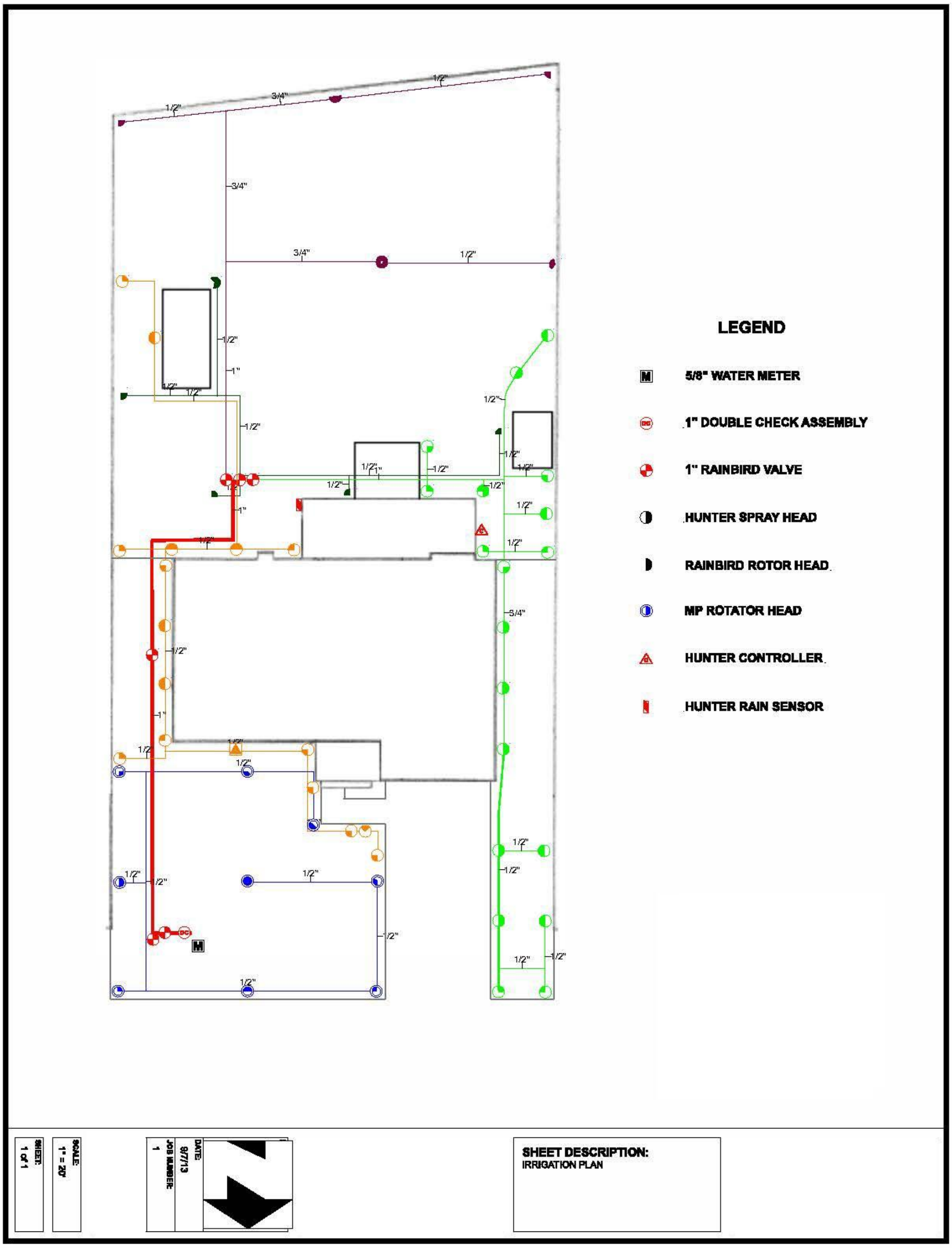
You told us that one benefit of an irrigation system is that it can spread water uniformly across a given plot of land. Thus, you must design an irrigation system that disperses water as uniformly as possible to each of the different containers. You may only use hydrostatic pressure and the earth's gravitational pull as the force to move the water and cannot make any adjustments to the containers in the given rectangular box. We will give you a list of materials you can use for the project and their corresponding prices. You may only use materials listed on this supply list. You must minimize the cost and adhere to the prices given on the supply list. You must design the system so the water depth in each container is 1.25 inches. You will have a main water source that will hold all the water you will use for one cycle of the irrigation system. When you run the irrigation system through the cycle, you will fill your water main with a pre-calculated amount of water. Then you will turn the valve so that the water runs through your system and consequently fills each water container. You must record how long it takes your irrigation system to run through one cycle and try to minimize the amount of time it takes to uniformly disperse the water.

Once you have finished your irrigation system (i.e. designed, built, tested, and refined your system), you will present your irrigation design to an irrigation contractor and justify your design (i.e., why did you design it the way you did). With the irrigation contractor present, you will run your irrigation system through one cycle. Once the cycle is complete, you will measure the water level (height) for each container and report to the contractor how accurately your irrigation system dispersed the water.

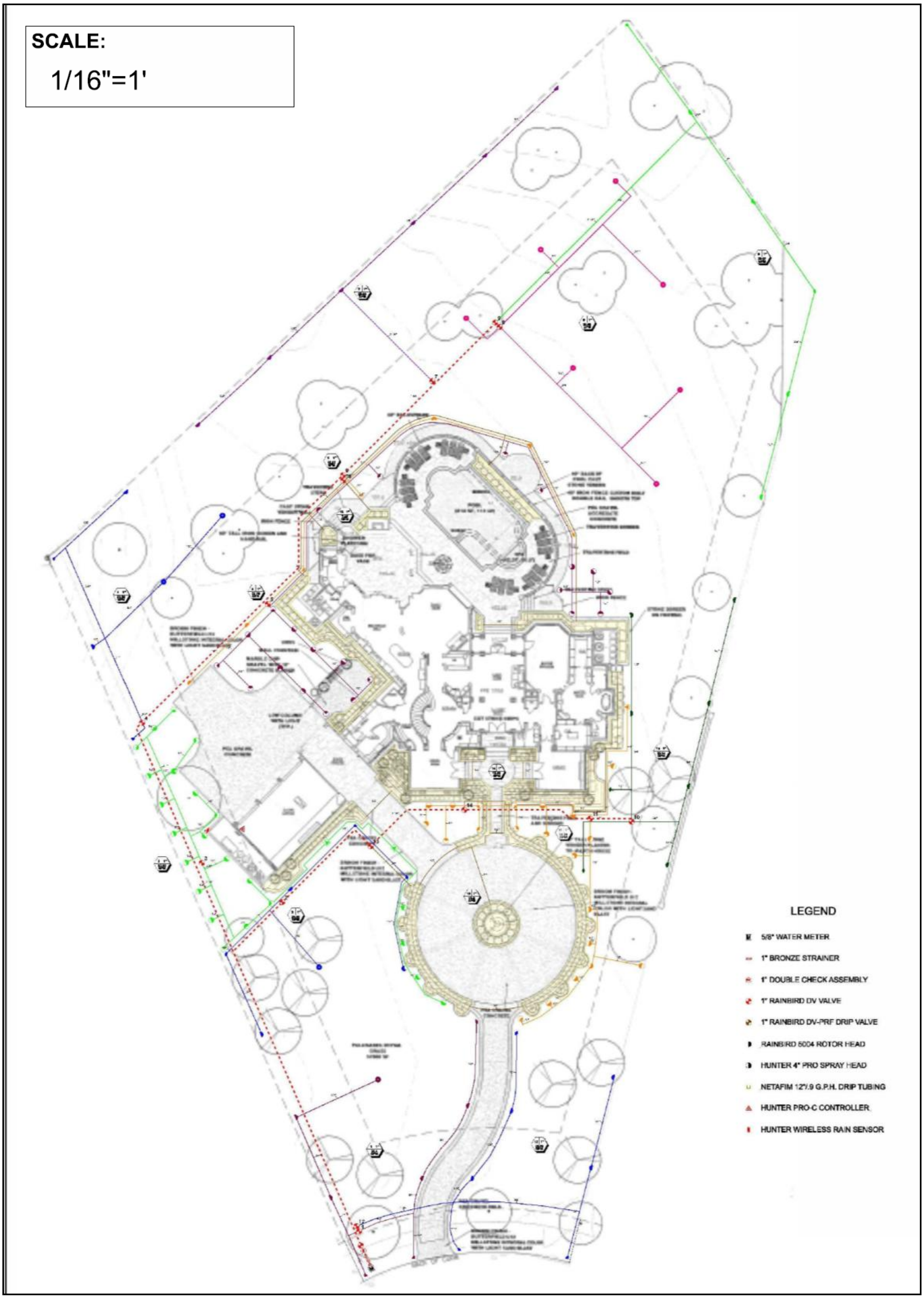
If the irrigation contractor is convinced that your irrigation system is well designed, then we will pay the irrigation contractor to install the sprinkler system. If the irrigation contractor is not convinced your irrigation system is well designed, then you will have to help the contractor install the system so you can better master the details regarding irrigation design and construction.

With Love,
Mom and Dad

Professional Sprinkler Design #1



Professional Sprinkler Design #2



Materials List

ITEM	UNIT COST
½" 90 degree Slip Elbow	$0.19
½" 45 degree Slip Elbow	$0.58
½" 90 degree Side Outlet Elbow	$1.18
½" Coupling	$0.29
½" 90-degree Tee	$0.35
½" Cap	$0.35
½" 90-degree Cross Tee	$0.98
½" PVC Pipe (1 linear foot)	$0.20
½" PVC In-line Ball Valve	$2.52
¾" 90 degree Slip Elbow	$0.35
¾" 90-degree Cross Tee	$1.79
¾" 45 degree Slip Elbow	$0.74
¾" Coupling	$0.35
¾" 90-degree Tee	$0.42
¾" Cap	$0.42
¾" PVC Pipe (1 linear foot)	$0.26
¾" PVC In-line Ball Valve	$3.05
¾" x ½" Bushing	$0.39
½" x ½" x ¾" 90-degree Tee	$0.71
1 ½" x ½" Bushing	$0.88
3" x 1 ½" Adapter Coupling	$3.72
2" x ¾" Bushing	$0.98
1 ½" x 3" Adapter Coupling	$3.72
3" x 2 ft. PVC-DWV Pipe	$6.28
Primer and Glue charge	$1.50

Sample Customer Invoice

Date	Order No.	Sales Rep.	FOB	Ship Via	Terms	Tax ID

Quantity	Item Description	Unit Price	Total

Subtotal:	
Tax:	
Miscellaneous:	
Balance Due:	

Checklist for Blueprint

Once you believe your blueprint is complete, take your drawing and this checklist to at least 2 other groups and have them check for the following items:

BP=blueprint	Yes	No
1. The BP contains the drawing of the house and is labeled as such on BP.		
2. The drawing of the house on the BP is accurate (measured correctly).		
3. The drawing of the house on the BP is precise.		
4. The BP contains drawings of all the water containers.		
5. The drawing of the water containers on the BP is accurate.		
6. The drawing of the water containers on the BP is precise.		
7. The dimensions of all house measurements are labeled on the BP.		
8. The dimensions of all water container measurements are labeled on the BP.		
9. The volume of water that each water container will hold (depth = 1.25") is labeled.		
10. The location of the pipe is drawn on the BP.		
11. The length of each section of pipe is labeled on the BP.		
12. The location of the orifices are drawn and labeled on the BP.		
13. The total amount of pipe (in linear feet) is displayed on the BP.		
14. The total number of fittings they will need to construct the system is displayed on BP.		
15. The total amount of water (in cups) necessary to run the system is displayed on the BP.		

REFERENCES

For help creating rubrics try http://rubistar.4teachers.org/index.php
A simpler version of this PBL is found at http://tryengineering.org/lesson-plans/irrigation-ideas
Special thanks to the owner of Raintec Irrigation Systems for helping with this PBL. http://www.raintecirrigationsystems.com/
Videos and other resources to help with concepts within this PBL:
https://www.youtube.com/watch?v=2UVoDRXx66Q
http://www.youtube.com/watch?v=mhZrzIomNSo#t=257
http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/water-pressure/