What does Project-based Learning (PBL) Look like in the Mathematics Classroom?

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Abstract This literature analysis addresses two issues concerning project-based learning (PBL) in the mathematics classroom: What it “looks like” and what its effectiveness in teaching skills. Articles addressing PBL in K-20 mathematics education were examined to determine what other discipline(s) the project included, what math topic(s) each addressed, and whether it demonstrated gains in students’ mathematical skills. Results show that about half of the projects applied engineering with the mathematics. Gains in achievement were mixed and transferred to standardized or state assessments only when PBL was a core component of a school’s curriculum. The lack of available research, however, discourages generalizations.

Keywords: project-based learning (PBL), mathematics education


1. Introduction

Project-based learning (PBL) is experiencing a resurgence in American classrooms from early elementary school through college [1]. It allows students to learn content within a context, apply prior knowledge, and gain skills not found in traditional education, such as how to collaborate. PBL is a cornerstone pedagogy for STEM/STEAM approaches in the classroom as it allows the integration of several disciplines within one project [2]. And while there is growing research in the use and benefits of PBL in science classrooms, there is currently little research of PBL in the mathematics classroom at any grade level.

One reason for this lack of research may be the belief that formal mathematics should be taught before applications are introduced to the students. Nathan [3] reviewed several studies that investigated the beliefs surrounding the difficulty level of story problems and symbolic problems in arithmetic and algebra. Teachers consistently rated the symbolic problems as the easiest for students to understand and the story problems as the most difficult. When researchers in mathematics education were also asked to rate the difficulty level of these problems, the majority likewise said that the story problems would be the most difficult and the symbolic the easiest. Because of this belief, both groups felt that formal symbolic problems should be taught before students are introduced to applications in mathematics. Similarly, Rogers, Cross, Gresalfi, Trauth-Nare, and Buck [4] investigated teacher beliefs about what it means to be successful in their content area and how that influenced their implementation of PBL. Their case study included one mathematics teacher. He believed that success in mathematics was equivalent to success on standardized assessments. As he tried implementing PBL in his classes, he became convinced that students could not learn from projects unless they had first mastered procedural mathematics. This teacher left the study halfway through the school year because he did not see how PBL would help his students to master the formal mathematics that the state exam required.

The other reason PBL may not be studied as much in mathematics education is because teachers are not able to develop or implement a suitable project. For PBL to be effective, the project should engage students in exploration, be challenging, connect to the prior experiences of the students, and be of interest to the students [5]. Additionally, the teacher needs to be comfortable both in the non-mathematical content addressed in the project and in his/her abilities to be in a facilitator’s role [6]. Finally, finding the time and resources to do a PBL unit is the most challenging barrier for teachers, as these projects take longer than traditional lessons to both develop and conduct [7].

This analysis of the literature will investigate two of the issues concerning PBL implementation in mathematics. First, what does PBL “look like” in the mathematics classroom? Second, can PBL increase students’ skills in formal mathematics? Understanding the research in these two areas may help teachers and researchers to design PBL units easier and be more accepting of them as a valid approach to mathematics learning.

2. Method

In order to identify studies and articles addressing PBL in the mathematics classroom, this researcher used Thomas’ [8] criteria for authentic PBL projects:
1) The students must be learning the central concepts through the project, rather than projects for enrichment and projects that applied prior learning.
2) The project centered on an ill-defined problem or driving question.
3) The project resulted in the construction of new knowledge for the students rather than a new way of considering already-learned material.
4) The project was student-driven with the teacher acting as a facilitator.
5) The project was realistic.

As an additional criterion, articles were included if they addressed mathematics learning for students in grades K-12 or undergraduates in college.

Academic Search Complete, ERIC, Educational Full Text and Google Scholar were searched using the following terms: project-based learning, PBL, mathematics, and constructivism. Although the search resulted in hundreds of articles, only thirty-one met the above criteria for PBL in mathematics education. Most of the rejected articles concerned science learning in STEM-based projects or pre-service teacher education. Seven of the accepted articles were authored by the same researcher, Brian Bottge. Of these seven, several addressed the same projects so the most recent article concerning each unique project was kept for this review. These included articles were also the most comprehensive studies that Bottge had conducted with each project. The final total number of articles kept for this review was twenty-seven.

The articles were then analyzed for the following information: grade level of the students, description of the project, mathematics addressed in the project, duration of the study, methodology, and results. The grade level of the students was then coded as follows: early elementary (K-2), late elementary (3-5), middle school (6-8), high school (9-12), and college. Two studies included students in grades five through eight; these were coded as middle school students. Most of the articles described at least one project, with the next most prevalent representation being middle school students. Most of the articles described at least one project, three described schools with full PBL curriculums, and one described the project’s objectives rather than the project itself. Table 1 describes the number of projects for each grade level.

Two of the full PBL curriculum schools were high schools and one was a middle school. These were not included in the above counts.

The most popular discipline outside of mathematics addressed in these projects was engineering. A little more than half of the projects addressed engineering standards, as they had students building, designing, or analyzing a physical object. Engineering was also represented across all grade levels, although the majority of these projects were done by middle school students or older. Science and finance were equally the second most popular, with each being represented in seven projects. Science projects were primarily completed by high school and college students. Students in elementary or middle school were the only students who worked with projects involving finances. Table 2 shows the distribution of disciplines across grade levels.

A range of mathematics was addressed in the projects as well. Most of the projects addressed geometry and measurement topics. Working with functions and formulas, data and statistics, and fraction and ratio topics were the next most common mathematics addressed, although only data and statistics were included in the elementary grade projects. All but six of the projects addressed multiple math topics. Table 3 shows the distribution of math topics across grade levels.

### 3. Results

Examples of PBL was found in all grade bands, from early elementary to undergraduate classes, and addressed a multitude of topics in mathematics. The majority of the articles concerned high school students, with the next most prevalent representation being middle school students. Most of the articles described at least one project, three described schools with full PBL curriculums, and one described the project’s objectives rather than the project itself. Table 1 describes the number of projects for each grade level.

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### Table 1. Number of projects per grade band

<table>
<thead>
<tr>
<th>Grade Level</th>
<th># Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary – early</td>
<td>5</td>
</tr>
<tr>
<td>Elementary – late</td>
<td>4</td>
</tr>
<tr>
<td>Middle school</td>
<td>7</td>
</tr>
<tr>
<td>High school</td>
<td>9</td>
</tr>
<tr>
<td>College</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 2. Number of projects per non-mathematics discipline

<table>
<thead>
<tr>
<th>Discipline</th>
<th># Projects</th>
<th>EE</th>
<th>LE</th>
<th>MS</th>
<th>HS</th>
<th>College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Engineering</td>
<td>14</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Finance</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Science</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

EE=early elementary, LE = late elementary, MS = middle school, HS = high school; One agriculture project included both middle and high school students; one engineering project included both high school and college students; three projects addressed both engineering and finance.
Table 3. Number of projects per math topic

<table>
<thead>
<tr>
<th>Math topic</th>
<th># Projects</th>
<th>EE</th>
<th>LE</th>
<th>MS</th>
<th>HS</th>
<th>College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry and measurement</td>
<td>13</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Data and statistics</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Fractions, ratios, proportions</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Money</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Charts and graphs</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Functions and formulas</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Trigonometry</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

EE=early elementary, LE = late elementary, MS = middle school, HS = high school.

Table 4. Number of articles showing gains or no gains in student achievement

<table>
<thead>
<tr>
<th>Math topic measured</th>
<th># Articles demonstrating gains</th>
<th># Articles not demonstrating gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Statistics</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fractions</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Trigonometry</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Word Problems</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>State or standardized exam used</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Students with LD measured</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>College grades</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>7</td>
</tr>
</tbody>
</table>

To determine if PBL can help students increase their skills in formal mathematics, the findings reported in each article were analyzed to determine gains based on the math topic tested, if standardized or state exams were used, and if students with learning disabilities showed gains. Most of the studies that reported such findings only reported one or two of these measures, and fifteen of the articles did not measure student gains in mathematical skills. Table 4 summarizes the results of the remaining twelve articles. Although these are not enough studies to make generalizable remarks, it is notable that three studies failed to show gains in fractions and word problems skills. Similarly, PBL did not always translate to success on standardized or state exams and were not consistently beneficial for students with learning disabilities. However, the three articles that did report gains on state exams were also concerning schools that had integrated PBL throughout their mathematics curriculum rather than as a stand-alone project or intervention. An equal number of studies demonstrated and did not demonstrate gains for students with learning disabilities.

4. Discussion

What does PBL look like in the mathematics classroom? This review found that PBL primarily integrates engineering principals with the mathematics, regardless of grade level. Students build or design real objects and learn the mathematics through that process of building or designing. These projects primarily addressed geometry and measurement topics, which are natural and required skills when building, but also allowed students to work with data and fractions. Science was also a common second discipline for math PBL, especially with high school and college students. Those projects allowed students to learn math modeling and function analysis while addressing more advanced science topics like marine biology. However, some projects combined math and science in elementary grade projects. In these projects, students learned basic data analysis to understand the natural world around them. Also with younger students, finance was a common second discipline for math PBL, which is not surprising because understanding money is often taught in those grades.

Unfortunately, there is not enough evidence that PBL in mathematics actually helps students to increase their mathematical skills. Only twelve of the twenty-seven studies found for this review measured student achievement; the remainder measured attitudes towards mathematics or STEM careers, or did not research the students themselves. The studies that did measure achievement showed mixed results. While topic-specific assessments tended to show gains in achievement, state and standardized assessments did not unless the entire math curriculum at that school was oriented towards PBL. This suggests that PBL gains only transfer to standardized measures when it is a regular occurrence for students rather than an isolated event. Results for students with learning disabilities was also mixed, with an equal number of studies showing gains and not showing gains for these students. Further research may help clarify both of these issues.

Most troubling, however, is the lack of research available for PBL in the mathematics classroom. With only twelve studies measuring achievement, and reporting
mixed results, we cannot say at this point in time if PBL is or is not an effective approach to math education. With only twenty-seven studies addressing PBL in mathematics at all, we cannot determine which disciplines pair well with mathematics in these projects. Nathan [3] found that teachers and researchers both believed that students would find story problems more difficult than symbolic ones. Perhaps this belief prevents researchers from looking closer at PBL for mathematics, since PBL is envisioned as being even more complex than story problems are. However, the studies in Nathan’s [3] review also presented those story and symbolic problems to student teachers and researchers both believed that students would find story problems more difficult than symbolic ones. However, the studies in Nathan’s [3] review also presented those story and symbolic problems to student and asked them to solve as many as they could. The students were more successful with the story problems.

References


Articles Used in This Analysis

Arnold, A. The effects of project based learning on middle school students’ attitudes and achievement in mathematics education (Doctoral dissertation), 2012.

Grade: MS
Project: Design and model a rollercoaster
Discipline: Engineering
Math: Geometry, basic statistics
Duration: 16 weeks


Grade: MS
Project: Building a variety of objects within a budget
Discipline: Engineering, finance
Math: Measurement, money, fractions
Duration: 7 months


Grade: MS
Project: 2 video problems: buying pizza for a party, designing a pet cage; 1 group also applied learning by building a compost bin with the least amount of wood possible
Discipline: Engineering, finance
Math: Budgeting, scale drawings, unit conversions, mixed numbers
Duration: 22-30 classes


Grade: MS
Project: Building a skateboard ramp, hover-board safety cage, and toy car stunt tracks; each within a budget
Discipline: Engineering, finance
Math: Ratios & proportions, fractions, measurement & geometry, graphing, statistics
Duration: 3+ months


Grade: HS
Project: Simulated environment where students cared for pigs
Discipline: Agriculture
Math: Numeracy including ratios, percents, fractions
Duration: 10 days


Grade: MS
Project: PBL charter school where the math curriculum uses 2 PBL-based programs
Discipline: Various
Math: K-8 math standards
Duration: multiple years


Grade: HS
Project: PBL high school, various projects - only one described was bungee-jumping Barbie
Discipline: Various
Math: HS math standards
Duration: 5 years

Grade: MS & HS  
Project: Operating a subdivision that integrates both suburban living and a farm; each grade level had a different focus of this problem  
Discipline: Agriculture  
Math: Multiple, especially function analysis and regressions  
Duration: 5 years, not reported was how much of each year was used on this project  
Grade: college  
Project: Determining if a gas additive improved fuel efficiency in cars  
Discipline: Engineering  
Math: Function analysis, systems of equations  
Duration: 1 semester  
Grade: HS & college  
Project: Building robots with Lego Mindstorms (camp); student choice using mechatronics (undergrads) that get shared with high school classes  
Discipline: Engineering  
Math: Multiple - stated in article were fraction/ratio and function/relation concepts and some trigonometry  
Duration: 1 week camp and integrated in the school year  
Han, S., Caparo, R., & Caparo, M. “How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement.” *International Journal of Science and Mathematics Education, 13*, 2015.  
Grade: HS  
Project: Various  
Discipline: Various  
Math: Various  
Duration: 3 yrs.; once every 6 weeks  
Grade: EE  
Project: Grade 1: observing bugs and nature; grade 2: marble track building; grade 3: bridge building  
Discipline: Science, engineering  
Math: Data collection and analysis, geometry & measurement, estimation  
Duration: Not reported  
Grade: college  
Project: Investigating & predicting brine shrimp movement and population changes  
Discipline: Science  
Math: Math modeling, data analysis, statistics, differential equations  
Duration: 5 class meetings  
Grade: LE  
Project: Charting weather and making predictions  
Discipline: Science  
Math: Bar and line graphs  
Duration: 2 weeks  
Grade: LE  
Project: Design a recreation room with soundproofing, facilities kids like, and under $7000  
Discipline: Finance  
Math: Measurement, budgets, data analysis  
Duration: 10 days  
Grade: college  
Project: Modelling volcanic ash fall after an eruption  
Discipline: Science  
Math: Math modeling, function analysis, interpretation  
Duration: Not reported  
Grade: LE  
Project: Designing, testing, and evaluating kites  
Discipline: Engineering  
Math: Geometry  
Duration: 1 unit, time not reported  
Grade: MS  
Project: Using LEGO robotics to design a green city, including powering wind turbines and designing a dam  
Discipline: Engineering  
Math: Measurement, using formulas, graphs, data analysis, informal ratios  
Duration: 1 week  
Grade: LE  
Project: Video game development  
Discipline: Technology  
Math: 3rd grade math standards  
Duration: Full school year  
Grade: HS
Project: Design, implement, and analyze ways to reduce vibration on buildings from earthquakes
Discipline: Engineering
Math: Trigonometry
Duration: 1 week

Grade: HS
Project: Chapter projects where students present an experiment or activity to the class; individual year-long projects of their choice from a list of physics projects
Discipline: Science
Math: Varied
Duration: Chapter-long and year-long

Grade: HS
Project: PLTW courses - Introduction to Engineering Design, Principals of Engineering, Digital Electronics
Discipline: Engineering
Math: Not specified
Duration: Each course lasted a full school year

Grade: EE
Project: Planning a party and purchasing items for an animal charity using donations received
Discipline: Finance
Math: Numeracy, geometry, charts and graphs
Duration: 1 month each

Grade: college
Project: Created a multi-function electric vehicle for a contest
Discipline: Engineering
Math: Calculus, graph theory
Duration: 5 weeks
Tural, G., Yigit, N., & Alev, N. “Examining problems in project work executed in high schools according to student and teacher views.” *Asia-Pacific Forum on Science Learning and Teaching, 10*(1), 2009.

Grade: HS
Project: Students came up with ideas
Discipline: Science
Math: Varied
Duration: Varied

Grade: HS
Project: Only objectives described
Discipline: Unknown
Math: Polygons, similar triangles
Duration: 4 weeks

Grade: HS
Project: Teacher-designed projects that implement the engineering design process
Discipline: Engineering
Math: Various, geometry mentioned
Duration: Varied: 1 week – 1 school year