Proceedings of The National Conference
On Undergraduate Research (NCUR) 2012
Weber State University, Ogden Utah
March 29 – 31, 2012

The Effects of Project-Based Learning (PBL) Approach on the Achievement and Efficacy of High School Mathematics Students: A Longitudinal Study Investigating the Effects of the PBL Approach in Mathematics Education.

[1]Anna Filcik, [1]Kristen Bosch, [1]Samuel Pederson, [2]Nicholas Haugen,
[1]Mathematics Department and [2]Engineering Department
Hope College
Holland, MI 49422 USA

Faculty Advisors: Dr. Vicki-Lynn Holmes and Dr. Yooyeun Hwang

Abstract

Project-Based Learning (PBL) is a teaching method that is significantly different from the conventional classroom teaching; however, the positive effects of PBL have not been clearly established. This longitudinal study investigates the effect of Project-Based Learning on secondary mathematics' students in order to determine both academic skill development and motivational factors that affect learning. Motivational factors to be measured include self-regulation, self-efficacy, and learning strategies. Unlike previous studies conducted in conventional school environments, this study is conducted on a dedicated project-based high school, where PBL is not being used as additional or supplemental teaching, but as a whole curriculum. This study provides the opportunity for teachers to reflect on the effectiveness of this pedagogical approach to mathematics teaching and learning. Because this study's participants represent a wide range of mathematical abilities and demographic diversity, it may bring clarity on controversial issues regarding the benefits of PBL on certain populations. Specifically, PBL has been shown to work well with students who already have a deep conceptual knowledge of the subject matter, but it may be less effective with those possessing only surface knowledge (Vernon & Blake, 1993; Dochy, Segers, van den bossche, & Gijbels, 2003). In addition, the benefits of PBL on low SES students are debated (Boaler, 2002; Delpit, 1988, Lubienski, 2000). Even though research shows that elementary mathematics students benefit from PBL, very little evidence is associated with secondary success (Petrosino, 2004; Strobel & Van Barneveld, 2009; Walker & Leary, 2009). Hence, this study provides a unique opportunity for teachers to understand the additional dimension of PBL approach on these various populations.

Keywords: PBL, mathematics, education

This study follows 8th and 9th graders through high school graduation, thus providing teachers with a solid picture of the developmental process of learning secondary mathematics through PBL.

1. Introduction

Project-Based Learning (PBL) is a teaching method that is significantly different from the conventional classroom teaching. In this teaching approach, students are challenged to design solutions for authentic and meaningful questions and problems in the real world. The PBL is not being used as additional or supplemental to "regular" teaching, but the whole curriculum is carried out through working on these authentic projects. Students in PBL classrooms work in small groups to complete the projects, and they work independently from their teachers as possible.

Research indicates that PBL, with its ‘hands-on, minds-on” (NCTM, 2002, p. ?), group problem solving approach to learning, enhances student’s ability to apply knowledge in real world scenarios and retain the knowledge learned (Gijbels, Dochy, Vanden Bossche, & Segers, 2005; Smith, 2003). The advocates of the PBL claim that students tend to be more motivated to learn the necessary information for their projects (Dunlap, 2005; Larmer, Ross & Mesgendollar, 2009). Generally however, the approach has been shown to work well with students who already have a deep conceptual knowledge of the subject matter, but may be detrimental to those with only surface knowledge (Vernon and Blake, 1993; Dochy, Segers, van den bossche, & Gijbels, 2003).

This fall of 2010, the Holland School District in Texas (or wherever) opened a new PBL high school (i.e., Holland New Tech high school), which will start with 8th and 9th graders in the first year. Demographics at Holland New Tech high, where PBL will be launched full scale in the fall of 2010 indicate a high at-risk population, with approximately 33% of 8th and 9th graders performing below minimum proficiency (Department of Education MEAP, 2009; Michigan Merit Exam, 2010). Additionally, approximately 39% are eligible for free and/or reduced lunch, a strong indicator for mathematics under-achievement (public school review, 2010). In light of Holland New Tech’s demographics, studying the approach that Holland New Tech employs on students with low mathematics skills and their resultant effects can impact the mathematics education community. Thus, this longitudinal study was designed to follow these students who are new to PBL curriculum from the beginning until they graduate from the high school to investigate the effects of the PBL approach in math education.

To compare the effectiveness of PBL approach in teaching and learning mathematics, we compared the PBL approach to a conventional way of teaching math. The comparison group was a nearby public high school that shared similar demographics. Holland Public Schools has agreed to allow us to observe the mathematics classrooms and interview their mathematics teachers for the duration of the study.

The goal of the present study is to identify the specific factors that contribute to the students’ learning in math within the context of PBL. We will look at both external and internal factors that may affect in math education in this new PBL high school. In external factors, we will look at the implementation of PBL including math teachers, teaching approaches, curriculum and small group work. In internal factors, we will look at the students’ progress in math skills, achievements and motivations.

Since the goals of the present study are to investigate strengths and weaknesses of the PBL program for the math education, the findings will inform the instructors to improve the approach that will affect students’ learning positively. The changes will be certainly beneficial to the students of the Holland New Tech high school in Holland. More importantly, it can be generalized to the other PBL programs and mathematics education in general.

The possible benefits of this study are both practical and tangible, with increased pedagogical content knowledge in mathematics being chief.

2. Method

During the fall of 2010, Holland School District opened a new Project=Based Learning high school (i.e., Holland New Tech), which began with 8th and 9th graders in the first year Tthese students are being following until graduation to investigate the effects of PBL on their mathematics learning. This study is a 5 year longitudinal project.

2.1 Participants

Holland New Tech’s demographics are comprised of a high at-risk population; approximately 33% of 8th and 9th graders perform below minimum proficiency in mathematics (Department of Education MEAP, 2009; Michigan Merit Exam, 2010). Additionally, approximately 39% are eligible for free and/or reduced lunch which is a strong indicator for mathematics under-achievement (public school review, 2010). The total number of students is 92 (40 females and 52 males; 47 8th and 45 9th graders). Ethnically, 42% European American, 29% Latino American, 13% African American, 1% Native American and 15% identified as “Other.”

Table 1. Participants Demographics

Experimental PBL School		Comparison Non-PBL	
Grade			
8^{th}	45 (52.94%)	8^{th}	173 (39.68%)
9th	40 (47.06%)	9th	251 (57.57%)
Gender			
Male	49 (58.33%)	Male	198 (45.31%)
Female	35 (41.67%)	Female	239 (54.69%)
Ethnicity / Race			
African American	11 (13.41%)	African American	21 (4.81%)
Asian American	0 (0%)	Asian American	17 (3.89%)
European American (White)	34 (41.46%)	European American (White)	170 (38.90%)
Latino(a) American	24 (29.27%)	Latino(a) American	173 (39.59%)
Native American	1 (1.22%)	Native American	5 (1.14%)
Other	12 (14.63%)	Other	51 (11.67%)

2.2 Procedure

Each semester, the mathematics teachers are interviewed and their classrooms observed three times per semester. For the interview, we use a semi-clinical approach, by starting the interview with standardized questions, but allowing their responses to drive the proceeding ones. Teachers are asked their philosophy of project-based learning in the teaching of mathematics, and their perceptions of how students are faring in this new pedagogy. Interviews are coded and qualitatively analyzed for emerging themes. As for classroom observations, teacher discourse is assessed for depth of knowledge displayed using *University of Louisville's Mathematical Knowledge in the Classroom Discourse* rubric. General feedback is provided to the teachers at the workshops. Teacher scores are kept confidential; only the researchers have access to this information. Final data collection is through the end-of-the year workshops where teachers and administrators gather on Hope's campus to interact and discuss the strengths and weaknesses of the previous year's PBL implementation. The workshops provide the venue for both educators and us to analyze and construct teachers' challenges, self- efficacy and reflections on PBL. A unique aspect of the workshops is that they provide a platform for teachers to ask questions to and dialogue with both administrators and researchers. These workshops not only allow teachers to reflect on the completed year, but to plan changes for the next year.

The students are given surveys twice a year. These surveys assess their degree of self-regulated learning, self-efficacy, and other study strategies using the *MSLQ Learning Inventory* (Vander Stoep and Pintrich, 1991). These motivational factors are examined for trend and factor analysis in determining the effects on academic achievement (multiple regression). Their mathematics grades and math scores on the MEAP/MME tests are compared (descriptive statistics, trend analysis (slope test and t-test). In addition a number of randomly selected students are interviewed once a semester. For trustworthiness of data, we have triangulated, teacher observations, interviews, and administer comments. Using parallel analysis for student factors, we include surveys, interviews, observations, and their achievement scores.

3. Results

Eighth grade classroom observations showed that there were different characteristics in classroom interaction and management styles between the PBL and Non-PBL classrooms. Students of PBL showed healthier group dynamics and social skills than the Non-PBL students who primarily worked independently on worksheets or written assignments. While the Non-PBL teacher seemed to have better classroom management, implanting an effective authoritative style, the PBL teacher was learning to balance the cooperative learning environment essential to PBL with his own authoritarian style. In both classrooms observed, the actual mathematics content was shallow, concepts were covered, but at a basic level. For example, the Non-PBL teacher was reviewing simplifying expressions such as (3 * 10 * 12) + (2 * 8 * 5). The PBL teacher was measuring distance in a map using the scale provided. Table 2 gives an overview of the first year observations.

Table 2. First Year Observations 2011

PBL			Non-PBL
	Spring 2011	Fall 2011	Fall 2011
Working in groups	Groups dynamics coming together	Comfortable with roles	Individual work
Working on projects	Relatively Project-based	Completely Problem-based	Worksheet | individual assignment
Classroom Management	Sporadic Mix-match of styles (cooperative learning environment– drill sergeant method)	Improved rapport Needs better time-management	Very effective Authoritative
Depth of Mathematics Content	Very shallow	Improving	Shallow
Concept Connection	Non existent	Improving	Weak
Technology Teacher Student	 Acceptable Excellent	 Comfortable	 Weak technology – overhead projector
Social Skills	Excellent	Excellent	Poor

Based on the first year survey results, the PBL approach showed significant gains in every area except effort regulation, meaning the amount of effort the students' persevered in learning the mathematics and time and study environment shows well that students manage their time in study environment. While the students did not decrease their efforts, they did not improve significantly in these areas. PBL students did significantly improve in rehearsal, a technique of rote memorization; elaboration, adding prior knowledge to new information; organization, metacognitive self-regulation, the awareness of their own learning process. Table 3 shows a list of mean scores by survey categories.

Using a non-parametric measure, the overall difference between the first and second year results in both PBL and Non-PBL were significant ($p < .001$). For certain categories the gains are so minimal that there was not enough power to discern statistical significance. Specifically, within PBL, Time and Study environment, effort regulation, and help-seeking were not significant. However, they all did show an increase which confirms the positive trend. Within Non-PBL, the categories were extrinsic-goal orientation, control of learning beliefs, test anxiety, and effort-regulation. Unfortunately, Non-PBL students showed unhealthy changes in control of learning beliefs and test anxiety.

Moreover, PBL outperformed Non-PBL in learning motivational gains and these differences are statistical significant. Therefore, we can conclude that the gains were not due to maturation, but are due to the PBL pedagogical approach.

Table 3. First-Year Survey Results – 2011

	PBL		Non-PBL	
	June 2011 (n=88)	Sept 2011 (n=68)	June 2011 (n=440)	Sept 2011 (n=311)
Rehearsal	3.21 (✓-)	3.58 (✓-)*	2.73 (✓-)	3.36 (✓-)*
Elaboration	3.00 (✓-)	3.46 (✓-)*	2.91 (✓-)	3.25 (✓-)*
Organization	3.26 (✓-)	3.70 (✓-)*	3.28 (✓-)	3.56 (✓-)*
Critical Thinking	3.69 (✓-)	3.85 (✓-)*	3.23 (✓-)	3.44 (✓-)*
Metacognitive Self-regulation	3.64 (✓-)	3.96 (✓-)*	3.53 (✓-)	3.70 (✓-)*
Intrinsic Goal Orientation	3.77 (✓-)	3.99 (✓-)*	3.53 (✓-)	3.65 (✓-)*
Extrinsic Goal Orientation	5.50 (✓+)	5.39 (✓+)*	5.55 (✓+)	5.48 (✓+)
Task value	4.47 (✓)	4.59 (✓)*	4.15 (✓-)	4.29 (✓)*
Control of Learning Beliefs	4.85 (✓)	4.97 (✓)*	4.78 (✓)	4.70 (✓)
Self-Efficacy for Learning and Performance--	4.90 (✓)	5.03 (✓+)*	4.78 (✓)	4.95 (✓)*
Test Anxiety--	3.67 (✓-)	3.74 (✓-)*	3.74 (✓-)	3.80 (✓-)
Time and Study Environment	4.46 (✓)	4.47 (✓)	4.11 (✓)	4.32 (✓)*
Effort Regulation	4.13 (✓)	4.15 (✓)	3.95 (✓-)	4.01 (✓)
Peer Learning	3.68 (✓-)	4.10 (✓)*	3.43 (✓-)	3.73 (✓-)*
Help Seeking	4.63 (✓)	4.65 (✓)	4.28 (✓)	4.28 (✓)

4. Discussion

Do students benefit from learning mathematics through the PBL approach?

The benefits can be discussed in two different aspects, content learning and motivation, including students' self-efficacy and self-regulation in learning mathematics. For the purpose of this paper, we will concentrate on the latter, while sharing teacher's first-year reflections on PBL.

After several decades of teaching mathematics in a "conventional" way, adapting a new style of teaching is not something that can be done quickly and effectively. Reflections on the first year of PBL teaching confirmed this. The PBL teacher expressed that it took time to become a PBL teacher. Specifically, throughout the first year, the teacher realized that it was more difficult to teach mathematics concepts through PBL approaches than to teach them through Problem-based approaches. For example when teaching prediction equations for linear regressions, the Project-based approach would require him to integrate several disciplines (e.g., art, history, science) into an authentic mathematics project, so that the learning of the concepts come as an outcome of a finished product. In effect, the students would solve a bigger real-world problem such as building a more effective sensory machine to predict tornado patterns, while learning the rudimentary knowledge of linear regression; students would end up learning about the regression line while solving this bigger problem. In reality, the PBL teacher seemed to think that this process was too complicated for his students to be engaged. First, he felt they could not do it, and they would not learn from the experience. Instead of using big authentic problems, the teacher implemented a series of smaller ones. The PBL teacher ended up simulating a bungee jumping activity with a Barbie doll. In this activity students had to predict when the doll would hit the ground (without taking into account velocity, gravity, or any other relevant scientific concept). The bungee problem became a problem in itself, not integrated with any other discipline nor real-world application. What the PBL teacher did do however, was keep the same basic structure of a project-based learning classroom, such as utilizing group work, integrating technology and requiring student presentations of their findings.

Another aspect of adjustment is the use of technology. The PBL teacher commented that not being comfortable with technology was an interference in teaching, making the tool ineffective for teaching and learning. In the second year, he felt more comfortable in using the technology, and thus was able utilize technology to enhance student learning.

In comparison, the Non-PBL teacher commented on her reluctance to employ technology and pedagogy that involved student collaboration and manipulative work. She claimed that the students did not like using or learning new things, and it was more of a "hassle" to implement new approaches. The traditional approach worked fine for her.

Students of PBL indicated that they liked the new approach to learning because it was different and more exciting than the traditional method. Most of these students had not done well under the conventional way of learning mathematics which constituted lecture and problem solving. These students were motivated to appreciate the value of mathematics more and engage in mathematics-based activities.

Based on the surveys given at the end of first year and in the beginning of the second year, there are clear positive changes in learning motivation of mathematics in PBL students. Specifically students were using more learning strategies (i.e., elaboration and organization) and critical thinking. They were a little more self-regulated, setting more intrinsic and less extrinsic goals, and willing to seek help from their peers. They also showed a greater appreciation of the value of mathematics as well as higher self-efficacy in learning mathematics.

Compared to PBL students, the Non-PBL student showed less visible changes, showing lower average scores in all categories except extrinsic goal orientation and test anxiety. Being extrinsically motivated means they are less autonomous and have a tendency toward debilitating anxiety, such as test anxiety. The survey scores confirm that tendency. The fact that the Non-PBL student gains were minimal, indicate the PBL gains can be attributed to more than maturation effects.

Although there are no standardized scores available at this point to compare the two schools, at least the survey results show that the PBL is beneficial in motivating students to positive direction in learning mathematics. This is especially significant when taking into consideration the at-risk population of the PBL school. While these results are preliminary, we are optimistic that these students will evidence continued success in learning motivation.

It needs to be noted that the PBL students on average were lower achieving students than their non-PBL students when the PBL school started. This means that within a year, the students were at least more engaged in learning mathematic than their non-PBL counterparts.

5. References

Boaler, J. (2002). Learning from teaching: exploring the relationship between reform curriculum and equity. *Journal of Research in Mathematics Education*, *33*(4), 239-258.

Bude, L., Imbos, T., Wiel, M., Broers, N., & Berger, M. (2009). The effects of directive tutor guidance in problem-based learning of statistics on students' perceptions and achievement. *Higher Education*, *57*, 23-36.

Ebby, C., Ottinger, M., & Silver, P. (2007). Improving mathematics instruction through classroom-based inquiry. *Teaching Children Mathematics*, October, 182-186.

Goodnough, K.C. and Hung, W. (2008).Engaging teachers' pedagogical content knowledge: Adopting a nine-step problem based learning model. *The Interdisciplinary Journal of Problem Based Learning*, *1*(2), 61-90.

Lubienski, S. (2000). Problem solving as a means towards mathematics for all: an exploratory look through the class lens. *Journal for Research in Mathematics Education*, *31*, 454-482.

Mergendoller, J., Maxwell, N., & Bellisimo, Y. (2007). The effectiveness of project based instruction: a comparative study of instructional methods and student characteristics. *The Interdisciplinary Journal of Problem Based Learning*, *1*(2), 49-69.

NCES. National Center for Educational Statistics, US Department of Education Institute of Educational Sciences. (n.d.). *Mathematics 2009: n* (2010451)NCES Retrieved from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2010451

Petrosino, A. (2004). Integrating curriculum instruction and assessment in project based instruction: a case study of an experienced teacher. *Journal of Science Education and Technology*, *13*(4), 447-460.

Petrosino, A., Lehrer, R., & Schauble, L. (2003). Structuring error and experimental variation as distribution in the fourth grade. *Math Think Learn*, *5*, 131-156.

Strobel, J., & Barneveld, A. (2009). When is PBL more effective? a meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *The Interdisciplinary Journal of Problem Based Learning*, *3*(1), 44-58.

Trafton, P., & Midgett, C. (2001). Learning through problems: a powerful approach to teaching mathematics. *Teaching Children Mathematics*, *7*(9), 532-536.

Walker, A., & Leary, H. (2009). A problem based learning meta-analysis: differences across problem types, implementation types, disciplines, and assessment levels. *The Interdisciplinary Journal of Problem Based Learning*, *3*(1), 12-43.