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The Effects of Problem-Based Learning on Mathematics Achievement of Elementary Students Across Time

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THE EFFECTS OF PROBLEM-BASED LEARNING ON MATHEMATICS ACHIEVEMENT OF ELEMENTARY STUDENTS ACROSS TIME

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The present study specifically evaluated the long-term effects of problem-based learning (PBL) instruction on the mathematics achievement of students who demonstrated higher ability in the subject area than their comparable peers. Subjects included 65 students from six south-central Kentucky elementary schools who participated in Project Gifted Education in Math and Science (Project GEMS), a grant partially funded through the Jacob K. Javits Gifted and Talented Students Education Program. The students were assigned to one of three conditions – PBL-Plus, PBL, or Control – based upon school of attendance. The participants were then administered baseline testing in the fall of the third-grade year using the Test of Mathematical Abilities for Gifted Students (TOMAGS). The TOMAGS was then re-administered each subsequent spring (grades 3-6) for growth data. A mixed two-factor ANOVA revealed that there was no significant interaction between the groups across time. Therefore, it was determined that PBL instruction did not result in a greater level of mathematics achievement compared to a traditional curriculum; in addition, quantity of PBL instruction did not impact mathematics achievement. Interestingly, all groups demonstrated significant gains in mathematics achievement regardless of treatment condition. Several limitations could have interfered with the results of this study, including student attrition, fidelity of implementation, and professional development in PBL curriculum received by the control schools (outside of Project GEMS). As a result,

the researchers recommend further research employing stricter fidelity checks and larger sample sizes.

Introduction

Students who are gifted or who demonstrate high academic ability (defined by the National Association for Gifted Children as aptitude or achievement in the top 10% or higher; NAGC, n.d.) are typically expected to thrive in school. However, if the needs of these students are not met, it is unlikely that they will reach their full potential (Rotigel & Fello, 2004). As it is, the standard curriculum in most schools does not adequately challenge those of higher ability (Gavin, Casa, Adelson, Carroll, & Sheffield, 2009; Rotigel & Fello, 2004). Upon reviewing the results of the National Assessment of Educational Progress (NAEP), Loveless, Farkas, and Duffett (n.d.) found that between the years 2000-2007, achievement levels of high achieving students (90^{th} percentile or higher) demonstrated minimal change whereas low achieving students (10^{th} percentile or lower) made much greater gains in achievement. Fourth-grade math scores for high achievers increased by ten points between 2000 and 2007, while scores for low achievers increased by eighteen points. Similarly, fourth-grade reading scores increased by three points for high-achievers and sixteen points for low-achievers; and eighth-grade math scores increased five points for high-achievers and thirteen points for low-achievers (Loveless et al., n.d.).

In a single-subject study of a child who demonstrated gifted abilities in language, Walsh and Kemp (2012) found that their subject, Rose, only demonstrated her advanced verbal ability when presented with complex, higher order questions; when presented with lower order questions, Rose's ability was not evident (the authors concluded that open-ended curriculum is essential to challenging children who display high ability and fostering their talent; Walsh & Kemp, 2012). Moreover, Adelson, McCoach, and Gavin

(2012) used data from the Early Childhood Longitudinal Study – a nationally representative sample of kindergarteners during the 1998-1999 school year – to examine the effects of gifted programming in mathematics and reading. Students were followed through the fifth grade, and were included in the "gifted" sample if they participated in a gifted program in either math or reading in the third through fifth grades. The researchers found that, at the students' fifth-grade year, there was no significant difference in achievement between students who were identified as gifted and enrolled in gifted programs and the achievement of non-gifted students in either subject area. Adelson et al. (2012) attributed this lack of success to numerous factors, including limited knowledge relating to meeting the needs of gifted students.

The implications of these studies are particularly important for students in the area of mathematics. The 2012 Program for International Student Assessment (PISA) survey conducted by the Organization for Economic Cooperation and Development (OECD, 2014) indicated that, among the 34 OECD membership countries, the United States ranked 27th in math achievement; and although performance in reading and science were ranked average, mathematics performance was below average (OECD, 2014). The highest performing students (Shanghai-China) outperformed students from the United States by the equivalent of over two years of formal schooling, and students from the United States demonstrated weaknesses in geometric reasoning and real-world application (OECD, 2014). Overall, 26% of the students surveyed in the United States did not meet the PISA baseline for mathematics proficiency, and only 2% were categorized as "high performers;" however, the NAGC estimates that 6-10% of the student population in the United States is comprised of high-ability students (NAGC, n.d.; OECD, 2014).

So an important question remains regarding the mathematics education of high-ability students: What strategies can be used to challenge these students and foster achievement? Research indicates that students with mathematical-giftedness achieve the most academic gain when presented with curriculum that contains higher order thinking probes; inquiry-based instruction; scaffolding and small group activity; prompts that require problem-solving and reasoning; elaboration; and real-world applications (Erickson, 1999; Gavin et al., 2009; Rotigel & Fello, 2004; VanTassel-Baska, 2013). One such pedagogical technique that combines many of these attributes is problem-based learning (PBL).

Project Gifted Education in Math and Science (Project GEMS) was established in order to examine the effects of a PBL curriculum on the achievement and interest of elementary school students identified as having higher ability in math and/or science compared to their same-grade peers (Inman, 2011). This five-year project, which was partially funded through the Jacob K. Javits Gifted and Talented Students Education Program, placed identified students from six schools into one of three conditions: a PBL-Plus group, and PBL group, and a control group. Students who took part in Project GEMS were followed through the duration of the grant and were assessed each year for growth in math and science achievement.

The purpose of the current study is to examine the effects of PBL on the mathematics achievement of students who demonstrate higher ability in the subject area. Will students who received PBL instruction demonstrate higher gains in academic achievement than those students who did not receive PBL instruction? Will gains in achievement differ based on quantity of PBL instruction received?

Literature Review

The following section will examine past research into the effects of PBL instruction on mathematics achievement; populations include K-12 students of all ability groups, including students demonstrating high ability or giftedness. Project GEMS will also be discussed in more detail, including the PBL curriculum used and students served.

Problem-Based Learning

Although PBL (a pedagogical technique that focuses on collaborative group work and open-ended problem-solving in order to facilitate the learning process) began as a method for instructing medical students during their training, it has since been adapted for use in various fields with almost every grade-level of students (Schmidt, Rotgans, & Yew, 2011). In the PBL procedure, students are placed into small groups and presented with an open-ended problem to solve or question to answer. These prompts are designed to activate and build upon prior knowledge, and are almost always related to real-world scenarios. The other students, in addition to the teacher, serve as scaffolds for developing one's knowledge base (Schmidt, Loyens, van Gog, & Paas 2007; Schmidt et al., 2011). Loyens, Magda, and Rikers (2008) identify five main goals of PBL for students: "a) construct an extensive and flexible knowledge base; b) become effective collaborators; c) develop effective problem-solving skills; d) become intrinsically motivated to learn; and e) develop self-directed learning skills" (p. 413). In alignment with these goals, research has demonstrated that students who are instructed under PBL become more intrinsically motivated, demonstrate greater levels of interest, showcase more independent learning, report higher levels of self-efficacy, have better-developed meta-cognitive skills (e.g., goal-setting and monitoring), and are more autonomous than students who are not instructed under PBL; the development of these strengths can promote higher levels of achievement (Ali, Akhter, Shahzad, Sultana, & Ramzan, 2011; Loyens et al., 2008; Roh, 2003; Schmidt et al., 2011).

The tenets of PBL are based in constructivist and sociocultural theories; students construct knowledge through a social context. The peer group and the teacher serve as scaffolds in order to facilitate the activation of prior knowledge and higher-order thinking (Gavin et al., 2009; Henningsen & Stein, 1997). In addition, there are two cognitive theory hypotheses as to why PBL is effective – the activation-elaboration hypothesis and the situational interest hypothesis. In the activation-elaboration hypothesis, PBL serves to activate prior knowledge and identify gaps in what the student already knows. Once this has been accomplished, students can then elaborate on this already-developed knowledge with new knowledge. Activities carried out in small groups are shown to have a higher success rate under this model than individual prompts (Schmidt et al., 2011). In the situational interest hypothesis, PBL students seek to make sense of the world around them and experience disequilibrium due to knowledge gaps. Students are thereby compelled to solve problems in order to satisfy natural curiosity and reach a sense of equilibrium (Schmidt et al., 2011). This is significant because “a higher level of situational interest…relates to higher levels of achievement” (Schmidt et al., 2011, p. 45).

Numerous studies have demonstrated PBL’s effectiveness with the teaching of mathematics. Ali, Hukamdad, Akhter, and Khan (2010) found that using PBL techniques increased the math achievement of a group of eighth-grade students in Bannu, Pakistan. In this study, Ali et al. (2010) randomly assigned 76 students to either an experimental or control group with 38 students each. A pre-test assessment based on problems from an eighth-grade textbook indicated that there was no significant difference in math achievement between the two groups at the onset of the study. The students then received four weeks of mathematical instruction, with the experimental group partaking in small group PBL activities (i.e., solving problems collaboratively, answering open-ended questions generated by the teacher) and the control group receiving traditional classroom lectures. At post-test, a significant difference (d = .79) was evident for math achievement between the two groups, with the experimental group outperforming the students in the control group. Ali et al. (2010) concluded that this finding provides evidence for the use of PBL in mathematics education to increase achievement.

Ali et al. (2011) used a similar methodology once again to demonstrate PBL's effectiveness in increasing student achievement. In this study, 38 eighth-grade students were assigned to either an experiment group or a control group with 19 students each. Both groups consisted of high achievers and low achievers. Students were given a pre-test of eighth-grade mathematics textbook problems (which demonstrated that there was no difference in overall ability between groups) and then received four weeks of math instruction delivered through either traditional, lecture-based means (control group) or through authentic, collaborative-based PBL means (experimental group). At post-test, students in the experimental group demonstrated greater academic gain than their control group peers; this was true of both low achievers (d = 1.15) and high achievers (d = .96). These findings demonstrate that a PBL curriculum can be used to foster mathematics achievement of students at all ability levels, including students of high ability.

In 1989, the state of California sought to reform their secondary math education guidelines for algebra and geometry. From this endeavor, the Interactive Mathematics

Project (IMP) Curriculum Development Program was created. The IMP incorporated PBL principles (i.e., small group collaboration, interactive problem-solving of open-ended tasks, application and integration of knowledge, and teacher-as-scaffold) that corresponded with the current Curriculum and Evaluation Standards set forth by the National Council of Teachers of Mathematics (NCTM; Clarke, Breed, & Fraser, 2004). Typical IMP classes consisted of approximately 32 students and focused on "problem-solving, reasoning and communication as major goals" (Clarke et al., 2004, p. 8). Instruction was comprised of modular curriculum units lasting approximately five weeks each. A total of 182 high school students from three California high schools participated in the three-year investigation of the IMP program. Data were also collected from 269 students not enrolled in an IMP classroom. At the end of the school year, students were asked to complete two questionnaires: the Mathematics Beliefs survey (measured self-efficacy and mathematical beliefs) and the Mathematics World survey (assessed how one perceives daily activities as mathematical in nature). Students' scores on the Mathematics Scholastic Aptitude Test (SAT) were also analyzed (Clarke et al., 2004). The researchers found that students who were enrolled in the PBL IMP classes reported higher levels of self-efficacy for mathematics (d = .49) and demonstrated more positive attitudes towards mathematics (d = .74). In two of the three schools, SAT scores were compared between groups; IMP students had higher scores at both schools, but the difference was only statistically significant at one site (d = .29) In addition, IMP students were more likely to view mathematics as a "societal need" with real-life implications, and place value on writing and communicating as a means of problem-solving (Clarke et al., 2004). Although the effects of PBL on student achievement appear to be minimal in this study, there are no baseline or growth measures by which to compare the students' SAT scores (taken in the fall of the second year of IMP implementation). Theoretically, students selected for the IMP program could have made more gains during the course of the program, but with only one measure of achievement, it is impossible to make those conclusions.

Gavin et al. (2009) analyzed the effects of a second curriculum based on PBL and NCTM standards – Project M^3. This curriculum was also aligned with Connecticut, Kentucky, and Massachusetts state standards, and was specifically designed to meet the needs of gifted learners (Gavin et al., 2009). Project M^3 is comprised of 12 units (four units at three grade levels) meant for students in grades 3-5. Each unit spans approximately six weeks of instructional time. The content covered in Project M^3 includes algebra, data analysis, geometry, and number and operations. A total of 11 schools from Connecticut and Kentucky participated in the four-year study. Students were identified as *mathematically promising* through the use of several identification tools, including the Naglieri Nonverbal Ability Test (NNAT), the Mathematics Scales for Rating the Behavioral Characteristics of Superior Students (SRBCSS), classroom performance, and teacher reports (Gavin et al., 2009). Classes were kept to an average of 20 students. These classes were then assigned to either an experimental condition or a control condition. Because some students were identified at different points, two experimental groups were present: Experimental Group 1, which comprised students selected during the first year of the program, and Experimental Group 2, which comprised students selected during the second year of the program. Students in the experimental conditions received the Project M^3 units in addition to the standard curriculum. Students in the control condition only received the standard curriculum. In addition, Project M^3 trainers visited the classrooms once a week to conduct observations and check for fidelity of implementation (Gavin et al., 2009). The researchers then collected testing data using the standardized Iowa Tests of Basic Skills (ITBS), along with open-response items from the NAEP and the Trends in International Mathematics and Science Study (TIMSS), to assess academic achievement. The results from the study demonstrate that, in all three grade levels, the mathematically promising students who received the Project M^3 units displayed significantly greater academic gains than did their mathematically promising peers in the control condition (see Table 1 for effect sizes; there were no significant differences between experimental groups). The greatest effects were evident in the students' performance on open-ended measures of achievement, whereas the effects were smaller on the multiple-response measure. Nevertheless, it was concluded that an enriched, PBL-based curriculum fostered student mathematic achievement across grade levels (Gavin et al., 2009). Furthermore, Gavin et al. (2009) attest that the use of two experimental groups, direct observations of trainers, and the use of a similar comparison group provide validity and strengthen the assumption that the Project M^3 units offer an effective framework for educating mathematically-gifted students and increasing their academic potential.

Table 1

Cohen's d Effect Sizes

	ITBS			Open-Response		
	3rd Grade	4th Grade	5th Grade	3rd Grade	4th Grade	5th Grade
Group 1	0.29	0.59	0.33	0.97	0.97	0.69
Group 2	0.44	0.45	0.58	0.86	0.93	0.89

Note. Effect sizes are from Gavin et al. (2009).

In sum, PBL is often regarded as superior to most standard curriculums in increasing the academic achievement of mathematically-gifted students (Roh, 2003; Rotigel & Fello, 2004; VanTassel-Baska, 2013). Roh (2003) attests that the traditional curriculum often underestimates the abilities of students, and that even kindergarten children can solve simple multiplication problems if presented in a problem-solving format. PBL also facilitates the development of creativity and communication skills that can be carried over to other domains, both in and out of the school setting. Students who create their own methods of solving problems tend to make fewer computational errors than when trying to adhere to a strict algorithm; this skill should be fostered in the educational setting through PBL so that students are able to develop critical thinking skills (Roh, 2003; Rotigel & Fello, 2004). Similarly, the ability to solve problems as part of a team using effective communication strategies is a skill developed through PBL that translates to success in and out of the classroom. Additionally, PBL practices are in alignment with the recommendations and standards established by the NCTM for the teaching and learning of mathematics (Erickson, 1999). Many common core standards for mathematics "use 21st century skills as a major part of the standards" (VanTassel-Baska, 2013, p. 74). This, in combination with societal expectations for students who are skilled at solving real-world problems, increases the need for PBL in mathematics education (Ali et al., 2010).

Project GEMS

Project Gifted Education in Math and Science (Project GEMS; Roberts, 2008) was a five-year grant funded in part through the Jacob J. Javits Gifted and Talented Students Education Program. The purpose of Project GEMS was to identify elementary students who demonstrated higher ability in math and science, and to foster student interest and achievement in these areas. Six public elementary schools located in south-central Kentucky were selected for participation. From these six schools, students in grades 2-5 were assessed in the spring using the ITBS in math and science and the Cognitive Abilities Test non-verbal subtest (CogAT). The students' scores from these measures were normed and combined with teacher ratings of student interest in mathematics and science to yield a composite score. This composite score was then used to identify the top fifteen students from each grade at each school. These students were invited to participate in Project GEMS the following academic year. Parental consent and student assent were obtained for participation.

Students were assigned to one of three conditions based upon which school they attended. Students from two of the participating schools were assigned to a *PBL-Plus* condition in which the students received PBL instruction in their regular classrooms in addition to PBL instruction in a one-day-a-week pull-out program called GEMS Academy. Students in two of the other participating schools were assigned to a *PBL* condition in which they received PBL instruction in their regular classrooms, but did not attend the GEMS Academy. The remaining students served as a control condition. Students from all six schools completed baseline testing in the fall upon entering the program, and then growth testing each spring. Assessments included the Test of Critical Thinking (TCT), the Fowler Diet Cola Test, and the Test of Mathematical Abilities for Gifted Students (TOMAGS).

Students in the PBL-Plus condition received a total of four units of PBL instruction per year – two in their regular schools and two at the GEMS Academy.

Students in the PBL condition received two units of PBL instruction per year. Students in the control condition did not receive PBL instruction as part of Project GEMS. PBL units were selected from the Project M^3 and Math Innovations curriculums (Gavin, Chapin, Dailey, & Sheffield, 2006; Sheffield, Chaplin, & Gavin, 2010). Students were instructed in grade-appropriate units, with the exception of the sixth-graders who attended the GEMS Academy; there, they were instructed in units from the seventh-grade Math Innovations curriculum. Curriculum units from Project M^3 spanned 29 to 41 days, and Math Innovations units covered 19 to 27 days. See Tables 2 and 3 for specific units taught in Project GEMS (Duck, 2014; Roberts, Tassell, Inman, & Wininger, 2011).

Table 2

PBL Curriculum for PBL-Plus Condition

	Project M^3			Math Innovations
	Grade 3	Grade 4	Grade 5	Grade 6/7
Regular Classroom	Unraveling the Mystery of the MoLi Stone: Place Value and Numeration What's the *Me* in *Me*asurement All About?	Factors, Multiples, and Leftovers: Linking Multiplication and Division Getting into Shapes	Treasures from the Attic: Exploring Fractions Funkytown Fun House: Focusing on Proportional Reasoning and Similarity	A Balancing Act: Focusing on Equality, Algebraic Expressions, and Equations Notable Numbers: Focusing on Fractions, Decimals, and Percents Sizing up Shapes: Focusing on Geometry and Measurement Fraction Times: Focusing on Multiplication and Division of Fractions and Decimals At This Rate: Focusing on Ratios and Proportions
GEMS Academy	Awesome Algebra Digging for Data	At the Mall with Algebra Analyze This!	Record Makers and Breakers What Are Your Chances?	Puzzling Proportions: Focusing on Rates, Percents, and Similarity Sizing up Solids: Focusing on Surface Area and Volume

Table 3

PBL Curriculum for PBL Condition

	Project M^3			Math Innovations
	Grade 3	Grade 4	Grade 5	Grade 6
Regular Classroom	Unraveling the Mystery of the MoLi Stone: Place Value and Numeration What's the *Me* in *Me*asurement All About?	Factors, Multiples, and Leftovers: Linking Multiplication and Division Getting into Shapes	Treasures from the Attic: Exploring Fractions Funkytown Fun House: Focusing on Proportional Reasoning and Similarity	A Balancing Act: Focusing on Equality, Algebraic Expressions, and Equations Notable Numbers: Focusing on Fractions, Decimals, and Percents Sizing up Shapes: Focusing on Geometry and Measurement Fraction Times: Focusing on Multiplication and Division of Fractions and Decimals At This Rate: Focusing on Ratios and Proportions

In addition, teachers from each school in the experimental conditions received professional development (training, modeling, and coaching) in the use of PBL curriculum for the teaching of mathematics. From 2009-2011, teachers in the PBL condition received between 56-69 hours of training, 18 hours of modeling, and six hours of coaching; teachers in the PBL-Plus condition received 36 hours of training, 18 hours of modeling, and four hours of coaching (Inman, 2011). This professional development was conducted by trained consultants from the College of William and Mary as well as Project M^3. Professional development information for the last two years of the grant was not made available.

Present Study

The present study specifically evaluates the long-term effects of PBL instruction on math achievement using data collected from Project GEMS. The guiding research questions are:

1. Will PBL instruction in mathematics yield higher levels of achievement compared to traditional classroom instruction (i.e., control condition) in students who demonstrate high mathematics ability compared to their peers?
    - Hypothesis: Students instructed with PBL will demonstrate higher levels of achievement than students who received traditional classroom instruction.
2. Will quantity of PBL instruction affect the level of mathematics achievement?
    - Hypothesis: Higher quantities of PBL will lead to greater gains in mathematics achievement.

Method

Participants

Students were selected for participation in Project GEMS during their 2nd grade year using the ITBS math and science subtest scores, CogAT non-verbal subtest scores, and teacher identification forms. The participants were then assigned to one of three conditions based upon which school they attended. Students from two of the participating schools were assigned to a PBL-Plus condition (four curriculum units of PBL per year); students from two other participating schools were assigned to a PBL condition (two curriculum units of PBL per year); and students from the two remaining schools served as a Control (no PBL through Project GEMS).

Only students who had participated in Project GEMS all four years (grades 3-6) with complete TOMAGS assessment data were selected for the presents study. A total of 65 students fit this criteria and were included in the sample. Although 90 students were originally identified for this sample, 25 were lost due to attrition (i.e., moving schools or leaving Project GEMS) or did not have complete TOMAGS data. Table 4 breaks down the number of participants by condition.

Table 4

Participants (n) by Experimental Condition

	PBL-Plus	PBL	Control
n	25	21	19

Materials

The TOMAGS is a standardized and norm-referenced assessment of math achievement in elementary-aged students (Ryser & Johnsen, 1998). Developed using the National Council of Teachers of Mathematics (NCTM) standards for curriculum and evaluation, the purpose of the TOMAGS is to identify students who demonstrate "talent or giftedness in mathematics" (Ryser & Johnsen, 1998, p. 1). There are two versions of the assessment: *Primary* for students aged 6-9, and *Intermediate* for students aged 9-12. Students can earn up to 39 possible points on the Primary version, and up to 47 points on the Intermediate version. The test may be administered individually or to a group by an examiner. The examiner reads an introductory prompt to the students and then allows the students to complete the assessment using as much time as they need. The examiner may read aloud any portion of the test, but should not provide any answers or define any terms. Once the student has completed the assessment, scores as calculated by allotting one point for every correct answer; incorrect answered are scored zero.

The TOMAGS was normed using two nationally-representative samples: a "normal sample" of 1,572 students not identified as gifted in mathematics, and a "gifted sample" of 1,130 students identified as gifted in mathematics (Ryser & Johnsen, 1998). The developers used Cronbach's coefficient alpha method to generate reliability estimates for both versions of the TOMAGS using both samples. Ryser and Johnsen (1998) found that the Primary version yielded an average coefficient alpha of .86 for the normal sample and .87 for the gifted sample. The Intermediate version produced an average coefficient alpha of .87 for the normal sample and .84 for the gifted sample.

Procedure

As part of Project GEMS, students completed the TOMAGS in the fall of their third-grade year (baseline), then each subsequent spring (growth). Third-graders completed the Primary version whereas students in fourth, fifth, and sixth grades completed the Intermediate version. Once testing was completed, raw scores were calculated. Because the two versions of the TOMAGS utilize different score ranges, a recoding system was generated using the "normal sample" norming tables in the TOMAGS *Examiner's Manual* (Ryser & Johnsen, 1998). This converted every raw score into a standard score (M=100, SD=15), allowing for comparison of scores across test versions and over time. Data analysis was conducted using a mixed two-factor ANOVA: 3 (groups) X 5 (TOMAGS).

Results

Mean TOMAGS scores were compared between groups across time using a two-factor ANOVA. Results from this analysis revealed no significant interaction between the groups across time $F(8, 248) = .865$, $p = .546$. Therefore, there is no evidence to suggest that PBL instruction in any quantity had a greater effect on mathematics achievement than did a standard curriculum. However, it is important to note that although there was no significant difference by experimental condition, each group did demonstrate a significant improvement in mathematics achievement over time $F(4, 248) = 45.575$, $p < .001$, $\eta_p^2 = .42$. Mean TOMAGS scores by group across time are depicted in Table 5 and estimated marginal means in Figure 1; effect sizes for each groups' growth from baseline (Fall 2009) to Spring 2013 are illustrated in Table 6.

Table 5

Mean TOMAGS Scores by Group across Time

	PBL-Plus	PBL	Control
Fall 2009	106.28	99.57	92.05
Spring 2010	114.08	105.57	103.32
Spring 2011	120.52	109.76	109.00
Spring 2012	122.72	110.29	109.16
Spring 2013	125.72	113.38	111.21

Table 6

Effect Size of Growth by Group across Time

	PBL-Plus	PBL	Control
d	1.72	1.09	1.87

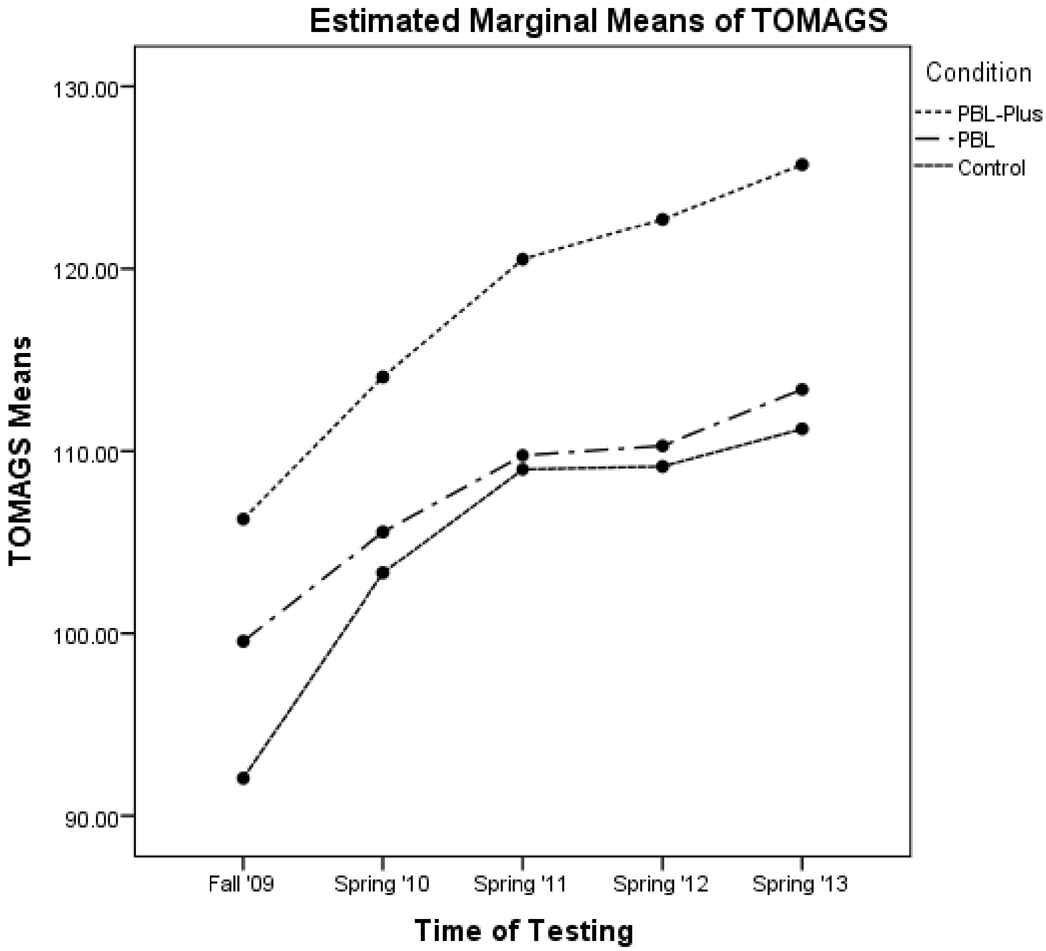

Figure 1. Estimated marginal means for TOMAGS scores by group across time.

Discussion

The purpose of the present study was to determine (a) if a PBL curriculum would increase student achievement in mathematics amongst higher achieving students, and (b) if a higher quantity of PBL instruction would positively impact level of achievement. It was hypothesized that students instructed with PBL would demonstrate higher levels of achievement compared to peers in the control group, and that greater quantities of PBL instruction would result in higher levels of achievement. However, the results of the present study did not support either hypothesis. Rather, all groups in the present study (including the control) demonstrated significant and positive effects.

How do these results compare to other studies measuring the effects of PBL? In their meta-analysis of 43 studies assessing PBL instruction in real-life classrooms, spanning from one semester to four years of PBL instruction, Dochy, Segers, Van den Bossche, and Gijbels (2003) found that PBL consistently improved students' application of knowledge (defined by the researches as *skills*; weighted $d = .46$). However, a negative trend was noted when addressing knowledge acquisition of students (defined by the researchers as *knowledge*; weighted $d = -.22$). The researchers purport that although students may not gain as much knowledge, they are better able to retain and generalize acquired knowledge due to the elaboration inherent in PBL instruction. As a result, students instructed under PBL will perform better on instruments assessing skills over knowledge (Dochy et al., 2003).

Likewise, Strobel and van Barneveld (2009) found similar results with their meta-synthesis of eight meta-analyses comparing the effects PBL instruction to traditional forms. Most meta-analyses focused on PBL curriculum tracks (i.e., two to four years of instruction) in undergraduate and graduate training programs. The researchers used a qualitative meta-synthesis approach and “created a correlation matrix that captured the measures of effectiveness and modifying variables reported in each study and the specific orientation of effect sizes (positive or negative) of each variable” (Strobel & van Barneveld, 2009, p. 48). Trends in effect sizes were indicated as either favoring PBL (+) or favoring traditional means of instruction (-). Results of this meta-synthesis are presented in Figure 2.

1 = Albanese & Mitchell (1993)
2 = Vernon & Blake (1993)
3 = Berkson (1993)
4 = Kalaian, Mullan, & Kasim (1999)
5 = Colliver (2000)
6 = Dochy, Segers, Van den Bossche, & Gijbels (2003)
7 = Newman (2003)
8 = Gijbels, Dochy, Van den Bossche, & Segers (2005)

		STUDIES		1	2	3	4	5	6	7	8	Overall ES Trends	Favours
NON-PERFORMANCE, NON-SKILL, and NON-KNOWLEDGE-BASED	Satisfaction	Student		+	+			+				+	PBL
		Faculty		+	+							+	
	Residency	1st choice		+		+						+	
KNOWLEDGE ASSESSMENT	Short-term	NBME 1		-	-	-	-	-	-	-	-	-	Trad'l Learning
		MCQ			-				-	-	-	-	
		ShortAns							+		+	+	
		Progress							-		-	-	
		Free Recall							+		- /+	+	
	Long-term	Retention		+					+		- /+	+	
PERFORMANCE or SKILL-BASED ASSESSMENT	Case Analysis	NBME 2		+	+	+	+		+		+	+	PBL
		Sims							+		+	+	
		Case-based	Cases						+	+	+	+	
			MEQ			+			+	+	+	+	
			Essay						+		+	+	
	Observation	Rating		+	+			'+	+		+	+	
MIXED KNOWLEDGE and SKILL	Oral								+		- /+	+	PBL
	USMLE 3							-	+		+	+	

Figure 2. Correlation Matrix. Reprinted from “When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms,” by J. Strobel and A. van Barneveld, 2009, *Interdisciplinary Journal of Problem-Based Learning, 3,* p. 58. Copyright 2009 by Purdue e-Pubs. Reprinted with permission.

Overall, the results of the researchers' meta-synthesis indicate that PBL yields more positive results than does traditional classroom instruction with regard to student skill development, long-term retention of knowledge, and satisfaction of students and teachers. However, measures of short-term retention and performance on standardized tests favored traditional classroom instruction (Strobel & van Barneveld, 2009). This would suggest that selection of assessment procedure can greatly affect outcomes when analyzing growth or achievement under a PBL curriculum.

It is also important to note that duration of PBL instruction may have moderating effects on the strength of treatment. The present study implemented treatment for four consecutive years, which is longer than many of the aforementioned studies; at the same time, the present study reported much stronger effect sizes (Ali et al., 2010; Ali et al., 2011; Clarke et al., 2004; Dochy et al., 2003; Strobel & van Barneveld, 2009). However, it is also significant that the lengths of individual curriculum units are comparable across studies, including the present study; as a result, it is unlikely that unit length would explain the lack of differences between the treatments and control group. Still, there are several limitations which could have interfered with the results of the present study. These include student attrition, treatment fidelity, and professional development acquired by the control schools.

Limitations

Multiple limitations are thought to be confounds to the results of the present study. The first of these is student attrition. The present study began with 90 students -- 15 from each of the six participating schools. However, 25 students were lost over the course of the study, leaving only 65 students for whom there was complete data. This resulted in an attrition rate of approximately 28 percent. Students were excluded from the final sample due to reasons such as a change in placement (i.e., moving schools), opting out of Project GEMS, or not completing the TOMAGS on any given year.

Fidelity of implementation, or treatment fidelity, must also be considered a limitation of the present study. With regard to this project, treatment fidelity is two-fold: the consistency of educators working with the grant, and regular fidelity checks. Throughout the duration of Project GEMS, the participating schools experienced a flux of teachers who left the school or were reassigned to a different grade, and new teachers who were introduced to the grant without any prior experience or training. Although this is common within the school environment, it is a hindrance for ensuring consistent and appropriate PBL instruction amongst the experimental conditions. Similarly, fidelity checks via teacher observation were to be conducted by trained personnel within each school to ensure treatment integrity and implementation. However, the observation forms were subjective in nature and were not conducted consistently (see Appendix for an example of a Project GEMS observation form). Several schools experienced changes in personnel conducting the observations, resulting in questionable reliability with regard to the measure and its results. In addition, during the second year of Project GEMS, these observations were conducted by outside evaluators not associated with the school; inter-rater reliability was not determined for these observations (Inman, 2011). Therefore, ensuring proper treatment fidelity was problematic.

A third limitation to the present study is professional development in PBL received by the control schools. Although the control schools did not receive any professional development though Project GEMS, each school received several hours of training in PBL curriculum, assessment, and teaching strategies independently. Between the years 2009-2012, select teachers from one control school received approximately 111 hours of PBL-based professional development specifically related to the teaching of mathematics. During that same time, teachers from the second control school received approximately 174 hours of professional development in PBL-based mathematics curriculum. Collectively, the control condition received close to 300 hours of mathematics-specific, PBL training during the first four years of the present study (data for the last year was not made available). This training could explain the lack of differences between growth in the control condition compared to the experimental conditions. Additionally, classroom observations were not conducted within the control schools; given the amount of PBL training received by these teachers, and the gains in achievement made by the control schools, observations could have allowed for insight as to why there were no significant interactions between groups.

Implications for Future Research

Given the results of the present study and the aforementioned limitations, it is recommended that future research examining the effects of PBL on mathematics achievement maintain strict fidelity checks to ensure proper implementation of the treatment. Belland, Kim, and Hannafin (2013) purport that PBL instruction is ineffectual without appropriate guidance and scaffolding. Without reliable fidelity checks, it is impossible to say whether or not students are receiving adequate instruction and support. In turn, control groups should be better selected and monitored so that accurate comparisons can be made against the experimental condition(s). Additionally, steps should be taken to help mitigate the effects of attrition commonly found in longitudinal studies. This could be achieved through larger initial sample sizes, creating a "project identity" amongst participants, and making involvement as convenient as possible (Ribisl et al., 1996). Finally, it is recommended that future research analyze the moderating effects of treatment duration on the strength of results.

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APPENDIX

Sample Observation Form

Teacher Behavior	Observable Evidence	Tally
Problem Solving Strategies:		
Engaged students in problem identification and definition	• Asked students to identify the central problem of an issue or experiment using proof from relevant content, data sets, concepts, or theories. • Asked questions such as "What is the central problem and how do you know?"	
Engaged students in solution-finding activities and comprehensive solution articulation	• Required students to develop and use specific criteria to come up with a solution to a problem. • Asked questions such as "How might you find out…?" • Asked students to apply criteria or analyze materials, observations, or experiments to find a solution to a given problem	
Critical Thinking Strategies:		
Encouraged students to judge or evaluate situations, problems, or issues	• Asked questions about assumptions of an observed phenomenon • Asked questions about the implications or consequences of a problem	
Creative Thinking Strategies:		
Solicited many diverse thoughts about issues or ideas	• Asked questions such as "Did anyone have a different idea or solution?" or "How else would we think about this question?" or "Did anyone find, observe, or classify something different?" • Encouraged students to provide varied ideas or scenarios	
Provided opportunities for students to develop and elaborate on their ideas	• Allowed time for students to write or discuss extended responses to prove their findings or ideas about a problem, experiment, set of data, or observation • Asked students to clarify their thinking • Asked "why" students thought as they did	
Research Strategies:		
Asked questions to assist students in making inferences from data and drawing conclusions	• Required answers to questions such as "What are your findings?" and "Why do you think…?" • Asked students to write conclusions to an experiment, observation or data set	

3 Correctly utilizes most or all problem-based learning strategies

2 Progressing, but incorrectly uses some problem-based learning strategies, doesn't use a significant number of strategies, and/or uses strategies intermittently

1 Incorrectly uses or doesn't use problem-based learning strategies

Comments: