©EIJEAS 2017 Volume: 3, Issue: 6, 140-158, Ohio, USA
Electronic International Journal of Education, Arts, and Science
http://www.eijeas.com

Science, Technology, Engineering, and Mathematics Project-Based Learning: Merging Rigor and Relevance to Increase Student Engagement

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Abstract

Increasing rigor and keeping students engaged in the classroom has become essential in the education of today's youth. Science, technology, engineering, and mathematics (STEM) project-based learning (PBL) has increasingly become more popular in education today as the demand for collaborative problem solvers increases in the job market. STEM PBL is an instructional method that blends rigor and relevance by providing the means to connect relevant real-world situations while maintaining high expectations of student achievement and increasing engagement. In order to study the effects of STEM PBL on student engagement, a quasi-experimental design was used. Quantitative data from the three focus groups were collected to assess student engagement within a STEM PBL classroom compared to a non-STEM PBL classroom. An exploratory factor analysis was preformed to more closely examine the 8 engagement structures and resulted in the creation of two higher order factors, (1) academic engagement (AE) and (2) behavioral engagement (BE). The results can be used to verify that there exists an improvement in student academic engagement between the intervention groups, comparing traditional mathematics lessons verses STEM PBL lessons. The results showed that the academic rigor and relevance provided through STEM PBL lessons increase students' academic engagement.

Keywords: mathematics achievement; project-based learning; rigor; relevance; STEM; student engagement

Introduction

Increasing rigor while keeping students engaged in the classroom has become essential in the education of today's youth. Statistics have shown that K-12 education in the U.S. suffers from a lack of rigor, especially in science, technology, engineering, and mathematics (STEM) subjects (Sahin & Top, 2015). Today's schools are under tremendous pressure to increase rigor in the classroom (Harada, Kirio, & Yamamoto, 2008) but are losing sight of the importance of providing an education that combines challenge and engagement (Yonezawa, Jones, & Joselowsky, 2009). Researchers revealed that disengagement is a noticeable factor in low student achievement (Stone, Alfreld, & Pearson, 2008). Educators need to be reminded that student engagement is critical to academic success (Yonezawa et al., 2009) and refers to the level of connection, interaction, and learning students demonstrate in classroom projects and activities (Gourgey, Asiabanpour, & Fenimore, 2010). It is essential that educators find methods of increasing rigor and student engagement simultaneously.

STEM project-based learning (PBL) activities are rigorous in content and provide students with meaningful opportunities to be actively engaged. "A STEM curriculum can serve as a natural progress to rigorous high school level science, technology, engineering, and mathematics classes" (Capraro & Nite, 2014, p. 1). Rigorous curriculum, instruction, and assessment, integrated technology and engineering in science and mathematics curriculum, and promotion of scientific inquiry and the engineering design process are all requirements of a high-quality STEM education program (Kennedy & Odell, 2014). Project-based learning actively engages students in deeper levels of comprehension and is a potentially powerful means to produce relevant and rigorous learning (Bicer, Navruz, Capraro, & Capraro, 2014; Han, Capraro, & Capraro, 2014; Harada et al., 2008). Therefore, the combination of STEM curriculum with PBL can serve as a possible solution to increase rigor and engagement in the classroom.

Rigor

STEM PBL activities can increase student engagement while providing rigorous content. Rigor is defined as the quality and intensity (American College Testing, I., 2007) of course work. Rigor can also be described as the extent to which classroom instructions challenge and demand students to use critical thinking skills (Paige, Sizemore, & Neace, 2013). It is important to create an environment where each student is supported and expected to learn at high levels. Providing support through scaffolding, while engaging students in more challenging work is essential to the definition of rigor (Blackburn & Williamson, 2009). The dimensions of rigor include active learning, meaningful content, higher-order thinking, and appropriate expectations (Draeger, Del Prado Hill, Hunter, & Mahler, 2013). A rigorous school environment is described as one where students are engaged in tasks that demand high levels of cognition and focus (Wolf, Crosson, & Resnick, 2005). It has been shown in studies that strong links between rigor and engagement are generated by combining academic rigor with the relevance of students applying their knowledge to real-world situations (Siri, Zinner, & Lezin, 2011). Increasing cognitive rigor of students' work has been shown to be effective for improving academic achievement and classroom engagement (Paige et al., 2013). STEM PBL is an instructional method that blends rigor and relevance to increase student engagement in the classroom.

Relevance

Relevance is an important link between increased academic rigor and student engagement. Relevant content can be referred to as content that relates to one's current interest, contributes to one's future goals, and is considered significant to one's identity (Corso, Bundick, Quaglia, & Haywood, 2013). Relevance can also be defined as having distinct meaning and purpose for students by accentuating the connection of curriculum content and skill acquisition with life (William & Wilson, 2012). There is an impasse in current educational frameworks that construct academic rigor and relevance as incompatible with one another (Williams & Wilson, 2012), but the truth is that rigor is directly correlated to relevance (Blackburn & Williamson, 2009). Providing relevant and engaging instruction that relates content to real life has become more important than ever (Sahin & Top, 2015). Researchers have shown that students appreciate opportunities to work together on real-life projects and believe that such collaborations will better prepare them for their future (Marchetti & Karpova, 2014). STEM PBL offers a balance of providing relevant context for learning and integrating rigorous content knowledge (Kennedy & Odell, 2014). Connecting with the real world allowed students to formulate and investigate questions and problems that are relevant to them (Hasni et al., 2016) increasing student engagement. STEM PBL provides the means to connect relevant real-world situations while maintaining high expectations of student achievement and increasing engagement.

Engagement

There are three specific types of engagement that can influence mathematical performance: affective, behavioral, and cognitive. Affective engagement is a measurement of students' sense of belonging, importance, and appreciation and is related to their positive or negative reactions to teachers, classmates, curriculum, and school (Fredricks & McColskey, 2012; Goldin, Epstein, Schorr, & Warner, 2011; Hospel & Galand, 2016). Positive affective engagement is believed to promote student involvement in school, both academically and non-academically. Behavioral engagement is measured by students' effort, participation, and ability to follow instructions. Behavioral engagement is comprised of students' observable actions or performance (Dotterer & Lowe, 2011; Fredricks & McColskey, 2012). Behavioral engagement is typically considered important for experiencing a positive academic experience. Cognitive engagement is a matter of students' level of mental effort in relation to their work; it refers to students' investment in learning and willingness to put forth the necessary effort to comprehend and master difficult skills (Fredricks & McColskey, 2012; Hospel & Galand, 2016). There have been several attempts to understand cognitive engagement, but generally it is unobservable (cf. Gresalfi & Barab, 2011). Innovative approaches to make this process more transparent have included methods such as "Cognitive Drive Bys" or "Cognitive Labs" (Winter, Kopriva, Chen, & Emick, 2006). Improving cognitive engagement may lead to improved learning, but the ability to directly influence it often requires proxy measures and the reliance on supposition. The influence of both affective and cognitive engagement has been shown to have an important positive effect on science and mathematics achievement (Chang, Mo, & Singh, 2013). Affective engagement has been used as a measurable indicator of cognitive engagement; typically, students only form some type of emotional response based on some experience cognitively interpreted.

STEM PBL

STEM PBL has increasingly become more popular in education today as the demand for collaborative problem solvers escalates in the job market. Education plays a crucial role in preparing and equipping future generations to take charge and face the challenges of the 21st century (Wan Husin et al., 2016). Project-based teaching is nothing new and originates from the work of authors like Dewey and Kilpatrick (Hasni et al., 2016). Project-based learning requires "doing" and "applying ideas" in real-world activities that are similar to activities in which adult professionals would engage (Krajcik & Blumenfeld, 2006). Researchers have proven that project-based models add rigor and relevance to any class setting (Jollands & Molyneaux, 2012) while also improving students' engagement and criticality in the learning process (Hanney & Savin-Baden, 2013) and heightening the quality of learning in the classroom (Galvan & Coronado, 2014). Group work is also highly correlated to students' enhanced sense of relevance for their everyday life and is related to higher levels of student engagement (Uekawa, Borman, & Lee, 2007).

Project-based methods have been seen as some of the best teaching methods for developing 21st century skills (Galvan & Coronado, 2014) so students can successfully function in a constantly evolving high-tech world (Capraro & Nite, 2014). Researchers have found statistically significant correlations between collaborative teaching strategies and development of 21st century skills such as digital literacy, inventive thinking, and effective communication (Wan Husin et al., 2016).

STEM PBL provides student-driven and student-centered instruction, uses authentic, real-life topics to provide context for content learning, increases student collaboration, and increases substance and rigor (Cook & Weaver, 2015). PBL allows for a variety of learning styles with real-world orientation beyond basic facts, encourages higher order thinking, and promotes meaningful learning from projects that connects students' new learning to prior knowledge (Moylan, 2008). It has been reported that rigor is more strongly linked to engagement (Cooper, 2014) in projects that require hands-on making, active experimentation, and "minds-on" experiences (Wohlwend & Peppler, 2015), and when students are authentically engaged in a lesson, they are more successful (Blackburn & Williamson, 2009). STEM PBL can help all students understand relevance, accept rigor, and improve their academic achievement (Clark & Ernst, 2008). STEM PBL successfully increases student engagement by merging relevant real-world applications and rigorous content knowledge.

Methodology

In order to study the effects of STEM PBL on student engagement, a quasi-experimental design was used. Three focus groups were created, and students were randomly assigned to one of the three groups taught by the two teachers selected for this study. Quantitative data from the three focus groups were collected to assess student engagement within a STEM PBL classroom compared to a non-STEM PBL classroom, to examine and understand how teachers in these settings create learning environments supportive of exploration and discussion, and to determine what contributes to or impedes students' engagement. This analysis will help to characterize the instructional enactments that are occurring in classrooms and examine how engagement and learning in a mathematical activity may be malleable depending upon the rigorous content and meaningful opportunity for active engagement.

The theoretical framework and measurement instrument for affective engagement in this study was built upon Rutgers' preliminary accomplishments (DeBellis & Goldin, 2006; Goldin, 2002; Goldin et al., 2011). The current study involved a set of "engagement structures", and the researchers used an instrument called the Rutgers University Mathematical Engagement Structure Inventory (RUMESI) to tap into the activation of these structures at the time of instruction.

Participants

Participants in this study were students and teachers from an inner city, Title 1 school where 88% of the student population was of low socioeconomic status. Teachers who participated were offered free professional development (PD) and a stipend for their participation. Two exemplar teachers (Teacher A and B) were selected as the "Case Study Teachers", and data were collected on 147 of their students. Both teachers participated in over 300 hours of professional development over the course of three years. Teacher A worked in a STEM focused middle school, had participated in 380 hours of STEM PBL professional development, and focused on bridging mathematics and real-world experiences in her instruction. Teacher B taught in a non-STEM focused middle school, and to enhance her instruction, she participated in a four-year study to improve algebra teaching and learning. During the four-year study, she engaged in 419 hours of professional development that focused on utilizing content knowledge, improving questioning techniques, and integrating instructional tools such as GeoGebra, calculators, and manipulatives.

While all of their students participated and completed the instrument, only data for the 147 randomly preselected students were provided to the research team. The students were classified by gender, at risk or not at risk, and ethnicity (Asian, African-American, Hispanic, or Caucasian). The three focus groups received different interventions.

Interventions

The intervention was administered in two settings. Teacher A was formally trained in STEM PBL (setting 1), and Teacher B received PD on mathematics content dealing with rational numbers and algebra without a pedagogical component (setting 2). In the first setting, Teacher A taught one STEM PBL lesson during the 9-week period, and it varied from 4-10 days, mean 6.1 days in duration. In the second condition, Teacher B administered the instrument after classroom instruction in mathematics in which group work was a component. Group work was most commonly reported as students working in pairs or groups of 4. The overall lesson characterization was bell work, topic introduction- in student language, demonstration, group practice, group practice with reporting out, and individual practice. The instrument was administered in both conditions before and after instruction in rational numbers. In an attempt to isolate the teacher effect from STEM PBL effect, the STEM PBL teachers also administered the instrument before and after instruction when they were not using STEM PBL instruction but were still teaching rational numbers. Time between the STEM PBL lesson and the other lesson was set to be 2 weeks (however, it varied from 7 to 16 days, mean was 13.6 days). This variability was due to schools not being on exactly the same schedule. This method resulted in three sets of scores: score for students who Group 1) received STEM PBL instruction, Group 2) were taught by a STEM PBL trained teacher but who did not use it for that lesson, and Group 3) were taught by a teacher who was not trained and did not implement STEM PBL but had content professional development.

Instrument

In the spring of 2008, the Rutgers team developed the Rutgers University Mathematical Engagement Structures Inventory (RUMESI), based on an expanded theoretical articulation of nine affective structures. It has been subsequently revised several times to improve the psychometric functioning of the instrument (Schorr et al., 2010). The RUMESI contains 37 items and takes about 10 – 15 minutes to complete. It measures each of the eight engagement structures described below. For instrument items see appendix. Students rated questions on a five-point Likert scale where 1 represented “this does not represent how I felt in class today” and where 5 represented “this greatly represents how I felt in class today”. An exploratory factor analysis (EFA) was performed on the data collected from the 37 items of the RUMESI and all items were loaded into 8 components. These 8 components were named and identified as engagement structures that measure the different types of motivating desires and possible engagement features. Table 1 (Adapted from Goldin et al., 2011) shows the 8 engagement structures and their measurement descriptions.

Table 1. Engagement Structures

Structure	Measurement Description
I'm Really Into This (IRIT)	Measures the motivation to solve the problem for its own sake; leading to sense of flow and accomplishment.
Check This Out (CTO)	Measures the motivation to achieve a nonmathematical "payoff" which can lead to intrinsic interest in the task or heightened extrinsic interest.
Let Me Teach You (LMTY)	Measures motivation to share knowledge, receiving satisfaction from teaching and helping others.
Look How Smart I Am (LHSIA)	Measures the motivation to impress others with the goal of achieving recognition that their own thinking is correct.
Get the Job Done (GTJD)	Measures the desire to fulfill an assigned task, receiving a sense of satisfaction from having fulfilled the commitment.
Pseudo Engagement (PE)	Measures the student's desire to stay under the radar, which decreases engagement.
Don't Disrespect Me (DDM)	Measures when a student felt that they were being disrespected, which distracted from engagement and desire to gain mathematical understanding.
Stay Out of Trouble (SOOT)	Analyzes the student's desire to avoid trouble or negative attention.

Of the 37 items, there were 3 items measuring IRIT, 4 for CTO, 4 for LMTY, 8 for LHSIA, 5 for GTJD, 2 for PE, 6 for DDM, and 5 for SOOT. A score of each structure was calculated for each student based on his or her survey responses. These scores were then used to analyze the engagement level of each focus group. The internal consistency reliability is .86 for all items of the instrument and the Cronbach's alpha for the present study were the following: IRIT= .90, CTO = .92, LMTY = .83, LHSIA = .70, GTJD = .73, PE= .81, DDM = .50, and SOOT= .91.

Factor Analysis

To search for patterns of correlations (Henson, Capraro, & Capraro, 2004) among the 8 structures, a second order exploratory factor analysis EFA was performed (Navruz, Capraro, Bicer, & Capraro, 2015). The factor analysis was conducted using Statistical Package for the

Social Sciences (SPSS) software version 24. A factor analysis is usually performed on studies with large sample sizes around 300 (Henson et al., 2004); therefore, because the sample size was much smaller, the data were inspected to ensure that it could be factor analyzed. Pallant (2007, p. 185) indicated that the data should meet three criteria: (1) the correlation matrix should have several correlation coefficients of .3 and above, (2) Bartlett's test of sphericity should be statistically significant ($p<.05$), and (3) the Kaiser-Meyer-Oklin (KMO) measure of sampling adequacy should be 0.6 or greater. To test the criteria a correlation analysis was performed. The correlation matrix showed that half of the coefficient indices were equal to, or greater than .3. The KMO measure of the sampling adequacy resulted in a value of 0.821, and the Bartlett's test of sphericity found an approximate Chi-Square value of 300.966 with $p<0.05$.

After examining these results, the 8 structures measuring student engagement were subjected to an EFA using the extraction method principal component analysis (PCA) with Varimax rotation. Table 2 presents the factor pattern matrix consisting of the coefficients that indicated the unique contribution of each variable to each factor (Henson et al., 2004); coefficients with an absolute value less than 0.44 were suppressed.

Table 2. Rotated Component Matrix of Engagement Structures

Structure	**Component**	
	1	**2**
GTJD		.775
SOOT		.675
LMTY	.610	
PE	-.833	
CTO	.542	
DDM	-.791	
IRIT	.710	
LHSIA	.819	

Note. Structure Coefficients less than .31 omitted

All variables were loaded under 2 components that were named Academic Engagement (component 1) and Behavioral Engagement (component 2). The factors obtained were second order factors (SOF) because they were abstracted from the 8 previously abstracted factors and not the original observed variables (Navruz et al., 2015). Factor analysis scores were saved as variables using a regression method when running the EFA in SPSS. Factor scores are composite variables that provide information about the item placement on the factors (DiStefano, Zhu, &

Mîndrilă, 2009). Using the means of the regression factor scores, confidence intervals were then produced to compare the effects of the factors on individual intervention groups. The value of Cohen's *d* and effect-size correlation, r, were calculated using the means and standard deviations for each possible combination of groups.

Results

The EFA resulted in the creation of two SOF, (1) academic engagement (AE) and (2) behavioral engagement (BE). The confidence intervals, in Figure 1, were computed using the regression factor scores saved during the EFA.

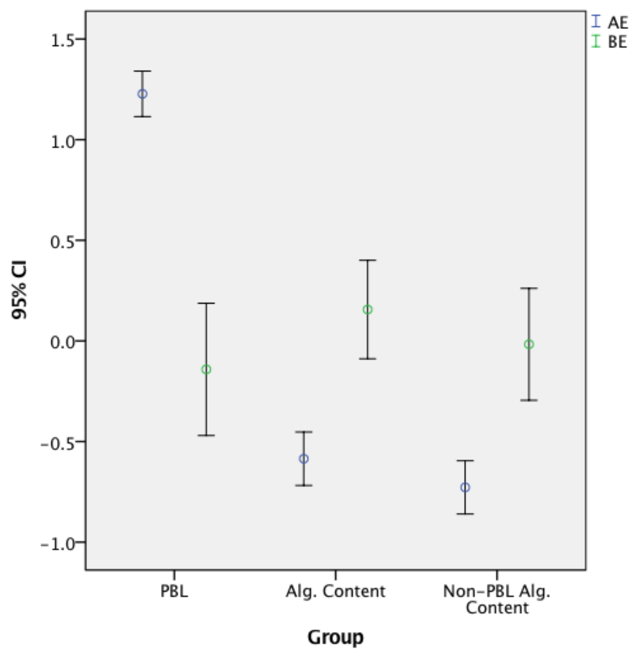

Figure 1. Academic engagement (AE) vs. behavioral engagement (BE).

The comparison between groups, using BE regression factor scores for the group means, indicated that the intervention did not have a statistically significant impact on behavioral engagement. The comparison of the AE scores resulted in a statistically significant difference between group 1 verses groups 2 and 3. The mean, standard deviation, and Cohen's *d* of the two factors are presented in Table 3, comparing Group 1 to Group 2 and Group 1 to Group 3.

Table 3. Descriptive Statistics and Effect Size Estimates for Academic and Behavioral Engagement

	Group 1		Group 2		Group 3		Group1 vs. Group2	Group1 vs. Group3
Variable	Mean	SD	Mean	SD	Mean	SD	Cohen's *d*	Cohen's *d*
AE	1.228	0.403	-0.585	0.472	-0.728	0.441	2.837	3.136
BE	-0.142	1.167	0.156	0.870	-0.017	0.926	-0.186	-0.077

Discussion and Conclusion

The results can be used to verify that there exists an improvement in student academic engagement between the intervention groups, comparing traditional mathematics lessons verses STEM PBL lessons. It is shown there are no statistically significant effects on BE between the STEM PBL lessons verses the traditional math lessons; therefore, the obtained results are not likely a teacher effect because the effect disappears for the other group taught by the same teacher but with a different pedagogical strategy. The strong effect of STEM PBL shown provides evidence that STEM PBL has a positive impact on student academic engagement.

Similar studies have shown strong links generated by combining academic rigor with the relevance of students applying their knowledge to real-world situations (Siri, Zinner, & Lezin, 2011). Increasing the cognitive rigor of tasks students engage in has been shown to be effective for improving academic achievement and classroom engagement (Paige et al., 2013). In another similar study, results showed that students who experienced PBL instruction had significantly higher overall critical thinking compared with students who experienced lecture-based instruction, and they continued to have higher scores 2 years afterwards (Tseng, Chang, Lou, & Chen, 2013). Previous researchers support that school engagement is an important predictor of academic achievement (Dotterer & Lowe, 2011), and engaging students in STEM PBL promotes instructional strategies that challenge students to innovate and invent (Kennedy & Odell, 2014); this supports how STEM PBL not only improves student engagement but emphasizes the possibility to improve academic achievement.

Overall, the present study shows that the academic rigor and relevance provided through STEM PBL lessons increase students' academic engagement. Further, longitudinal research is needed to observe the possible long-term effects of STEM PBL on student academic engagement and examine its impact on mathematics achievement. An additional exploratory analysis should be used to make progress in understanding the integrations among the factors and the effects of students' prior achievement.

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Appendix

RUMESI

For all questions, the ratings were from 1-5.

(1) means - This does not represent how I felt in class today.

(5) means - This greatly represents how I felt in class today.

LMTY – Let Me Teach You 4-20

16. I wanted to teach another student something that I knew that this other student did not know.
17. I listened carefully to the ideas of someone I was trying to help.
18. I helped someone see how to do the math.
19. Others listened carefully to my ideas.

SOOT – Stay Out Of Trouble 5-25

26. I was worried I might do something that would get me into trouble with one or more students.
27. I paid attention to the way others were reacting to me.
28. I hoped people would not pay attention to me.
29. I cared more about feeling OK than about solving the math problem.
35. I felt relieved when all the work was done.

GTJD – Get The Job Done 5-25

30. I wanted to make sure that all the required work was completed.
31. The most important thing for me was getting the answer to the problem.
32. I worked on getting the answer to the problem.
33. I tried to get members of my group to work to get the answer to the problem.
34. I wanted the teacher to think I am a good student.

PE – Pseudo Engagement 2-10

37. I wanted to look like I was doing work even when I wasn't.

38. I worried that I might get in trouble with the teacher.

CTO – Check This Out 4-20

7. I realized that if I worked hard at the problem, I could figure it out.

3. As I made progress, I became more interested in understanding the math.

36. I felt proud about what I accomplished.

5. I felt that learning the math today would benefit me or pay off for me.

DDM – Don't Disrespect Me 6-30

25. I was not going to let someone disrespect me and get away with it.

21. I argued strongly in support of my ideas.

22. I had an unpleasant disagreement.

41. I achieved a good understanding of the math we worked on today.

23. My ideas were challenged by others.

24. Some person or some group of people tried to disrespect me.

IRIT – I'm Really Into This 3-15

1. I concentrated deeply on today's math problem.

4. I was so into my work that I tuned out things going on around me.

2. I was fascinated by the math today.

LHSIA – Look How Smart I AM 8-40

11 I wanted people to think that I'm smart.

12. I tried to impress people with my ideas about the problem.

13. People seemed impressed with the ideas I shared about the problem.

14. People saw how good I was at the math we did today.

15. I felt smart.

20. I wanted to show someone that my way was better.

42. I was a lot better at math than others today.

21. I argued strongly in support of my ideas.