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RESEARCH ARTICLE

Fostering growth: The impact of STEM PBL on students' self-regulation and motivation

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Abstract

There is an increasing concern in the United States regarding the workforce's ability to maintain a competitive position in the global economy. This has led to an increased interest in effective science, technology, engineering, and mathematics (STEM) education. The purpose of this study was to investigate the effect of STEM project-based learning (PBL) on students' self-regulation and motivation to learn. Secondary students (n = 60) participated in a STEM summer camp in which STEM PBL was utilized. Results showed that students increased their self-regulation skills (t = 2.83, df = 59, p = .004) and motivation (t = 2.25, df = 59, p =.004), with Cohen's d effect sizes of 0.395 and 0.404, respectively. Student-centered learning and peer collaboration while solving real-world problems were likely the greatest contributing factors to the outcomes. Educators should utilize the results to provide opportunities for students to experience STEM PBL.

Keywords: motivation, self-regulation, STEM PBL

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I. INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education is defined as a set of interdisciplinary instructional and learning practices designed for grades K–12 (Bicer, Capraro, & Capraro, 2017; Capraro, Capraro, & Morgan, 2013; Awad, 2023). Often, STEM education is delivered through project-based learning (PBL), which is a student-centered instructional strategy in which students collaborate to solve relevant real-world problems (Baidal Bustamante et al., 2023; Bicer et al., 2017). Engaging in STEM PBL activities has been shown to improve students' higher order thinking skills (Capraro et al., 2013), self-regulation, and motivation to learn because it facilitates their contribution to their own learning (Dominguez & Jamie, 2010; Erdogan & Senemoglu, 2017; Kaldi, Filippatou, & Govaris, 2011; Wan Husin et al., 2016). The relationship between engaging in STEM PBL and improved self-regulation and motivation to learn is critical because students' self-regulation and motivation have a significant impact on their academic careers (Erdogan & Senemoglu, 2017). Researchers have found a strong correlation between self-regulation, learning, achievement, and academic performance (Brown & Harris, 2013; Lawrence & Saileella, 2019; Gniewosz et al., 2015). Although researchers have investigated various instructional strategies including PBL, that foster students' self-regulation and motivation to learn, few have examined the influence of STEM PBL intervention on these variables. Therefore, researchers in the present study investigated the effect of engaging in STEM PBL activities during a STEM summer camp on students' self-regulation and motivation to learn.

II. RELATED LITERATURE

STEM PBL

PBL is an instructional method that affords students opportunities to collaborate while applying ideas and solving problems situated in real-world contexts. This form of instruction has been found to be highly effective in helping develop individuals' 21st century skills because it involves the convergence of relevant real-world applications with rigorous content knowledge (Galvan & Coronado, 2014; Hasni et al., 2016). These characteristics of PBL instruction make it well suited as a conduit for teaching STEM content because of the overlap between the four STEM fields; their relevance to long-term, global challenges; and the in-depth, hands-on learning that is at the core of the instructional strategy (Capraro et al., 2013; Beier et al., 2019). These three core constructs make student acquisition of STEM-related content more accessible.

The use of STEM PBL enables students to be engaged in the diverse components of problem solving, interdisciplinary curriculum, hands-on activities, group work, and open-ended questions (Han et al., 2016; Kwon, 2017). The last two components are central to the STEM PBL process, as students must work with their peers in pairs or as a group to solve problems with ill-defined tasks and a well-defined outcome (Bicer et al., 2017; Han, Capraro, & Capraro, 2015). When students are engaged in STEM PBL activities, they use personal, and at times idiosyncratic, methods and strategies to respond to the ill-defined task given to them (Han et al., 2015). The well-defined outcome gives enough direction that the lesson objectives can easily be met. Using STEM PBL as an instructional strategy thus allows teachers to deliver student-directed inquiry (Han et al., 2016; Lee, 2022). For example, STEM PBL was utilized in teaching rational numbers to 9th graders (Kwon et al., 2019). The students were tasked with creating objects utilizing the mathematical principles of rational numbers, which served as the clearly defined objective. In open-ended assignments, students autonomously sought information, selected materials, and designed and built their objects.

There are other benefits to using STEM PBL as an instructional strategy. In STEM PBL, students' progress through engineering design process stages (see Figure 1) that are measured using formative assessments to ensure they meet the intended learning objectives (Capraro et al, 2013, Han et al., 2016). This characteristic of STEM PBL enables instructors to monitor student learning while also allowing students to think critically, creatively, and independently. In this way, the STEM PBL instructional strategy is inherently designed around the constructivist view wherein students are actively investigating their own learning process rather than passively receiving information from a third party (Bicer et al., 2017; Han et al., 2016). In fact, the instructional elements of STEM PBL, such as discovery learning, hands-on learning, real-world scenario tasks, and student-centered learning, are associated with the constructivist approach to education (Holstermann, Grube, & Bögeholz, 2010; Steffe & Gale, 1995). This approach to education, alongside STEM PBL instruction, can have positive influences not only on student content knowledge but on a student's relationship with learning as well.

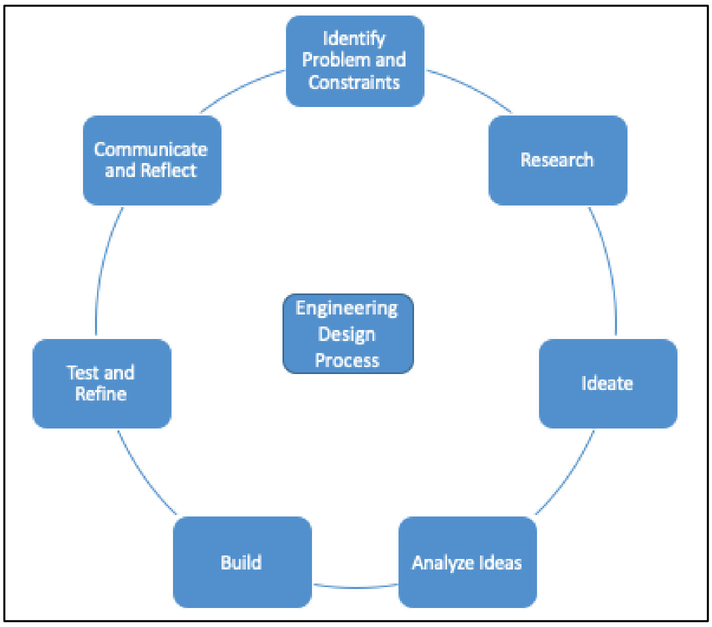

Figure 1. Engineering design process stages.

The use of constructivist learning approaches have been correlated to positive feelings toward learning, communication, and collaboration and the development of self-regulation and motivation to learn (Dominguez & Jamie, 2010; Erdogan & Senemoglu, 2017; Kaldi et al., 2011). When engaging in STEM PBL, students typically learn through constructivist-based practices in which they are actively constructing knowledge during the learning process (Craft & Capraro, 2017), and this constructivist component of STEM PBL has been found to positively influence student engagement and academic achievement (Cook & Weaver, 2015; Kwon 2017). STEM PBL has much to offer learners, and engaging students in this instructional method has the potential to positively impact their learning and understanding, enhance their problem-solving and collaboration skills, and support the development of self-regulation and motivation.

Self-regulation

Self-regulation involves an individual's capability to control his or her actions and emotions with no external interventions. It is defined as a cognitive and behavioral constructive process through which individuals have the ability to monitor, regulate, and control their cognition, attention, emotions, and behavioral impulses (Blair & Diamond, 2008; Stefanou, Stolk, Prince, Chen, & Lord, 2013; Winne & Perry, 2000; Zimmerman, 1986). Skills such as planning, monitoring, paying attention, inhibiting reflexive actions, and delaying gratification are essential to effectively navigating the social world and are executed through self-regulation (Kitsantas & Cleary, 2016; Pintrich, 2000; Zimmerman, 2000). Students who successfully self-regulate are metacognitively, motivationally, and behaviorally active participants in their learning (Bandura & Schunk, 1981; Colbert & Cumming, 2014), and they develop and flexibly maintain strategic behaviors to achieve their own goals (Duckworth & Carlson, 2013; Lawrence & Saileella, 2019). The internal process of self-regulation has been found to be key to becoming a prosperous lifelong learner and is associated with students' academic achievement and high levels of motivation towards learning (Cleary & Platten, 2013; Kitsantas & Zimmerman, 2009). In both STEM PBL and self-regulated learning, knowledge is student directed, the development of autonomy is present, collaboration is key, and student motivation is important (Leary, 2012; Gniewosz et al., 2015). Therefore, STEM PBL instructional strategy is symbiotic with the promotion of self-regulated learning in students.

Motivation

Motivation has been defined as an internal condition that arouses or reinforces behavior (Saracho, 2019) and is particularly interconnected to conscious or subconscious motives that explain individuals' choices (Theodotou, 2014). Importantly, motivation has been linked to other adaptive outcomes, such as improved learning, well-being, and performance (Ryan & Deci, 2000). Motivation itself is a multifaceted construct that comprises several interrelated components, including interest, perceptions, beliefs, values, and actions (Lai, 2011). Furthermore, a student's motivation to learn is highly dependent on their individual interests, academic goals, and personal values (Hall & Goetz, 2013; Saracho, 2019).

Interest. Individual interest can be thought of as an object or activity that has emotional value and personal importance; in academia, interests are often predictors of the classes, degree programs, and career paths students choose to pursue (Hall & Goetz, 2013). High levels of individual interests play an active role in supporting learning experiences through mechanisms such as increased attention, deeper processing of content, and increased persistence toward the learning objective, all of which lead to greater achievement in school (Ericsson, Krampe, & Tesch-Römer, 1993; Hidi, Renninger, & Krapp, 2004).

Goals. Goals are mindful anticipations of the consequences of one's actions and in academics settings are guiding forces that motivate learning behavior (Hall & Goetz, 2013). Individuals' needs and goals encourage, or motivate, action by focusing performance, behavior, and choices to fulfill and actualize them (Anderman & Wolters, 2006). When a student sincerely wants to accomplish a goal, autonomy is stimulated, leading to increased levels of motivation and accomplishment (Saracho, 2019). Gonida and Lemos (2019) found that goals are correlated with greater perseverance, productive self-regulation, and positive patterns of academic engagement.

Values. Students' values, from an educational perspective, are their perceptions of importance and utility of learning; for example, a particular course may not be valued because it is not relevant to a student's goals (Wentzel & Miele, 2016). Task values are beliefs about the opportunities afforded by particular activities and situations (Gonida & Lemos, 2019). Eccles et al. (1983) proposed that individuals' expectations and values directly influence task selection and performance.

These three factors are key for sustaining the associated behaviors related to motivation and are important components in the education process (Dweck & Leggett, 1988; LaForce et al., 2017; Linnenbrink-Garcia & Patall, 2016). Nolen and Ward (2008) make the important point that student motivations are not fixed and instead are strongly influenced by their environment, interactions with peers, and activities in the classroom.

Motivation can be situational and influenced by instructional strategies. Social cognitive theories of motivation would suggest that students are motivated to engage in activities when they feel a task holds value, set a goal for that task, and believe they have the ability, skills, and resources to accomplish that goal (Wentzel & Miele, 2016). Instructional strategies such as STEM PBL create environments that are centered around student choice and interest and have been found to foster student engagement and motivation to learn (Bicer et al., 2017; Krajcik & Delen, 2017; Young, Ortiz, & Young, 2017). Specific techniques used in STEM PBL instruction have also been found to positively influence student motivation. For instance, hands-on learning, meaningful real-world contexts, and integrated mathematics and science content embedded in STEM PBL have been found to awaken students' interest and facilitates the development of motivation to learn (Bergin, 1999; Hidi et al., 2004; Holstermann et al., 2010; Krapp, 1999). The fact that technology, an important aspect of modern teaching practices and student learning, is also often embedded in STEM PBL is important to consider as well. In fact, some studies found that integrating technology into teaching increased some students' motivation to learn because doing so provided an alternative and often interactive way for them to engage in STEM lessons (Hollenbeck & Fey, 2009; Kwon, 2017). In these ways, educational components of STEM PBL have an important role in fostering students' motivation to learn.

Motivation as viewed in a systems approach lays the foundation for understanding the nexus of self-regulated learning and motivation. The two constructs are complex and unavoidably interconnected. The research we undertake situates students in a rich context in which these two constructs have the potential to occur and flow naturally from the assigned learning activities. The purpose is to investigate the extent to which the evidence suggesting that quality STEM PBL instruction leads to improvements in self-regulated learning and motivation is correct, as there currently exists a debate regarding the malleability of these factors. Specifically, some researchers believe that both motivation and self-regulation are robust to change (e.g., Eckerlein et al., 2019; Usher, 2012), but others argue that even short-term mediators can have important impacts on these factors (e.g., Hall & Goetz, 2013; Saracho, 2019; Smit, de Brabander, Boekaerts, & Martens, 2017). Our research question was the following: Did students' self-regulation and motivation change as a result of participating in STEM PBL?

III. METHODS

Participants

The student participants in this study were 60 middle and high school students attending a two-week STEM summer camp at a Tier One university in the United States. They were selected as participants through convenience sampling. The camp was open-enrollment, and students either self-selected to attend or had parents who registered them for the camp. For this study, there were 29 female students (48%) and 31 male students (52%), and their grades ranged from 7th through 12th. The breakdown of students across different grade levels is as follows: 13% in 7th grade, 6% in 8th grade, 17% in 9th grade, 17% in 10th grade, 17% in 11th grade, and 30% in 12th grade. Students were from various U.S. states and other countries. Their ethnic backgrounds included Caucasian (59%), Hispanic (19%), Asian (13%), and African-American (5%). The remaining students self-identified as no specific ethnicity (4%).

Intervention

A non-randomized quasi-experimental design was used to understand how engaging in STEM PBL influenced students' self-regulation and motivation to learn. During the 2-week STEM camp, participants received 60 hours of STEM PBL instruction. This instruction was delivered daily through several one-and-a-half hour-long classes. In between classes, students attended campus tours and experiential opportunities (chemistry and physics shows, lab tours, panel sessions, and educationally responsible affinity time). All STEM PBL activities utilized during the camp were developed by STEM PBL professionals (see Table 1) and were required to have the following components as part of the design: active collaborative engagement, student-centered instruction, limited lecture time by the instructor, and hands-on, product-focused outcomes completed in dyads or small groups.

Although all students were required to participate in several STEM PBL activities, they did have some control over what activities they engaged in through their choice of which camp they attended. At registration, students were informed of what activities would take place during each camp and its associated courses. With this information, students were able to select which camp and courses to participate in based on their own personal interests, though it is possible that some parents made this decision for their students.

Prior to the STEM camp, instructors received at least one semester of professional development that was designed to improve their content knowledge of specific STEM-related topics. The professional development additionally helped instructors practice implementing STEM PBL instruction that connects content knowledge and real-world contexts, using assessments for feedback, and exercising classroom management.

Table 1. STEM PBL instructional content explained

Instruction	Description	Examples of Activities
Coding	Learning the basic and advanced concepts of coding and using a program to create codes.	*Creating codes using "Hour of Code," "Scratch," or "Python" to: - draw a picture - make a storybook - create a word guessing game
Microcontroller	Learning the basic concepts of coding and how electricity functions in a microcontroller.	*Making circuits on a breadboard and programing a microcontroller to: - change colors and brightness with LEDs - measure temperature - spin a motor - compose music
Cryptography	Connecting STEM-related knowledge to real-world situations.	*Encrypt and decrypt messages using various ciphers (e.g., Caesar cipher, Vigenère ciphers, multiplicative ciphers, etc.) *Breaking codes using technology
Structures	Understanding what work goes into building bridges.	*Planning, designing, and building a bridge while considering how much it costs and how strong the bridge should be
3D printing	Understanding spatial visualization in a real-world situation through 3D modeling.	*Measuring objects for 3D modeling *Designing and printing 3D models using 3D CAD software and a 3D printer

We used a single-group design for this study because we wanted to carefully examine changes in self-regulation and motivation in the participants through a foundational theory building model. In doing so, it was important to understand that neither self-regulation nor motivation is a content-based factor. That is, neither self-regulation nor motivation is a taught concept. One cannot teach students self-regulation nor motivation in the same explicit way one might teach centripetal force or the multiplication of two-digit numbers. Instead, self-regulation and motivation can only be influenced by experiences with instructional characteristics. Therefore, the learning experiences of the STEM summer camp, rather than the content knowledge the students were exposed to, were likely to impact the two psycho-social factors. As such, the use of comparison groups would provide little advantage over our model.

Instrument

To measure students' self-regulation and motivation, researchers adapted parts of the Motivated Strategies for Learning Questionnaire (MSLQ) by Pintrich, Smith, Garcia, and McKeachie (1991). The motivation questions in the MSLQ scale were designed to measure students' perceptions of the reasons for why they engaged in a learning task. The self-regulation questions were developed to measure students' fine tuning and continuous adjustment of their cognitive activities. Pintrich et al. (1991) reported Cronbach's alpha levels for motivation and self-regulation of .68 and.79, respectively. In the present study, the instrument consisted of 12 items for self-regulation (Cronbach's $\alpha = .78$) and eight items for motivation (Cronbach's $\alpha = .74$). Our results compare favorably to the original survey results.

Pintrich et al. (1991) tested for the factor validity of the MSLQ scales by running two confirmatory analyses. The scale correlations with final grade were significant, albeit moderate, demonstrating predictive validity. Moreover, fit indices from the confirmatory factor analysis indicated that the MSLQ showed reasonable factor validity (GFI = .77, CN = .07, RMR = 122; Pintrich et al., 1991, p. 69).

The sample items of the instrument are the following: "When reading for this course, I make up questions to help focus my reading", "I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying", "When I study for this class, I set goals for myself in order to direct my activities in each study period", "I think that what we are learning in this class is interesting", "Even when study materials are dull and uninteresting, I keep working until I finish", "I expect to do very well in this class", "I think that what I am learning in this class is useful for me to know", and "Understanding this subject is important to me".

The student participants in the present study were asked to demonstrate the extent of their agreement with the items of both self-regulation and motivation on a seven-point Likert scale from "not at all true of me" to "very true of me" (coded from 1 to 7). The questionnaire took approximately 15 minutes to complete and was administered on the first day of the STEM camp (pretest) and on the last day of the STEM camp (posttest).

Analyses

There were four scores missing from the pretest. Because the percentage of missing data was small, the researchers decided to impute the missing pretest data to retain the posttest data (Buhi, Goodson, & Neilands, 2008). First, a linear interpolation method was used to replace these missing values. Once the missing scores were replaced with the predicted scores, the researchers computed descriptive statistics for the sample to see the mean and standard deviation difference. Paired-sample t tests were used to examine whether students' self-regulation and motivation statistically significantly increased after participating in STEM PBL activities. A Bonferroni correction was used because multiple univariate tests were calculated to answer the research question. There were two paired-sample t tests, so the Bonferroni correction was calculated by dividing the original alpha level, .05, by two to get the new alpha value, .025. Moreover, Cohen's d effect size estimates were calculated for both self-regulation and motivation in order to determine the magnitude of the observed effect and the practical importance of this study. Reporting effect sizes is considered a best practice for quantitative studies (Capraro, 2004; Wilkinson & the American Psychological Association Task Force on Statistical Inference, 1999).

IV. RESULTS

The descriptive statistics were computed to estimate the center and spread of the data for the pretest and posttest by dependent variables (see Table 2). Both students' self-regulation and motivation mean scores increased from pretest to posttest, indicating that, on average, student self-regulation and motivation increased. However, the growth of scores from pretest to posttest in motivation was higher than the growth in self-regulation (see Figures 2 and 3). Within the survey, the items related to self-regulation, particularly "When I study for this class, I set goals for myself to direct my activities in each study period," and for motivation, the item "Understanding this subject is important to me," exhibited the most significant increase in results.

Table 2. Descriptive statistics for pretest and posttest by self-regulation and motivation

	pretest		posttest	
	Mean	SD	Mean	SD
Self-Regulation	54.8	6.7	57.7	7.7
Motivation	44.1	5.3	46.3	5.8

Note. N = 60, Motivation range = 8–56, Self-regulation range = 12–84

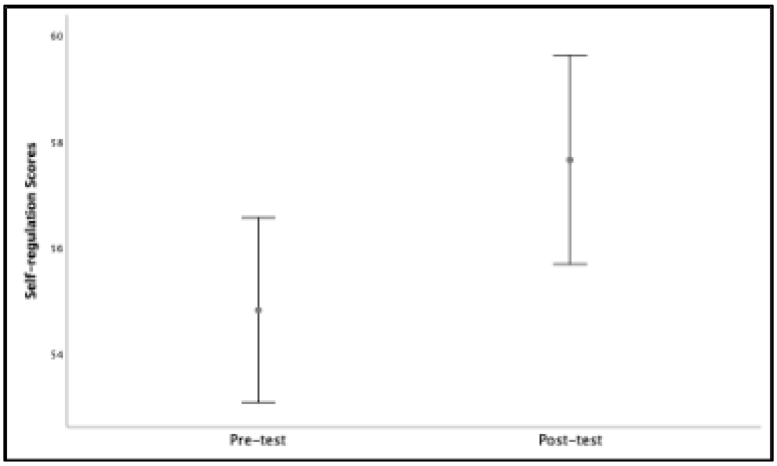

Figure 2. Point estimates of students' self-regulation.

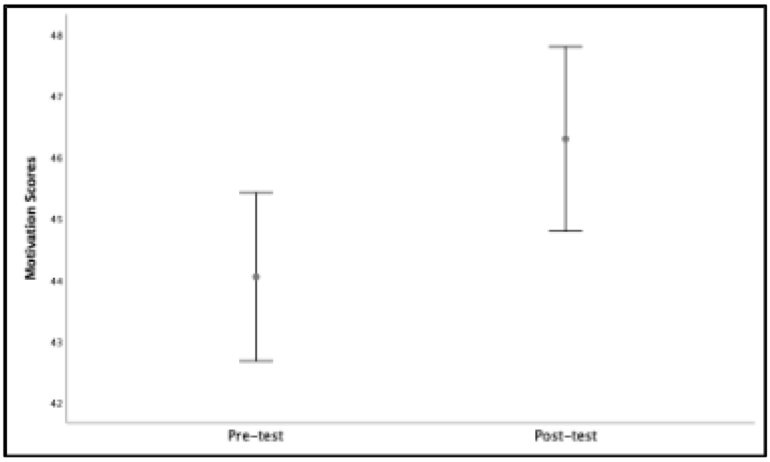

Figure 3. Point estimates of students' motivation.

Table 3 contains the results of the paired sample t tests, which were used to determine whether students' self-regulation and motivation statistically significantly changed after STEM PBL instruction. Results from the analyses revealed that the difference between pretest and posttest scores for self-regulation were statistically significant (t = 2.83, df = 59, p = .004).

The Cohen's d effect size for this difference was .395. Similarly, results from the analyses revealed that the difference between pretest and posttest scores for motivation was statistically significant (t = 2.25, df = 59, p = .004). The Cohen's d effect size for this difference was .404. The level of this effect is relatively strong given previous findings in educational research (Capraro, 2004; Thompson, 2006), and it is somewhat in line with previous research on motivation (Gonida & Lemos, 2019; Han et al., 2016; Kwon, 2017).

Table 3. Paired-sample t-test results for self-regulation and motivation

	N	Mean Difference	df	t	*p*	95% C.I.
Self-Regulation	60	2.9	59	2.99	0.004	[0.94, 4.73]
Motivation	60	2.2	59	2.96	0.004	[0.73, 0.77]

V. DISCUSSION

STEM Project-Based Learning (STEM PBL) has emerged as a creative and innovative instructional method within the realm of mathematics education. Traditionally, mathematical concepts have been viewed as isolated from real-world contexts. However, this perception is changing, with an increasing recognition that mathematics permeates everyday life and serves as a cornerstone for the development of various fields and nations. STEM PBL has been emphasized for its ability to bridge mathematics with other disciplines and enhance the efficacy of learning in mathematics. Particularly in Korea, STEM education policy has been implemented in schools for over a decade, with STEM PBL recognized as an effective activity-based learning method that increases students' affective and cognitive engagement (Lee et al., 2019; Lee et al., 2022). We anticipate that the findings of this study, conducted in the United States, could provide inspiration for education in Korea.

Based on the descriptive statistics, the researchers were able to determine that there was an increase in both student self-regulation and motivation following the intervention. This suggests that most of the students developed greater self-regulation (M(post)-M(pre) = 2.9) and motivation (M(post)-M(pre) = 2.2) after experiencing STEM PBL activities for two weeks.

The paired-sample t-test results indicated that these increases in self-regulation and motivation were statistically significant. Students may have increased their self-regulation statistically significantly because of active engagement in STEM PBL activities. This result aligns with previous research that found STEM PBL can influence the development of self-regulation and motivational elements (Han et al., 2016; Dominguez & Jamie, 2010; Erdogan & LaForce et al., 2017; Senemoglu, 2017; Wan Husin et al., 2016; Yabas et al., 2022). Students had to set goals for their learning to be able to create a final product for each STEM PBL activity, which involved monitoring and regulating their cognition and behaviors, and this may have allowed them to self-regulate during their learning process. Moreover, students were not only able to apply these disciplines to real-life scenarios but were also able to choose to study subjects that matched with their own interests. This allowed for a greater possibility of students developing interest in STEM topics.

The scholarly significance of this study is in the contribution to both theoretical development and strategically applied research development. First, the results reinforce the notion that using STEM PBL is aligned with constructivist learning, though there are some aspects of enactivism or embodied cognition used in this instructional method. It was not possible to disentangle students' engagement in the learning process from their active physical engagement; because of this, we believe the interaction of constructivism and enactivism yielded the outcomes.

The physicality of the learning that took place in this study is a dimension of STEM PBL that must be discussed. Learning in situated activities where students are moving and interacting with peers may become highly sought after by both students and instructors in the modern world, as it adds a dimension to interpersonal interactions that are increasingly missing in a society that is becoming more and more digital. Therefore, this study provides needed evidence that something is happening with real-world personal learning activities that encourage and require peer cooperation, which appear to be positively received by students and seem to have a strong positive impact on motivation.

The implications for learning in a STEM PBL framework that affords both a constructivist and embodied cognition paradigm include an increase in student learning that cannot be attributed to chance, time, or a combination of the two (Hollenbeck & Fey, 2009; Kwon, 2017). Although the obtained effects for a pre/post-intervention analysis cannot be compared to true experimental designs, there are important insights that can be drawn from the results as long as there is no attempt to generalize to any sample or relatively large obtained effect size estimates for the results of the STEM PBL experience. The obtained effects ranged between a 1/4 and 1/3 of a standard deviation. Typically, these are considered large for educational studies, and because the outcomes are closely aligned to the proximal measures of the STEM PBL activity, it is not likely that the obtained estimates would be attributed to chance or maturation. This is partly due to the fact that motivation is somewhat robust to change, meaning it is not easily influenced. For example, if you measured or estimated a group's motivation toward learning and then measured it again without any modifications to or different experiences in the learning environment, it is unlikely there would be a change in student motivation. Therefore, motivation is like other dispositional characteristics: without some intentional experiences, a group is unlikely to change its mean motivation score over a relatively short period of time. Therefore, the changes in motivation are likely aligned to student experiences in STEM PBL. As such, further research should explore the ways in which group mean motivation changes due to or is affected by different mathematical instructional pedagogies.

In this study, instructors had completed professional development before participating in STEM PBL instruction. Instructors were not only knowledgeable in preparing and implementing STEM PBL activities in classrooms, but also had strong content knowledge. Therefore, it seems prudent to state that for classrooms seeking to implement STEM PBL and achieve a similar effect on student self-regulation and motivation, teacher training or professional development is needed for teachers to properly and effectively implement STEM PBL.

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