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The effect of STEM problem-based learning on students' mathematical problem-solving beliefs

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Abstract

The purpose of this quasi-experimental study was to investigate the effect of science, technology, engineering, and mathematics (STEM) problem-based learning (PBL) intervention on students' problem-solving beliefs (PSB). To this end, the PSB questionnaire was administered to a group of eighty-six 10th graders across different socio-economic spectra working with an expert facilitator in a rural school that received curricular support and resources to specifically develop STEM teaching in eastern South Africa. The sample participated in two time periods (pre- vs. post-intervention) in which problem-based activities were utilized. A quantitative evaluation of the impact of an intervention on students' subsequent beliefs as well as qualitative analysis of interviews with a sample of fourteen purposively selected students is presented. Results showed that participants increased their mathematical PSB ($p < .001$, $d = .50$). The implications of these findings speak to the potential for teachers to utilize the results to provide opportunities for students to experience PBL activities.

Keywords: STEM, mathematical problem-solving, problem-based learning, problem-solving beliefs, problem-solving ability

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has been recognized a critical for a country's ability to maintain a competitive position in this global and competitive market. For instance, the Department of Basic Education (2009) focused on STEM education in an effort to increase the number of previously disadvantaged students pursuing STEM subjects and careers. Educating students in STEM subjects helps them learn how to work with *problematic tasks*[1] by integrating knowledge and skills from a variety of perspectives and using a variety of approaches. To show how mathematics is central to understanding science- and engineering-related careers, all stakeholders want to improve students' achievement levels in mathematics (Bansilal & Lephoto, 2022). It is important to note that mathematics is critical to the learning of any STEM subject; therefore, students must be able to think mathematically in a scientific context. The use of an interdisciplinary approach to problem-solving is desired skills for today's workforce (Young et al., 2011). In fact, an interdisciplinary approach to STEM education has the potential to engage groups who are underrepresented in STEM careers in powerful ways (Honey et al., 2014).

The likelihood that students will participate in the STEM careers depends in part on their beliefs about STEM subjects and their ability to integrate mathematical knowledge into science, technology, and engineering subjects. Students' learning in STEM education, however, is dependent upon a complex constellation of knowledge, skills, goals, and beliefs. STEM learning is not purely cognitive (Schoenfeld, 1985); students' problem-solving beliefs (PSB) are key to take into account.

[1] In this paper, the researcher used the term problematic tasks to designate "a situation that proposes a mathematical question whose solution is not immediately accessible to the solver, because he [or she] does not have an algorithm for relating the data with the unknown or a process that automatically relates the data with the conclusion" (Callejo & Vila, 2009, p. 112).

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Contribution to the literature

- The purpose of this study was to investigate and to shed light on the effect of STEM problem-based learning (PBL) on students' mathematical PSB and understand their experiences of the PBL approach; most efforts tend to address the STEM disciplines separately
- This study contributes to the existing literature on the importance of measuring students' mathematical beliefs as they could directly influence their STEM problem-solving ability.
- Further, the study contributes to literature as it found that, in the quest for teaching for conceptual understanding, students' previous knowledge is important as it provides the basis for better understanding of problems.

Thus, the effect of STEM *PBL*[2] is an important aspect in the learning of students of science- and engineering-related subjects. In emphasizing the importance of beliefs in learning. Goldin et al. (2009) point out that *beliefs*[3] influence "the success or failure of massive curricular reform efforts across entire countries" (p. 14). Additionally, research has shown that students are more likely to pursue careers in STEM fields if they hold positive mathematical beliefs (PSB) (Wang, 2013). For instance, in Kwon et al. (2021), findings indicated that support providing students with STEM PBL activities increased their PSB.

However, not only do most efforts tend to address the STEM disciplines separately, but there is also little research on how best to integrate the STEM disciplines and on the factors that make integration more likely to foster positive outcomes (Pearson, 2017). More particularly, there exists little research on how mathematical PSB specifically are influenced by the use of STEM PBL in formal education settings (Hmelo-Silver, 2004). The purpose of this study was to investigate and to shed light on the effect of STEM PBL on students' mathematical PSB and understand their experiences of the PBL approach. The following research questions guided the investigation:

(1) What is the effect of a PBL on influencing students' PSB?

(2) How do students respond to the PBL approach used to capture their beliefs in applying mathematical knowledge to solve science-, technology-, and engineering-related problems?

A caveat is in order here. Although extensive evidence that PBL is powerful approach (Felder & Brent, 2016), the aim of this paper was not to show that the PBL approach to STEM education works; that all or most participant students' PSB improved after the intervention. This is not a causality type of research aimed at establishing causal associations between an intervention and performance. In general, the purpose of quasi-experimental studies in STEM education is not necessarily to determine what works but rather to acknowledge that there are alternative explanations for the apparent causal association in part because of the inability to sufficiently control for important confounding variables that emerge (Shadish et al., 2002).

The researcher hoped to show that the PBL approach to STEM education makes sense, including showing that some of the difficulties that students are likely to experience with this approach. Difficulties are not only inevitable–interdisciplinary problems slopes are a complex notion (especially understanding the idea of "slope") and no approach is going to make them easier to solve and to teach. However, they must be overcome for learning to occur and in turn for a country to maintain a competitive position in the global economy.

The remainder of this paper is organized in this way. It begins with a description of the specific theoretical basis underpinning the study. A brief discussion of methods follows, highlighting the design used to address the questions posed in this study. This is followed by separate presentation and discussions of the quantitative and qualitative results. The paper concludes by considering both results and recommendations for future studies.

THEORETICAL BACKGROUND

Studies on Problem-Based Learning

PBL is an instructional method under the umbrella term "inductive teaching and learning" which encompasses a range of other instructional methods, including inquiry learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching (Felder & Brent, 2016). It has been widely adopted in diverse fields because of its close affiliation with interdisciplinary learning (Kwon et al., 2021). The

[2] The term PBL is defined as an instructional method that enables students to learn through facilitated problem-solving, working in collaborative groups to learn through solving authentic (real-world) problems that do not have a single correct answer, and taking responsibility for their own learning (Felder & Brent, 2016; Hmelo-Silver, 2004; Yew & Goh, 2016).

[3] As with most common language words drafted into educational research, there is no commonly accepted definition of the word "beliefs." While existing definitions vary, there one common element present in virtually all of them is that the student sees the statement of belief as true. Thus, "beliefs" is defined as an individual student's attribution of "truth value" to their ideas (p. 59).

PBL as an approach to learning and instruction stands firm within the cognitive psychology tradition. The emergence of PBL is generally attributed to: Dewey's (1929) plea for problems to be a starting point for learning; Bruner's (1971) notion that people generally want to know more about their world, and; Engeström's (2012) idea that people use tools to understand and solve the problem thus transforming it. In PBL, students learn through collaborative problem-solving and reflecting on their previous knowledge and experiences (Hmelo-Silver & Barrows, 2008).

However, PBL, unlike collaborative learning which involves group learning, allows for individual learning (Fader & Brent, 2016). Hmelo-Silver and Barrows (2008) analyzed in detail how students construct their knowledge in a PBL tutorial throughout the problem analysis and reporting phase. The discourses of students and *facilitators*[4] were examined and described to show how both groups played important roles in the collaborative and collective knowledge building. In their study of an expert PBL facilitator, Hmelo-Silver and Barrows (2008) demonstrated how *scaffolding*[5] was provided and gradually removed by the facilitator's use of different types of questions. There is extensive evidence that PBL promotes long-term retention of knowledge and a broad range of thinking (including critical thinking) and problem-solving skills (Hung et al., 2008; Prince & Felder, 2006; Severiens & Schmidt, 2009). Additionally, PBL allows students to combine theory and practice in real situations (Chen et al., 2019).

In Japan, Chen et al. (2019) conducted a study with twelve 10th grade science class. The study included four PBL lessons (50 minutes per lesson) over 4 weeks (one lesson per week). Prior to the lesson, students were required to take a problem-solving questionnaire which concerned their prior awareness of whether and how to use PBL skills in typical science classes as the prequestionnaire, a pre-test to check their prior knowledge, and a post-test to see whether their related knowledge had changed. They concluded that the PBL was an efficient approach to using learning strategies and functional tools in STEM education.

The present study provided important insights into how an expert facilitator effectively used open-ended metacognitive questions to facilitate students' discussion and how students' collective knowledge developed throughout verbal interactions within the PBL tutorial. This type of learning involves a participant structure which encourages the progressive transformation and improvement of knowledge rather than the usual IRE pattern in which the teacher *initiates* a question, generally aimed at getting a student to display their knowledge, the student *responds*, and the teacher *evaluates* that response reproduction and display of knowledge (Hmelo-Silver & Barrows, 2008). Noteworthy is that *problem-based approaches to learning* are compatible with work environments in STEM fields where most work involves extensive collaboration.

Studies on Students' Problem-Solving Beliefs

Despite the increase in the careers *that* demand STEM subjects, the number of students who are interested in STEM-related careers is decreasing (Felder & Brent, 2016). Various factors have been identified as contributing to this problem. Kwon et al. (2021) characterize this shortage as the result of students' lack an understanding of what STEM professionals actually do. This lack of understanding is amplified among students of color and female students because of the dearth of role models in STEM fields at all educational and professional levels (King, 2017; Levine et al., 2015). In emphasizing the importance of teacher quality as one of the most powerful levers in improving education, King (2017) points out that some teachers tend underestimate female students' potential and hold low expectations for their academic success. However, organizing learning around authentic problems helps to overcome these disparities and improves the likelihood of increasing students' beliefs to learn STEM subjects (Prince & Felder, 2006). Sümen and Çalışıcı (2021), however, point out that for students to be successful in problem-solving, beliefs about problem-solving skills need to be developed with students' problem-solving skills.

Stylianides and Stylianides (2014) assert that many students across all levels of education have certain beliefs about mathematical problem-solving that tend to influence negatively these students' ability or willingness to engage productively with problem-solving. *Curriculum and evaluation standards for school mathematics* (National Council of Mathematics Teachers [NCTM], 1989) has identified problem-solving as the most important topic in mathematics. In this study, the hypothesis is that understanding student's beliefs about STEM education is key in alleviating the diminishing numbers of those pursuing STEM fields. However, an investigation of STEM students' beliefs about problem-solving is an investigation of their mathematical beliefs because mathematics is central to understanding in STEM subjects. Thus, it is from this perspective that this study examined students' mathematical PSB.

[4] In this study, the term facilitator refers to an instructor who plays roles in guiding, encouraging, clarifying, mediating, and sometimes even lecturing in problem-based approaches to learning (Prince & Felder, 2006).

[5] The current usage of the notion of scaffolding refers to all human and technological prompts, supports, and hints provided to support learning (Hmelo-Silver et al., 2009).

Callejo and Vila (2009) developed research aimed at relating first-year high school students' (7th grade) mathematics problem belief with the actions taken in the approach phase (i.e., understanding the problem and devising a plan) of nonstandard problems. They selected two students of high academic performance based on a previous exploratory study of 61 students. The results identified different types of approaches to problems that determine their behavior in the problem-solving process, finding two aspects that explained their approaches to problem-solving:

(1) the presence of a dualistic belief system stemming from the student's school experience and

(2) motivation linked to beliefs regarding the difficulty of the task.

Prendergast et al. (2018) developed a research aimed at identifying 975 Irish students' beliefs about mathematics across nine high schools. They used the Indiana mathematical belief scale, an existing 30-item (five-scale) self-report questionnaire, to quantitatively measure these beliefs. An analysis of the data revealed that students who were further through their secondary education had a stronger belief that not all problems could be solved by applying routine procedures. The same students held fewer positive beliefs in contrast to their younger counterparts that they could solve time-consuming problems and that conceptual understanding was important.

Current researchers argue that mathematics PSB directly influence mathematics beliefs and that students who have stronger PSB may have higher mathematics performance and competence, influencing their career planning (Kwon et al., 2021). In contrast, high school students are susceptible to having their career trajectories affected by beliefs caused by poor mathematics achievement (Franz-Odendaal et al., 2016). It is from these perspectives that the researcher concluded that it is important to investigate the effectiveness of instructional strategies that can promote students' mathematical PSB, which can affect their achievement and their participation in STEM careers.

MATERIALS AND METHODS

Research Design

The study adopted a sequential mixed methods method employing two designs: a quasi-experimental and an exploratory case study to allow participants to tell their stories, act as the starting point for future studies, and help the researcher to suggest methods for further examination (Bansilal & Lephoto, 2022). Though ideal for generalizable results, random assignment to intervention was not possible to accomplish. It is important to mention that this study used a within-subjects design to test the effectiveness of the intervention without a control group. In this design, the researcher compared one group's outcomes before and after the intervention.

Participants and Context of the Study

The data reported in this paper were collected as part of a larger project to evaluate the impact of the intervention, with a particular focus on increasing student participation in STEM fields through PBL teaching method' and it took place during February of 2020. The study was conducted according to ethical research procedures prescribed by the School of Education Ethics Committee at the University of KwaZulu-Natal. Informed consent was obtained from the parents or legal guardians of students' participating in this study.

The setting for the quasi-experimental design was a group of eighty-six 10th grade students working with an expert facilitator and conveniently recruited from one rural school in eastern South Africa that receives curricular support and resources to specifically develop STEM teaching, in a naturally occurring setting. There were 45 male participants and 41 female participants, who self-identified as African (79.3%), Indian (9.1%) and Colored (4.7%), with the remainder providing no specific ethnicity. This sample, which was at very different levels of mathematics ability and from diverse socioeconomic spectra, was part of the population of high school students in Dinaledi schools[6] for which the researcher intended to make inferences and observations. In its quest to increase the participation and performance in mathematics and physical science by historically disadvantaged students, the Department of Basic Education established the Dinaledi school project, in 2001 (Department of Basic Education [DBE], 2009). These schools were provided with resources (e.g., textbooks, tablets, projectors, and laboratories) to improve the teaching and learning of mathematics and science. The school is also supported and funded by a private trust (Lemmon, 2017).

For the intervention, approximately 21 of the 86 students who completed the PSB questionnaire volunteered to participate in the intervention. There were 15 male participants and 6 female participants, who self-identified as African (77.5%), Indian (10.1%), and Colored (5.2%), with the remainder providing no specific ethnicity. The setting for the case study design included twelve students drawn from the 86 who participated in the survey. They were then recruited by an e-mail inviting them to take part in the interviews. Of the fourteen, 7 were male, 3 were female, with the

[6] The word "Dinaledi" means "Stars" in the Sesotho language, which is one of the indigenous languages, along with IsiZulu, commonly spoken in South Africa.

remainder providing no specific gender. The participants were chosen on the basis of their willingness to answer the questions and their ability to give critical feedback. Their age ranged from 14 to 19 years.

Data Collection

Three data collection methods were used for this study: the mathematical PSB questionnaire, the intervention that was framed on the PBL approach, and the interviews.

The PSB questionnaire

The purpose of this problem was to address the research question *What is the effect of a PBL on influencing students' PSB* The mathematical PSB (**Appendix A**) questionnaire, adopted from Kwon et al.'s (2021) student mathematical problem-solving belief survey, is a 36 Likert-type scale item that measured participants' beliefs about mathematical problem-solving. It was administered using a pre- and post-survey design through paper-and-pencil. Participants completed the PSB questionnaire on their first and last days of the intervention. The PSB questionnaire consisted of items adapted from two scales. On the one hand, it consisted of items in the Indiana mathematics beliefs scale which was developed by Kloosterman and Stage (2010) to be administered to high school students and teachers to capture their beliefs about mathematics as a subject, how mathematics is learned, and mathematical problem-solving. On the other hand, it consisted of items in the Usefulness Scale which was developed by Fennema and Sherman (1976) whose main purpose was to gain more information concerning either all students' or specifically females' learning of mathematics and beliefs about the usefulness of mathematics currently and in relationship to their future education and careers.

The PSB questionnaire measured participants' beliefs about mathematical problem-solving on a 5-point scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). Evidence based on the instrument's content during piloting process, demonstrated that items constituting the instrument were relevant to and representative of the construct of beliefs about solving. For each of the six beliefs there were six items, three of which were positively worded. In each belief, three of the negatively-worded items were reverse coded prior to analysis. The internal consistency was $\alpha = .79$, indicating a suitable reliability (Creswell, 2012). Inter-scale correlations showed statistically significant results (Kloosterman & Stage, 2010). In the next sub-section, the researcher, exemplify the PBL as an approach to learning STEM subjects in a more integrated way, especially in the context of real-world issues. Students were expected to apply mathematical techniques to the solution of this practical problem which may occur in sciences (especially in physics), technology, and engineering. The questionnaire took an average of 30 minutes to complete.

Intervention

The effects of a STEM PBL intervention on 10th graders' mathematical PSB was investigated in an attempt to respond to the growing calls to emphasize the connections between and among these subjects. exemplify the philosophy of STEM integration. To this end, a non-randomized quasi-experimental design was used to understand how engaging in STEM influenced students' PSB and STEM problem-solving ability. During the intervention, students engaged in a single open-ended task that was 90 minutes long over five days. Thus, students engaged in STEM PBL instruction for at least 900 minutes. Students were expected to complete the task that required them to apply their current understanding and skills to new contexts that highlight core STEM concepts. As in typical PBL, the facilitator provided scaffolding to each small group by gauging what aspects of learning and understanding participants found problematic and thus needed to be supported.

During the intervention, students engaged in projects to understand the following terms and concepts so as to relate their mathematical knowledge to problems involving potential energy (stored energy); kinetic energy (energy of motion); conservation principle (i.e., the conservation of mass-energy); gravity; velocity; friction; and slope. All of the concepts allowed students to connect STEM knowledge and skills to this authentic situation that arises from attempts to understand the world (Hmelo-Silver & Barrows, 2008). Briefly, students were presented with a foam pipe insulation to make a roller coaster track with twists and turns. For the roller coaster itself, marbles were used.

The task required the students to find the measure of the initial height needed to have the marble successfully navigate a loop in the track. They were asked to record at least 5 separate tests with the marble to determine the height at which the marble successfully navigated a loop in the track. In each case, they were required to measure the *slope* of each track configuration that formed a hill. This latter task is represented in **Figure 1**.

Additionally, students actively engaged in hands-on learning and their work was judged by professionals in STEM fields who also conducted clinics in which they spoke about their experiences. The intervention ended with visits to laboratory tours meant to provide students with first-hand experience of the work of STEM professionals, including providing ample interactions with female STEM professionals. Student groups finally converged to write and turn in their final report on the solutions. Briefly, participant students worked in groups of four to five to examine and define the problem, explore what they already know about underlying

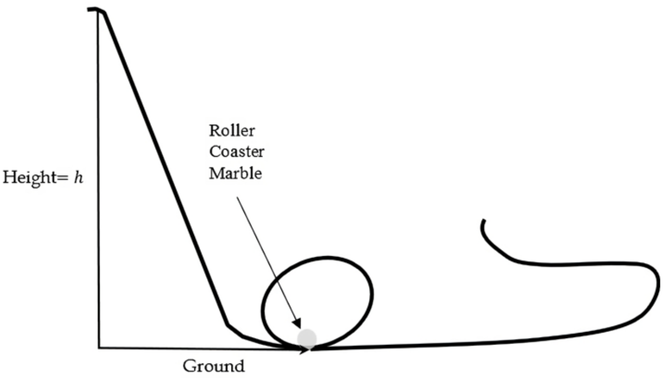

Figure 1. The measure of the average slope of the track leading into the loop with twists and turns further down (Felder & Brent, 2016)

concepts related to it, identify what they need to learn and where they can acquire the information and tools necessary to solve the problem, evaluate possible ways to solve the problem, solve the problem, and report on their findings (Nilson, 2010). A rubric was used to assess the students' work on the problem.

Interviews

The face-to-face interviews were conducted to answer the second research question, *How do students respond to the PBL approach used to capture their beliefs in applying mathematical knowledge to solve science-, technology-, and engineering-related problem?* After receiving ethical approval, students were recruited via email which contained full information about the goals of the larger project, including that their data would be destroyed after five years, and they may withdraw their consent at any time of the study. In the fourth week of the school year, one focus group took part with 3 participants. It was difficult to recruit participants for further focus groups; hence, the majority of the data collection took place through individual interviews. Ten participants took part in one-on-one semi-structured interviews, with one participant having also taken part in the focus group.

During the interviews, students were asked about their experiences of the intervention, their interactions with others during the completion of the task. Interviews took place either via Zoom or on the cell phone and were audio recorded. Both sets of interviews took place after school hours. They typically lasted 30-40 minutes and focus group continued until saturation was reached. They were audio recorded and then transcribed by a professional transcriber.

Analyses

To answer research question 1, data were analyzed using SPSS 16.0. Paired-sample t tests in which the researcher adjusted the Bonferroni adjusted alpha level to .01, confidence intervals, and Cohen's (1988) d effect sizes were determined to provide a complete picture (Kwon et al., 2021). Descriptive statistics were provided to contextualize the data in terms of measures of center and spread for the variables of students' problem-solving before and after the intervention. Specifically, paired-sample t tests were used to determine if there was a statistically significant difference between the pre- and post-survey questionnaire scores for PSB.

Analysis continued to determine if the statistically significant result was due to sampling error or due to effect size. For this information, the effect size was determined, using Cohen's (1988) d effect magnitude measures. Further, Cohen's (1988) d effect sizes were calculated to facilitate meta-analytic thinking and to understand the impact of the intervention in standardized metric (Capraro, 2004). Because statistical significance may be inadequate in influencing policy, the effect size estimate was determined to provide insights into the practical importance or the magnitude of change one could expect for each change in standards deviation, without sample size being a factor (Creswell, 2012).

Then, confidence intervals were constructed to assess the effect of sample size and error. In addition, confidence interval (CI), which is an interval estimate that indicates the precision, or likely accuracy, of the mean (Cumming & Finch, 2005), is important to determine because they provide a clear depiction of the spread and center of the data and range for which means from other similar studies would be contained 95% of the time (Capraro, 2004). However, it is important to provide an interpretation of figures with error bars and analyze the relationship between CIs and statistical significance testing (Cumming & Finch, 2005).

To answer research question 2, a mix of focus group discussions and individual face-to-face interviews with students were conducted during the 2020 school year. Thematic analysis was used to identify common themes related to the ways in which participants approached and experienced learning to solve STEM-related problems within the PBL method. First, an inductive approach to the analysis was used, which involved deriving codes and subsequent theory from the data itself without any preconceived ideas influencing the analysis. Second, a deductive approach to the analysis was used with two categories–usefulness of mathematics currently and usefulness of mathematics in relationship to future education, vocation, or other activities, drawn from the PSB questionnaire–used as codes.

Analysis of the data followed the six steps described by Braun and Clarke (2006). This involved familiarization with the data. A colleague familiar with PBL was asked to code the transcripts to determine an inter-coder reliability index. Initial coding, which involved checking of the transcripts against the audio recordings, were read through three times to become familiar with the data. Relevant passages were

Table 1. Paired sample statistics for pre- and post-test

		N	Mean	SD	SME
PSB	Pre-test	86	104	5.70	0.61
	Post-test	86	118	4.60	0.50

Note. SD: Standard deviation & SEM: Standard error mean

highlighted, and notes were made about the key ideas expressed by participants. Formal coding was then carried out in Excel spreadsheet. As the analysis progressed data excerpts and codes were discussed the colleague and themes were developed. The themes were developed in an iterative process that involved returning to the data to check that the themes were representative of the interviews throughout the analysis stage.

RESULTS

The results are reported by research questions. As depicted in **Table 1**, the means of pre- and post-survey scores for students' PSB were 104.7 ($SD = 5.7$) and 118.5 ($SD = 4.6$), respectively. This represents an increase in the means after students participated in the intervention organized around STEM PBL. A paired-sample t test, 95% confidence interval, and effect size were used to provide a complete picture of how students performed on the pre- and post-surveys. The standardized effect size (d), which is calculated by dividing the mean difference by the standard deviation, was 0.52 which suggested that the intervention was practically important.

In **Table 2**, the matched-pairs t-test indicates that the mean of the difference is also significant [$\bar{x} = 3.80, t = 4.97$ $(df = 68.31), p = .002, d = .52$] with 95% CI [1.77, 5.91], suggesting that participant students showed a statistically significantly positive increase in their mathematical PSB ($p < .01$).

Second, the PBL approach and the problem had an impact on the way in which students approached their roller coaster task. Taking an inductive approach to data analysis, it was found that some aspects of the problem were linked to students adopting an integrated approach to the problem, developing a high degree of persistence, having high aspirations for working on the solution. A complex interplay was found between students' views on the usefulness of mathematics currently and usefulness of mathematics in relationship to future education, how to apply their mathematical knowledge to different aspects of STEM subjects, and the use of a rubric to mark which necessarily gave marks for working (as students were used to marking of "exercises" where mathematical procedures and algorithms led to only a single answer).

It can be argued that students were knowledgeable on the different method of teaching adopted by their teacher. They linked the underlying concepts of traditional teaching method and problem-based teaching method. The participants showed the high hope of achieving something for working on the solution to the problem (high aspirations). The high aspirations emanated from their persistence and the use of a rubric in marking their work. The approach seemed to encourage students to keep trying to solve the problem even when they got stuck and checking their working thoroughly. They thus developed persistence. These two concepts by a student whose subjects included mathematics and physical science, Mandla (pseudonym), are captured in the excerpt below.

> Researcher: What is the difference between this teaching method and the one you are used to?
>
> Mandla: Yeah, theirs is a great difference because, hmmm you see, let's say that you have algebra, the teacher will show you the steps to solve an equation … that equation is not made to show you how it is relevant for your life. You could show us that.
>
> Researcher: How did you solve the problem? I mean … was your knowledge of mathematics important in solving the problem?
>
> Mandla: Oh, yes. Very much so. The maths knowledge helped us to see the importance of reaching high expectations in solving the problem. Hmmm, for example, Dina [student] brought the idea of gradient to make up the solution, hmmm, yesterday.
>
> Researcher: Can you tell me more about the role of mathematics in the solution of the problem?
>
> Mandla: Yes. I can say that mathematics is so important in understanding science. Hmmm … if … you see … let's say in the problem, we would not have been able to solve the problem without going back to mathematics to talk about the gradient of each track that forming a hill.

Let us turn to the interview with Naicker (pseudonym), who was enrolled in a class designed for

Table 2. Paired sample t-test results

Variable	Paired differences					t	df	p	Cohen's d
	MD	SD	SME	95% CID					
				Lower	Upper				
Post-/pre-test of PSB	3.80	1.20	0.13	1.70	5.99	4.97	68.31	.002	0.52

Note. MD: Mean difference; SD: Standard deviation; SEM: Standard error mean; & CID: Confidence interval of difference technology education. He was 19 years of age and had just lost her mother. This is her words in the interview.

> Researcher: What is the difference between this teaching method and the one you are used to?
>
> Naicker: Our teacher did not use different subjects to show us the clear link. He used math and we did not make connections between the mathematics and technology. But, here, we mix maths in the technology that we learn. I'm encouraged to do that 'cause it shows clearly that maths is everywhere.
>
> Researcher: How did you solve the problem? I mean … was your knowledge of mathematics important in solving the problem?
>
> Naicker: Yes. Maths is clearly the master to understand my technology. Knowing maths very well helped us to see the way forward in finding a solution to the problem after we tried so very hard to think about ways to find a solution to the problem. It's a problem we see during trips to the park. Yes, maths was good.
>
> Researcher: Can you tell me more about the role of mathematics in the solution of the problem?
>
> Naicker: Yeah … but do you want me to tell you the importance of maths in the problem?
>
> Researcher: You have it right … go ahead.
>
> Naicker: Yes. I can say that maths is so important in understanding your work in technology. In fact, the rubric provided us with the details to work and gave us inspiration in achieving the results we got. Our perseverance definitely changed because I was thinking that beforehand if we couldn't solve a problem we would … hmmm … perhaps try it a few times. Then, normally we'd just ask the teacher for help. But, then, I could really go for help from my classmates; we just had to stick it through and just keep bashing out attempt after attempt after attempt after attempt … hmmm … until we understood it. So, then, I finally saw that we actually did put the work in, the problem would eventually be solved.

The usefulness of mathematics in current and future endeavors was commented on by a number of participants. When the researcher wanted to close the interview, I asked one participant, Novita (pseudonym), to say a few words about the problem-based interactions in class. This is her utterances in the excerpt below:

> Researcher: We have reached the end of the interview. Thank you very much for attending the interview. Do you have anything to add?
>
> Novita: Yes, sir. I want to say that the method you have used to teach us has shown us the current importance of mathematics. But, will this maths be used as we do medicine at varsity?
>
> Researcher: Thanks for the question. Yes, medical doctors must dispose medicine and let the patient know how much … the volume … the patient will have to take to get better and be healed.
>
> Novita: Oh, I see. Yeah, what you said makes a lot of sense to me. Thank you, hmmm, very much. I don't have anything else to ask … Thank you.

The researcher turned to Khaya (pseudonym) for additional words to the interview and this is what he had to say:

> Researcher: We have reached the end of the interview. Thank you very much for attending the interview. Do you have anything to add?
>
> Khaya: Oh … yeah … could you let me know about the future that maths plays in the engineering degree I want to do when I finish school?
>
> Researcher: Thanks for the question. I think you should have seen that maths is all around us, in the solution to the problem. Shortly, yes, mathematics is important for engineering studies. But, there's a special branch of mathematics that deals with problems "in real life" situations … applied mathematics. Let's take one of the most important mechanical features in a car as an example: the braking system. To do this, engineers have to fine-tune the brake force of a car – the brake force being the amount of force or pressure that is needed to bring something to a complete stop. To work out the brake force of a car, you have to consider all the different mechanical and physical components that come into play. In truth, all the greatest engineering inventions of the 20th century were chiefly of mathematics. Do you see there's no way you can do away with mathematics in engineering?
>
> Khaya: Yeah, I can see very well. But, I'm inspired by the method of teaching you used.

A complex interplay was found between participants' views on the usefulness of mathematics currently and usefulness of mathematics in relationship to future education, how to apply their mathematical knowledge to different aspects of STEM subjects, and the

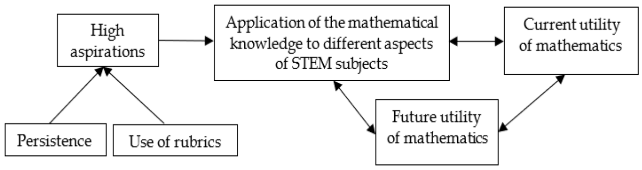

Figure 2. Thematic map illustrating relationships between interview data themes (Braun & Clarke, 2006)

use of a rubric to mark their task which necessarily gave marks for working (as students were used to marking of "exercises" in which procedures and algorithms resulted in one answer). In the end, a thematic map was created to illustrate the interrelationships between the themes (**Figure 2**).

DISCUSSIONS

Overall, the results in the STEM school revealed that students have a good understanding of the importance of mathematics in their learning of science and engineering subjects. This may be due to the STEM focus of the school. The results in this study demonstrated that students' PSB could directly influence students' STEM problem-solving ability. Although this association has never been reported in the literature before, it is directly related to students' STEM career goals (Kwon et al., 2021). Further, they showed that the students struggled to understand PBL. In the quest for teaching for conceptual understanding, students' previous knowledge is important as it provided the basis for better understanding of the problem. The quantitative result is consistent with Prendergast et al.'s (2018) study which found that students improved their beliefs that not all problems could be solved by following regular procedures. Similar results were obtained by Callejo and Vila (2009) who found that students recognized the role of their beliefs regarding the nature of the task.

Bansilal and Lephoto (2022) argue that mathematics is a gateway to science-related careers and all stakeholders want to improve their mathematics. The students were able to successfully see how important mathematics is to understanding their knowledge in science and engineering subjects. However, student sense-making of the links was not explicit in the task observed. The data from the STEM school were compared with that from a study by Kwon et al. (2021) involving 68 participants who were selected from a group of 253 middle and high school students who attended a 1- or 2-week STEM summer camp during 2019 at a tier one university. There were 37 male participants and 31 female participants, and their grades ranged from 7th to 12th. Except for three participants, most were from Texas (US).

In the case of Mandla, there is good evidence from his response that the PBL approach used to capture his beliefs in applying mathematical knowledge to solve science-, technology-, and engineering-related problems. He saw the difference between the method of teaching used during the intervention and was able to comment about its usefulness of mathematics in him being able to solve the problem. At this approach, students would find it easy to comprehend the more complex topics and thus avoid memorization. Similarly, Chen et al.'s (2019) found that the PBL was an efficient approach for students. When these students proceed to tertiary level, they can draw meaningfully on the mathematics they have been exposed to into the STEM related task. Thus, if learning by regurgitating happens this early at grade 10, by the time students get to grade 12, they will not see the mathematical concepts when they have to write examinations that demand an in-depth understanding of a coherent high school curriculum.

In Naicker's case, the rubric gave him some inspiration in finding a solution to the task. The level of perseverance increased and that eliminated going to ask questions to the teacher rather than working together as a group with other students in finding as solution to the task. This suggested that PBL approach worked for her by seeing how mathematical knowledge was helpful in working in the task. She mentioned that teaching by her teacher focused on discrete pockets of knowledge which inevitably push students towards rote learning to reach a solution to the "exercises." This suggested that, in order to provide opportunities for the improve their PSB regarding how mathematics works practically in solving science-, technology- or engineering-related problems, students required practical applications of such problems in their learning.

Novita and Khaya expressed views on the usefulness of mathematics currently and usefulness of mathematics in relationship to future education. This suggested the importance of mathematics for their future careers. The principal argument is that the mathematics curriculum covers a vast range of topics that relate to science-, technology- or engineering-related problems. The complex interplay found between students' views on the usefulness of mathematics currently and usefulness of mathematics in relationship to future education, suggested that there is much more information that can be gathered regarding effect of PBL on students' PSB.

The participants' response to the PBL approach used to capture their beliefs in applying mathematical knowledge to solve science-, technology-, and engineering-related problems provided evidence for a need by students, in general, to be exposed to such learning. However, current research that addresses how long the effects of such an intervention persist and the extent to which the effects measured in is too little (Kwon et al., 2021). The recommendation is that such STEM schools need to be widened to benefit a larger population of students. In our analysis we did not look at the nature and depth of the teacher links to ascertain how relevant the link-making was in teaching for understanding of the particular concept. Such an analysis could be valuable in terms of assessing the quality and potential impact of the links themselves.

Limitations of the Study

It is important to note that the intervention in this study did not assign participants to treatment and control groups based purely on chance, but instead students were encouraged to take part based on the Dinaledi status of their school. The lack of control group compromised the strong internal validity. Thus, any effects cannot be definitively attributed to the intervention itself. If the intervention helped students to realize that STEM education was not for them and changed the curriculum by dropping out of STEM subjects, the results would experience an increase in the average in PSB. The reason for this increase, however, would have been because these students left the intervention, not because the PBL improved students' PSB.

Despite it being near impossible to claim that the intervention was the most plausible driver of the results, studies employing quasi-experimental designs are still worth doing because they improve our understanding of the causal effects of interventions by focusing on internal validity (Gopalan et al., 2020). In addition, the nature of the project has limited the volunteer pool to students who might be somewhat more comfortable with STEM subjects and more open to discuss their experiences of the intervention. Although the use of volunteer participants limits the generalizability and conclusions, the diverse backgrounds of the students were typical of teachers across South Africa. Thus, it is reasonable belief that the results of this study generalize beyond this sample to many other educational settings.

CONCLUSIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

In this study, the researcher sought to explore the effect of STEM PBL intervention on students' mathematical PSB. The results demonstrated that students' PSB could directly influence students' STEM problem-solving ability. By holding PSB constant, it was found that there is a statistically significant relationship between these and ability to solve STEM-focused problems. Interviews with students also highlighted some concerns that could be addressed in the intervention. The researcher highlights two aspects of this concern in particular. First, students perceived the task to have a high workload–but this may be largely attributed to perception that could be mitigated by improving their experiences with STEM problems that integrate the various subjects (Levine et al., 2015). In the sample of students who took part in interviews, most found the intervention beneficial and would recommend it to others. Students indicated that they spent a mean of 2 hours working on task, which if anything, is slightly less than would be expected for an integrated STEM task. Second, students reported frustration at losing marks over mistakes they made due to inability to apply their previously learnt mathematical knowledge and skills to solve the problem.

Many other researchers could derive similar implications from most of the findings in this study. Although this study used only a 5-day-long intervention, evidence suggested that PSB can benefit from short-term interventions. This study can be most useful for researchers to design future studies aimed at examining how students' PSB can be used as leverage to increase participation in STEM careers. Further, recommendations include increasing student awareness of the ability to think using formal operations strategies for increased cognitive development, and to explain independent variables affecting student cognition.

The study, being of an exploratory and quantitative in nature, raises a number of opportunities for future research. In future investigations, it might be possible to use a long-term PBL intervention with students from all high school grades to develop a full picture of how PBL affect students' beliefs and how it predicts their future participation in STEM fields. Thus, although the investigation with this particular sample provides important insights regarding high school students' PSB that have not been done before and provides important considerations for future studies with large samples of students with broad diversity of attributes and backgrounds will be needed, especially such samples from urban settings.

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APPENDIX A: STUDENT MATHEMATICAL PROBLEM-SOLVING BELIEF SURVEY

Belief 1: I can solve time-consuming mathematics problems.

1. Mathematics problems that take a long time don't bother me. (+)
2. I feel I can do mathematics problems that take a long time to complete. (+)
3. I find I can do hard mathematics problems if I just hang in there. (+)
4. If I can't do a mathematics problem in a few minutes, I probably can't do it at all. (–)
5. If I can't solve a mathematics problem quickly, I quit trying. (–)
6. I'm not very good at solving mathematics problems that take a while to figure out. (–)

Belief 2: There are word problems that cannot be solved with simple, step-by-step procedures.

1. There are word problems that just can't be solved by following a predetermined sequence of steps. (+)
2. Word problems can be solved without remembering formulas. (+)
3. Memorizing steps is not that useful for learning to solve word problems. (+)
4. Any word problem can be solved if you know the right steps to follow. (–)
5. Most word problems can be solved by using the correct step-by-step procedure. (–)
6. Learning to do word problems is mostly a matter of memorizing the right steps to follow. (–)

Belief 3: Understanding concepts is important in mathematics.

1. Time used to investigate why a solution to a mathematics problem works is time well spent. (+)
2. A person who doesn't understand why an answer to math problem is correct hasn't really solved problem. (+)
3. In addition to getting a right answer in mathematics, it is important to understand why answer is correct. (+)
4. It's not important to understand why a math procedure works as long as it gives a correct answer. (–)
5. Getting a right answer in math is more important than understanding why the answer works. (–)
6. It doesn't really matter if you understand a mathematics problem if you can get the right answer. (–)

Belief 4: Word problems are important in mathematics.

1. A person who can't solve word problems really can't do mathematics. (+)
2. Computational skills are useless if you can't apply them to real life situations. (+)
3. Computational skills are of little value if you can't use them to solve word problems. (+)
4. Learning computational skills is more important than learning to solve word problems. (–)
5. Mathematics classes should not emphasize word problems. (–)
6. Word problems are not a very important part of mathematics. (–)

Belief 5: Effort can increase mathematical ability

1. By trying hard, one can become smarter in mathematics. (+)
2. Working can improve one's ability in mathematics. (+)
3. I can get smarter in mathematics by trying hard. (+)
4. Ability in mathematics increases when one studies hard. (–)
5. Hard work can increase one's ability to do mathematics. (–)
6. I can get smarter in mathematics if I try hard. (–)

Belief 6: Mathematics is useful in daily life.

1. I study mathematics because I know how useful it is. (+)
2. Knowing mathematics will help me earn a living. (+)
3. Mathematics is a worthwhile and necessary subject. (+)
4. Mathematics will not be important to me in my life's work. (–)
5. Mathematics is of no relevance to my life. (–)
6. Studying mathematics is a waste of time. (–)