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The Impact of Problem-based Learning on Pre-service Teachers' Mathematics Pedagogical Content Knowledge

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Abstract: Predictors of teacher effectiveness in relation to student achievement are based on the ability to use a range of evidence-based teaching strategies. Australia's Teacher Education Ministerial Advisory Group (TEMAG) report that some tertiary providers working with pre-service teachers (PSTs) are using pedagogical practices which are not informed by established research. This paper reports on the impact a student-centred, PBL teaching approach had on third-year Bachelor of Education PSTs' PCK in a mathematics education subject, compared to a similar group taught using a conventional teacher-directed approach. A quasi-experimental group-by-time design was used to determine the impact of the intervention. Contrary to meta-analyses regarding the efficacy of PBL compared to teacher-directed instruction, findings from this study show the PSTs from the PBL group developed their mathematics PCK as well as those who were taught using a teacher-directed instructional approach, Wilks' Lambda = .71, F (1, 35) = 14.33, p < .01.

Background and Context

It is stated in the international literature (Carroll & Foster, 2010; National Research Council, 2010; Office for Standards in Education, 2005; TEMAG, 2014) that knowledge of subject matter and pedagogical approaches are important elements of teacher effectiveness, and therefore, should be a focus of PST education. In Australia, the TEMAG (2014) presented 38 recommendations which they believe will provide the structural change needed to strengthen its initial teacher education programs. *Recommendation 6* requires initial accreditation of teacher education programs to be linked to tertiary providers demonstrating that their programs use evidence-based pedagogical approaches (TEMAG, 2014, p. xii). *Recommendation 14* requires that "higher education providers deliver…a range of pedagogical approaches that enable PSTs to make a positive impact on the learning of all students" (2014, p. xiii) and further stating "the difference between expert teachers and pre-service teachers is this depth of pedagogical content knowledge" (2014, p. 18). The study reported here investigates PBL used in a semester-long undergraduate mathematics education subject in order to provide evidence of its potential value in pedagogical practice for developing the mathematics PCK of PSTs. The National Australian Curriculum strands and sub-strands of Algebra, Measurement, Geometry and Probability and Statistics provide the content for the mathematics education subject the participants were studying.

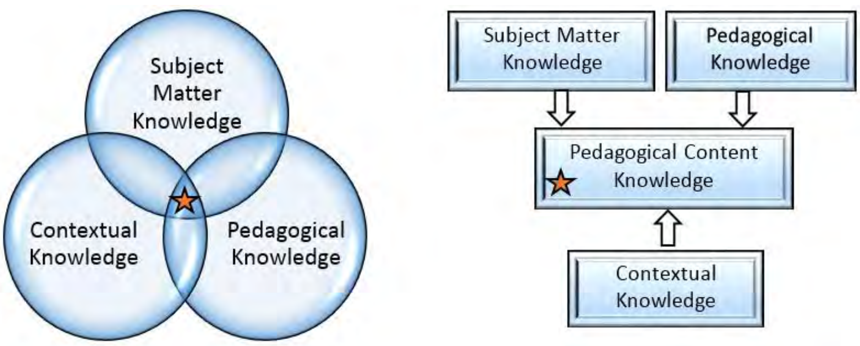
Literature Review

Toward a Framework: Pedagogical Content Knowledge

In this paper, the author adopts a representation of mathematics PCK based on Gess-Newsome's (1999) transformative model, where PCK exists as a separate knowledge base rather than occurring when content and pedagogical knowledge are integrated by the teacher during instruction. This discussion of PCK begins with its conceptualisation (Shulman, 1986) and progresses to Gess-Newsome (1999) who categorised the construct of PCK into two models – the integrative and transformative. Researchers that followed and progressed the construct will also be discussed in the context of Gess-Newsome's models.

Pedagogical content knowledge has been traditionally defined as "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8). Shulman called for the need to explore PCK as the inherent interconnection between content knowledge and pedagogical knowledge. In subsequent research, PCK was recognised as being either an integration of or transformation from teachers' content knowledge and their pedagogical knowledge (Gess-Newsome, 1999; Grossman, 1990; Marks, 1990). For example, Grossman (1990) blended the traditionally separated knowledge bases of content and pedagogy, identifying PCK as a unique domain of teacher knowledge. Marks (1990) indicated that PCK, by its nature, contains elements of both content knowledge and pedagogical knowledge. In such a structure, the teacher must first examine and interpret the content for its composition and significance. The interpretations are then transformed as necessary to make it comprehensible and compelling in a particular context (to a particular group of learners in a particular subject area). Pedagogical knowledge can be seen in a teacher who adopts pedagogically useful representations of the content, use of questioning strategies, knowledge of assessment or knowledge of their students' learning processes. Consider a teacher who must determine the correctness of different answers given by students when demonstrating 100% using a geoboard (a board covered with a square grid with pins at the corners of the squares to which students attach rubber bands to create 2D shapes). Firstly, the teacher must not only determine any errors in those responses, but also the nature of those errors. Next, the teacher would have to strategically choose the type and timing of responses to use with the students based on his or her knowledge of them.

Gess-Newsome (1999) progressed the conceptualisation of PCK by categorising the construct into two models - as either an integration of or transformation from teachers' content knowledge and their pedagogical knowledge. Figure 1 illustrates the integrative model and the transformative model.



Integrative model **Transformative model**

Figure 1: Two models of teacher knowledge (*Gess-Newsome, 1999, p. 12*)
= PCK - knowledge needed for classroom teaching

Under the integrative model PCK does not exist as a separate category of knowledge, but combines content, pedagogical and contextual knowledge used by the teacher during instruction. The integrative model can be likened to a teacher who draws upon the three categories of knowledge during his/her classroom practice, but during that process the three categories of knowledge do not lose their distinct characteristics. In the transformative model, the three knowledge categories are synthesised and transformed to form a new knowledge category. Content knowledge, pedagogical knowledge and contextual knowledge are inextricably combined into PCK as a new form of knowledge.

In the context of mathematics, Chick (2003) articulated PCK as a form of teacher knowledge which, in addition to mastery of the content, incorporates how the mathematics content is used in teaching. Chick et al. (2006) conceptualised a framework for analysing mathematics PCK as a mix of content and pedagogy: (a) completely intertwined with pedagogy and content, (b) content knowledge in a pedagogical context, and (c) pedagogical knowledge within a content context. The first category (a) of the framework is consistent with the transformative model.

Ball et al. (2008) chose to investigate what teachers need to know about the mathematics content they are asked to teach and how and where they might use such knowledge in practice. Based on those two questions and their analyses of videos of teaching practice and subsequent design measures of mathematical knowledge arising from those videos, they developed a working definition of ‘mathematical knowledge for teaching’ (MKT). This phrase was defined as: “the mathematical knowledge that teachers need to carry out their work as teachers of mathematics” (2008, p. 4). Their studies led to the conclusion that *how* teachers hold mathematical knowledge may be as important to their effectiveness as *how much* they hold. However, the MKT structure is primarily an integrative model in that the authors’ conception of the knowledge bases remain separately identifiable.

The transformative model used in the context of PCK for teaching mathematics is supported by Silverman and Thompson (2008). Their conceptualisation of mathematics PCK is underpinned by a teacher’s mathematical understanding that pervades through the instructional sequence, is integral for learning beyond the classroom mathematics and that “play into a network of ideas that does significant work in students’ reasoning” (2008, p. 501). Consequently, Gess-Newsome’s (1999) transformative model, which proposes that PCK exists as a separate knowledge base, the amalgamation of content, pedagogical and contextual knowledge, forms the conceptual framework for mathematics PCK assessed in the study reported here.

Deliberating on the pedagogical approach for the development of mathematics PCK in PSTs, this study considers Barrows’ (1986) taxonomy of problem-based learning.

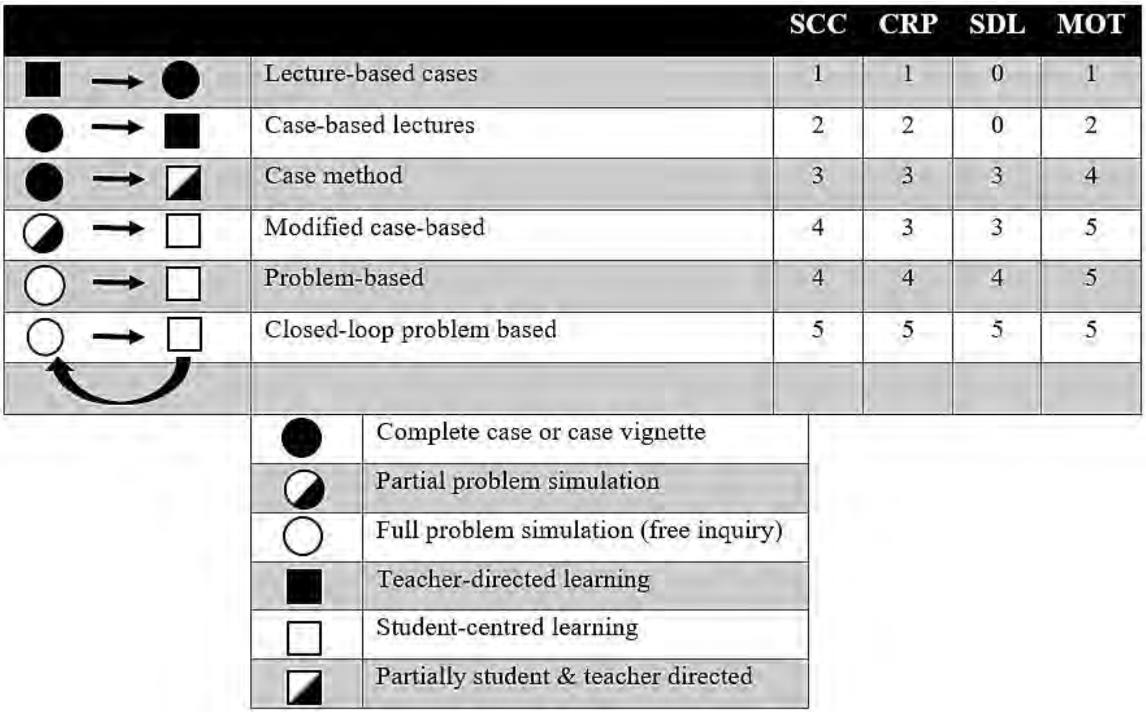
The Nature and Effectiveness of Problem-based Learning (PBL) in Higher Education

PBL as a pedagogical approach in higher education was pioneered at McMaster University for use in their medical education programs. The adoption of PBL by the McMaster group and Barrows (1986) was a result of students’ dissatisfaction with their medical school’s use of a traditional instructor-led model of teaching and the vast amounts of information they had to absorb, which was perceived to have little relevance to medical practice (Barrows, 1996). The McMaster group perceived “students were excited by working with patients and solving problems” (1996, p. 4). As a result, the university adopted PBL using a student-centred, problem-solving orientation designed to prepare medical students in the art of clinical reasoning to solve complex medical problems (Barrows, 1994; Hmelo-Silver, 2011).

To define the key components of PBL, students work together collaboratively in small groups to analyse, research and find solutions to complex, open-ended, real-world problems which have many potential solutions. The instructor enables the learning process by challenging the students' thinking through asking key, higher order questions which probe deeply into what students know or do not know. The instructor, as the facilitator, has a responsibility to avoid transferring his or her own knowledge when guiding the students, instead, attempting to provoke thought and provide direction. Next, the students determine what they need to learn to solve the problem. This may require research, discussion and re-analysis of the problem. The resulting information the students assemble is analysed and then synthesised by the group into new coherent forms of understanding required to solve the set problems. The process is usually completed with a tangible solution to the problem in the form of a presentation (Hmelo-Silver & Barrows, 2015).

To suitably describe the features of the PBL approach used in this study, Barrows' (1986) taxonomy of problem-based learning identifies the use of explicit processes to facilitate learning based on the needs of the discipline, the educational method employed and the skills of the instructors. Barrows suggested that a PBL method has the potential to address four educational goals: (1) structuring of knowledge for use in clinical contexts (SCC); (2) developing an effective clinical reasoning process (CRP); (3) developing effective self-directed learning skills (SDL); and (4) an increased motivation for learning (MOT). Barrows conceptualised that his PBL taxonomy provided an awareness of these variations and educational objectives "to help teachers choose a problem-based method most appropriate for their students" (Barrows, 1986, p. 481). His taxonomy is illustrated in Figure 2.

The design and format of the problems are a major variable, identified in Figure 2 as circles. The degree to which the learning is student-led or teacher-directed is the other major variable, denoted by squares in Figure 2. Barrows estimated the degree for how well each variation of PBL meets each of the four educational objectives using a score from 0-5. Of all six variations in his PBL taxonomy, Barrows determined that closed-loop was the best option to enhance all four educational objectives for medical students such as acquiring the essential work-based skills to diagnose and heal effectively.



	SCC	CRP	SDL	MOT
Lecture-based cases	1	1	0	1
Case-based lectures	2	2	0	2
Case method	3	3	3	4
Modified case-based	4	3	3	5
Problem-based	4	4	4	5
Closed-loop problem based	5	5	5	5

Figure 2. Taxonomy of Problem-based Learning (Barrows, 1986, pp. 482-483)

The closed-loop (reiterative) PBL approach is the most student-centred in Barrows' taxonomy using free inquiry with full problem simulation. Closed-loop PBL is an extension of the problem-based method with the addition that once students complete their self-directed learning, they are asked to evaluate their research, processes and solution(s). Students are then asked to return to the original problem to reflect on how they might have improved their research and reasoning processes based on what they learned during their self-directed learning, thus closing the loop. The advantage of the closed-loop PBL method is that it addresses the students' development of effective self-directed learning skills, their clinical reasoning processes, and their structuring and synthesis (through reflection) of knowledge for use in clinical contexts. These steps require them "to go beyond the acquisition and discussion of new knowledge in a way that allows them to see its value and to evaluate actively their prior knowledge and problem-solving skills" (Barrows, 1986, p. 484).

Due to its affinity to not only medical education, but to the particular features of *professional* learning in general, PBL has become regarded as a pedagogy which offers benefits to other professional practices, including schools of education (Burn & Mutton, 2015; Kriewaldt & Turnidge, 2013; McLean Davies et al., 2013; Novikasari, 2020; Strobel & van Barneveld, 2015). For example, Barrows' (1986) four educational objectives for medical students correspond with the educational objectives PSTs are required to achieve in order to diagnose student learning needs and teach mathematics effectively (Burn & Mutton, 2015; Carnegie Corp. of New York, 2001; McLean Davies et al., 2013). Distinctively, PSTs need to possess an understanding of mathematics content, curriculum and assessment to determine the cognitive demands of a task for their students. The PSTs must also analyse the students' mathematical solutions and arguments and identify learning difficulties and misconceptions and apply their PCK to overcome these problems (Australian Professional Standards for Teachers, 2018).

This type of clinical practice/reasoning structure has been adopted in teacher education programs. In 2008, the University of Melbourne's Graduate School of Education re-designed their Master of Teaching degree (McLean Davies et al., 2013) based on the principles of the Carnegie Corporation of New York – in particular the idea that the teaching profession be 'understood as academically taught clinical practice profession" (Carnegie Corp. of New York, 2001, p. 1). The re-design of the program was further underpinned by Levine's (2006) declaration of exemplary teacher education programs which identifies one of the criteria as exemplary because of how "they integrate and balance academic and clinical instruction" (p. 101). Initial research regarding first graduates' satisfaction with their training in the re-designed program showed that 90% claimed they were 'well' or 'very well' prepared for the real life of a classroom (McLean Davies et al., 2013) compared to the Australian Education Union's (2009) survey of 1545 new teachers across Australia that, on average, 40-45% claimed they were 'well' or 'very well' prepared.

Burn and Mutton (2015) examined features of other programs which provided opportunities for PSTs to engage in clinical reasoning practice to develop their abilities to teach effectively. They concluded that for PSTs studying within their scope, with access to expert facilitators, "clinical practice allows them to them to engage in a process of enquiry: seeking to interpret and make sense of the specific needs of particular students, to formulate and implement particular pedagogical actions and to evaluate the outcomes" (2015, p. 219).

Problem-based Learning for Developing Pedagogical Content Knowledge

Limited studies exist on PBL's effectiveness in the development of PSTs' PCK (for example, Erdogan & Senemoglu, 2017; Mohamed, 2015; Pepper, 2013; Zamri & Lee, 2005).

Erdogan and Senemoglu (2017) examined the effectiveness of PBL in a language testing and evaluation subject to investigate PSTs' academic achievement and self-regulation. The results indicated PBL was effective in developing the PSTs' knowledge, comprehension and application-level achievements as they worked on real-life problems. However, the PBL approach had no significant effects on their self-regulation. The PSTs indicated the large group sizes negatively impacted their ability to share responsibilities and collaborate due to the challenges of meeting outside of class time. The PSTs expressed three to four as a desired group size.

Pepper (2013) presented PBL to a cohort of second-year science education students to determine their perceptions of the teaching approach while planning lessons for Year 7 students. The PSTs mostly welcomed the independent learning and the opportunity to collaborate and share the responsibility for designing and developing authentic teaching materials. They described the learning approach mainly as interactive and engaging and reported a perceived increase in their confidence to plan and deliver a Year 7 science investigation since completing the PBL activity. The PSTs indicated an appreciation for being introduced to PBL and that they will likely use it to engage their future students.

Zamri and Lee (2005) examined the implementation of PBL on PSTs' PCK in a tertiary mathematics education subject. The objective of the six-week PBL study was to investigate the PSTs' attitudes, activities and perceptions pre and post PBL session. The process began with the PSTs, in groups of four to five, scrutinising a problem scenario. They were provided time for group collaboration to identify the issues, investigate relevant materials and resources and plan a solution. During the process, they were tasked with identifying the different pedagogical approaches to teaching mathematics. In their last class, the PSTs demonstrated their solutions to the class. The results from the student attitude survey indicated a significant difference regarding their attitudes and perceptions towards PBL in the context of teaching mathematics. The results from PSTs' activities survey show that the PBL sessions provided opportunities to consider alternatives to solving problems and to locate, evaluate and utilise appropriate learning resources in the context of teaching mathematics.

Each of the studies provided insight into PSTs' perceptions of PBL as a teaching and learning approach and how it enacted and transformed their PCK while participating in a PBL program. A further review of the literature did not reveal any other PBL studies aimed at developing mathematics PCK during PSTs' tertiary education other than Martin et al., (2013). As a result, there is a gap in the literature which supports the significance of this study. Therefore, this study aimed to investigate the effectiveness of the closed-loop PBL (Barrows, 1986) pedagogical approach with PSTs.

Based on the literature that concludes that not all graduating PSTs possess adequate mathematics PCK to teach effectively, the research question that guided the study was:

1. What impact will using closed-loop PBL instead of a teacher-directed instructional approach have on PSTs' mathematics PCK?

Method

The participants (N=37) were PSTs in the third year of a four-year Bachelor of Education degree at a regional Queensland university in Australia. All participants were enrolled in their mathematics education subject at one of two campuses of the university, and this determined the control group and the treatment group for the study. Separating the treatment group and control group to different campuses largely reduced the risk of interaction. Table 1 summarises the demographic information for each group. The Australian

Curriculum strands and sub-strands of Number and Algebra, Measurement and Geometry, and Statistics and Probability provided the mathematics specific content of its type in the Bachelor of Education degree. The study was conducted in accordance with all required ethics protocols.

Cohorts		Treatment group Campus 1	Control group Campus 2
Number of Students		17	20
Gender:			
	Females	15/17	18/20
	Males	2/17	2/20
Age (years)			
	Range	20-45	20-47
	Mean	28	25.5
	Median	24	21
Prior Teaching Experience (days)			
	< 10	1	0
	10 – 15	3	2
	16 – 25	2	2
	>26	10	15
Teacher Aide Experience		1	1

Table 1: Demographic Data for the Treatment and Control Group Cohorts of Pre-service Teachers

The Mathematics Pedagogical Content Knowledge Instrument (MPCKI)

Three studies formed the basis for the development of the multiple-choice MPCKI: the CEMENT project (Callingham & Beswick, 2011), the MPCK study (Cheang et al., 2007) and the TEDS-M study (Tatto et al., 2008) with item contributions and permission from Callingham and Beswick (2011), Cheang et al. (2007) and acknowledgement of the use of released items from the TEDS-M (International Association for the Evaluation of Educational Achievement [IEA], 2012). The items used from the three contributing instruments were chosen because of their real-world attributes and alignment with the content of the mathematics subject in which the student participants were enrolled.

The MPCKI was designed and validated using Rasch modelling in a pilot study (Martin & Jamieson-Proctor, 2020) with students of a similar demographic, studying the same subject within the same program, only a year earlier. The 54 multiple-choice questions which measured PSTs' mathematics PCK were based on 12 scenarios of classroom teaching (three algebra, three measurement, three geometry, three statistics and probability) and structured to fit a standardised format requiring responses to multiple choice items per scenario (example scenario in Appendix A). The Rasch analyses from the pilot study (Martin & Jamieson-Proctor, 2020) revealed the empirical hierarchy of the difficulty of the items, which was used to restructure the 54 item MPCKI into two instruments (pre-semester and post-semester) measuring the same constructs at a similar difficulty level, thus minimising testing and instrumentation threats. Based on an examination of the logit values indicating the levels of difficulty of each item provided by the Rasch modelling, 18 of the 54 items did not have a similar level of difficulty with another item containing similar subject matter. As a result, these 18 items were used in both the pre-semester and post-semester instrument. The remaining 36 items were divided equally between the pre- and post-tests with each item matched with an item in the other test in terms of subject matter and levels of difficulty. As a result, both the pre-semester MPCKI and post-semester MPCKI contained 36 questions with each asking the same number of subject matter questions at the same or similar difficulty level (see Appendix A and Appendix B).

Research Design

The participants of the control group (n=20) were taught using a traditional lecture/tutorial teacher-directed approach and the treatment group participants (n=17) were instructed using closed-loop PBL. Both instructors had similar years of mathematics education lecturing experience. The lecturer who was recruited to teach the control group, used a traditional teacher-directed pedagogical approach. The second lecturer, who uses a constructivist approach to teaching, adopted the closed-loop PBL pedagogical approach to deliver the subject to the treatment group. Prior to the start of the study the researcher provided the 'PBL' lecturer with literature on the closed-loop PBL framework and professional development on the practice of facilitating a PBL classroom. This involved discussions and modelling for preparing groups to work collaboratively in a PBL environment and how best to ask meta-cognitive questions which focus on encouraging explanations and recognition of knowledge limitations (Leary et al., 2013).

For both cohorts, the semester was 15 weeks with 10 weeks required for on-campus attendance. During the on-campus classes, both cohorts were presented with the identical content topics and real-world, open-ended, moderately ill-structured tutorial problems (see example in Appendix C) related to the topics (Jonassen & Hung, 2015). In week 1 of the semester both the treatment group and the control group were asked to respond to the MPCKI pre-test. The learning objective for weeks 2 and 3 was for the PSTs to be able to progress school-aged students' understanding of simple geometrical and numerical patterns to comprehending simple algebraic equations. Weeks 2 and 3 was used to address the weeks' learning objectives for both groups while simultaneously preparing the treatment group of PSTs to begin working and learning in a PBL environment. The preparation for the treatment group required a different pedagogical approach compared to that used with the control group and to that used in other subjects studied by the students. Weeks 2 and 3 were therefore used to help them develop the skills to work collaboratively and to take charge of their own learning as opposed to being fully directed by the tutor.

The semester content was identical for both groups, but how it was presented was different. The control group was introduced to the content using teacher-directed instruction in the 10 weekly 1-hour lectures, each followed by a 2-hour tutorial, where they engaged with the real-world, open-ended decision-making tutorial problems, albeit led by the tutor. Alternatively, the treatment group was expected to investigate the week's content and the same real-world, open-ended tutorial problems during a 3-hour workshop, in which they were facilitated to be self-directed. Students in this cohort worked independently and in working groups of 4-5 students to investigate the problem that was posed, identify gaps in their knowledge, fill those gaps through self-directed learning and research and create their solutions.

The following section provides a detailed description of how the content and pedagogical strategies were delivered to the control group during the 1-hour lecture and then how they engaged with the tutorial tasks during the 2-hour tutorial.

Outline of the Teacher-directed Approach used with the Control Group during the Study

1-hour teacher-directed lecture: Each week for one hour the control group of PSTs attended a lecture in a traditional lecture theatre. The lecturer displayed a PowerPoint presentation using the theatre's LCD projector screen and delivered, slide-by-slide, using a teacher-directed instructional approach, the week's curriculum content and pedagogical strategies related to the content. The students were primarily passive listeners.

1x2-hour teacher-directed tutorial: Following each lecture, a 2-hour tutorial was conducted in a classroom with the tutorial problems framed around the week's curriculum and pedagogy topic. The tutorial session began with the lecturer informing the students that, after being divided into four groups based on their preferred teaching year level, they would create a lesson plan in response to one of two real-world, open-ended problems. Their response should demonstrate their ability to address difficulties children experience with specific mathematics concepts and skills. Essentially, two groups worked on one of the problems while the other two groups solved the other problem. In the following week, the process was repeated for the control groups with the other two of four problems.

Next, led by the lecturer and complemented with PowerPoint slides, the two real-world, open-ended tutorial problems were presented and unpacked. This was accompanied by a review of the pedagogical strategies the students would need to solve the problems. Relevant concrete materials were brought to class by the lecturer for the PSTs to utilise as part of their solutions of each problem. Other resources made available during the tutorial were (a) iPads with internet access, (b) a variety of textbooks aimed at teaching primary school mathematics and (c) the lecturer to answer questions.

Students then placed themselves into four groups of four or five and were tasked with developing a lesson plan which addressed the specific real-world, open-ended tutorial problem. Visiting each group in turn, the lecturer answered questions and assisted students' reasoning processes. The lecturer confirmed or suggested possible activities and solutions in terms of the pedagogical strategies that were 'expected' to be used. The students then reorganised their solutions and wrote-up the solutions to the problems on a provided lesson-plan template. Circulating to each group for the second time, the lecturer established that each group's solutions met the subject's learning outcomes. Groups which struggled were assisted to develop an 'acceptable' solution. In a teacher-led whole class discussion, each group in turn provided their solution to how they would enact their PCK to remediate the children's difficulties. Feedback and/or alternative solutions were provided by the lecturer. Any questions asked by other students were generally answered by the lecturer.

The next section provides a description of how the PBL cohort was facilitated in their self-discovery of the content and pedagogical strategies during their 3-hour workshop, in order to compare and contrast the approaches of the two different lecturers. Also described is the student-led process used during the following week's 3-hour workshop where the groups delivered their solutions in the form of a simulated lesson which addressed the mathematics content covered that fortnight.

Outline of the PBL Approach used with the Treatment Group in the Study

3-hour, student-directed workshop: Each week the PBL cohort attended their 3-hour workshop, with no lecture component. The room chairs were prearranged into four groups of four or five students each, with each group placed in teams based on their preferred teaching year level.

At the start of each workshop, the lecturer informed the students that each group would create a lesson plan in response to one of four real-world, open-ended problems to demonstrate their ability to address difficulties children experience with particular mathematics concepts and skills. Using the closed loop PBL process, the groups spent the remainder of the workshop engaged in a process of discovery/research and collaboration to determine the information they needed in order to remediate the children's difficulties and allow them to provide a solution to the problem posed. It was the group's decision how to best utilise the time in their 3-hour workshop. Relevant concrete materials (the same materials as provided to the control group) were available to the groups. Other resources made available during the workshop were (a) iPads with internet access, (b) a variety of textbooks aimed at teaching primary school mathematics, (c) access to lecture information and (d) the PBL facilitator as a coach/mentor.

While the groups engaged with their problem, the lecturer, using a PBL facilitation process, supported the students' thinking by responding to their questions with probing questions of her own… questions which the students should be asking themselves to guide their thinking. Thus, Socratic Dialogue (van der Linden & Renshaw, 2004) was engaged where the lecturer was neither the author nor transmitter of knowledge, but rather an assistant to the learners' search for solutions to the problems. This dialogue included questioning the students' search for evidence as well as the justification for their choice of lesson activities which they believed would address the difficulties children experience with the mathematics topics. At the onset, the students were frustrated because their questions were being answered with more questions by the facilitator, even if it was in order to assist them to search for evidence and apply reasoned arguments. In this way the students were enabled to centre their thinking on the learning objectives of the subject and, they were guided towards identifying what they knew and what they needed to find out. This iterative approach was undertaken so the students would become more confident in identifying the specific information they needed to discover to solve the problem that was posed.

The following week, during the 3-hour workshop, each group took turns delivering the lesson to their peers in a simulated classroom using their choice of materials and teaching strategy. After delivering their lesson, informal feedback was provided to the group members by their peers and the lecturer.

To close the loop, after delivering the lesson each group member responded to a set of reflection questions such as: If you were to revisit the original problem, what improvements would you make to your reasoning process? These questions requested they reflect on the effectiveness of their process in solving the problem, both individually and as a group.

Data Collection and Analysis

The pre-semester MPCKI was administered in week 1 and the post-semester MPCKI was administered in week 15 for the purpose of measuring changes over time of the treatment and control groups as well as compare the two groups mathematics PCK at the start and end of the semester. A mixed between-within repeated measures ANOVA (Tabachnick & Fidell, 2019) was used to compare the mean scores (between-subjects) across two time periods (within-subjects) to analyse and interpret the overall mean scores from each MPCKI test. The overall mean scores for each MPCKI scale (pre- and post-test) were determined by adding up the raw scores of the 36 items for each PST and calculating the average. The mean score obtained from the MPCKI ranged from 0-1 as a result of each of the 36 responses being coded as a 0 or 1 [0-36/36].

Prior to analysing the results from the ANOVAs, it was important to check that certain assumptions were not being violated. The general assumptions which apply to parametric tests when comparing group means include (a) dependent variables are measured on a continuous or interval scale rather than discrete or categorical scales, (b) measurements are not influenced by other measurements (independence of observations), (c) populations samples are normally distributed and (d) samples are obtained from populations of equal variance (homogeneity of variance) (Field, 2017).

First, the data collected from the MPCKI (as summated rating scales) were treated as continuous data and classified as scale variables in SPSS. Second, in terms of independence of observations, the participants from each of the two cohorts were formed from two separate campuses. As a result, there were limited interactions between participants across cohorts. Third, to test whether the scores were normally distributed, a Shapiro-Wilk test was conducted in SPSS for each of the data sets. Tests of Normality statistics returned non-significant values indicating the samples did not deviate significantly from normality. The fourth assumption to be met was that of homogeneity of variance/covariance. To test these assumptions, SPSS provides the Levene's Test of Equality of Error Variances statistic. The Levene's test returned a non-significant value indicating no significant deviation from equality of variances for each of the times (pre and post) between the two groups (treatment and control) (Field, 2017; Pallant, 2016).

Results

A mixed between-within repeated measures ANOVA was conducted to assess the impact of the closed-loop PBL teaching method (treatment group) compared to teacher-directed instruction (control group) on PSTs' mathematics PCK mean scores at two points in time (pre-intervention and post-intervention, Table 2). There was no significant group by time interaction, Wilks' Lambda = .99, $F\,(1, 35) = .031$, $p = .86$, $\eta^2 = .001$. There was however a significant main effect for time, Wilks' Lambda = .71, $F\,(1, 35) = 14.33$, $p < .01$, $\eta^2 = .29$ with an increase in PCK scores from Time 1 to Time 2 for both groups. The Eta squared value of 0.29 indicates a relatively small effect size. Cohen (1992) considers an effect size of 0.2 as small, 0.5 medium, and 0.8 large. However, as stated by Burns and Burns (2008, p.244), "If the sample is small [as in this study], you can assume that a significant result is probably also practically significant". As Burns and Burns points out, if the sample is small, and the result significant at .01, as in this study, even though the effect size is small, the result has potential practical implications.

Point in Time	**Pre-intervention**			**Post-intervention**		
	N	**M**	**SD**	**N**	**M**	**SD**
Treatment Group	17	.431	.019	17	.500	.022
Control Group	20	.413	.017	20	.475	.020

Table 2. Mathematics PCK Scores for the Treatment Group and Control Group at two Points in Time

Therefore, in this study, the MPCKI results indicate that both teaching methods were able to assist PSTs to enhance their mathematics PCK from Time 1 (pre-intervention) to Time 2 (post-intervention). Thus, our hypothesis that the PBL group would display a greater increase in PCK than the control group as a result of the teaching method is rejected. Further, there was no significant difference between the two groups at either the pre-intervention or post-intervention. Figure 3 illustrates the profile plots comparing the two teaching methods pre-intervention to post-intervention for the treatment group and control group. Further, as there was no significant difference between the two groups at the pre-test it can be assumed that prior learning did not impact one group more than the other. They started the same with respect to mathematics PCK.

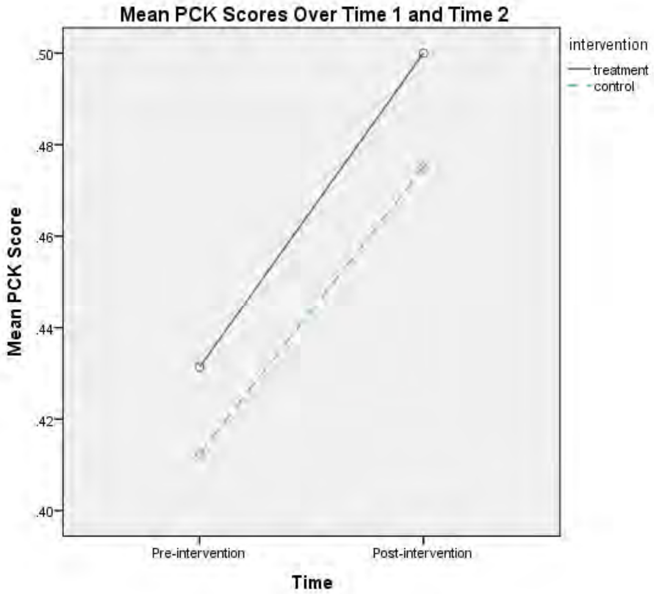


Figure 3: MPCKI Results of the Mean PCK Scores for the Treatment and Control Groups Over the 15 Weeks

Discussion

The MPCKI multiple-choice items were designed to measure PSTs' mathematics PCK. It was hypothesised the study would demonstrate significant outcomes between the two teaching methods with regard to developing PSTs' mathematics PCK.

The pre-semester MPCKI results were used prior to the commencement of the intervention to establish that both groups had a similar level of mathematics PCK. In effect, both groups had similar knowledge about how to teach mathematics at the start of the semester irrespective of prior learning. During the four-month intervention period the two groups were exposed to different pedagogical approaches. At the end of the intervention the MPCKI was used to compare the control group and treatment group levels of mathematics PCK. The ANOVA results indicated no significant difference in the effectiveness of the two types of teaching methods in their ability to develop the PST' mathematics PCK. Thus, it appeared that the PBL intervention had not achieved an improvement as expected in the treatment group's mathematics PCK when compared to the control group's mathematics PCK. However, meta-synthesis findings from Strobel and van Barneveld (2015) suggests a multiple-choice survey designed to measure the attainment of content knowledge favours traditional instruction over a PBL pedagogical approach. However, both groups performed equally well on the post-test MPCKI. Thus, in this study, closed loop PBL did not hinder the development of the PSTs' PCK, and it was as effective as traditional instruction, when PCK is measured using the multiple-choice MPCKI.

Further, meta-analysis findings exist on the positive impact of PBL on outcomes related to application of PCK in teacher education studies (Walker & Leary, 2009), similar to the learning which was facilitated by the PBL intervention in this study. Studies which used closed-loop PBL as their pedagogical intervention "indicated some of the largest findings in favour of PBL ($d = 0.54$) (Walker & Leary, 2009, p. 23). Further, when the PBL cohort in this study were asked an additional 'closing the loop' reflection question designed to capture whether they felt PBL had been more effective than their past experiences with traditional instruction, 16 of 17 students responded in the affirmative. Representative statements include:

It [PBL] was more student-led. As a group we went and explored the different ideas and the resources to find out what we wanted to do to work out the actual method of how we were going to teach it. So we were trying to incorporate what we had learned into how we were going to teach it.

Having to actually get up and do it [teach] and using strategies… So you're seeing what works and what doesn't work. And you're getting feedback as well on what they [peers and facilitator] think worked and what didn't work.

It's helped my mind learn to structure sequences for lesson planning in specific relation to mathematics.

The view provided by students regarding a dissatisfaction with traditional teacher-directed instruction, in terms of developing their mathematics PCK is further demonstrated by the following representative responses:

It [traditional instruction] doesn't help my learning. It [traditional instruction] doesn't make me think about what I should be learning to get the answers.

It [traditional instruction] was all about recall and trying to remember things.

With lecturing, I listen but it doesn't make sense to me. I'll forget it as soon as I walk out.

Limitations and Future Research

This study was conducted over the course of one semester (four months) with a relatively small sample size (N=37), however, the result may be considered practically significant (Burns & Burns, 2008). Inherent limitations of the study arose when it was decided to use convenience sampling in the study; thus, the sample used in the study means the results cannot be attributed to the whole or larger population. Applying closed loop PBL for just one semester in just one subject potentially limited the impact of the pedagogical approach on the breadth of dependent variables investigated. It is recommended that any replication of the study should be conducted with a larger sample size and for longer than one semester with the same instructors: potentially swapping roles/instructional groups. In the context of swapping instructional groups, consider both the treatment and control groups created solutions to real-world, open-ended problems in the form of a lesson plan during class time. However, the PBL treatment group of PSTs were required to enact their PCK in a simulated classroom. The control group of PSTs were provided direct instruction in the use of teaching strategies and resources which were used to create solutions to the problems, but they did not deliver their lessons in a simulated classroom. Their class time was allocated to discussing, with teacher-direction, how they would enact their mathematics PCK.

Conclusion

This study is considered an initial attempt to investigate the effect of the social constructivist, closed-loop PBL method (Barrows, 1986), in comparison to teacher-directed instruction on PSTs' PCK in a tertiary mathematics education subject. Based on the research presented, and in relation to assessing mathematics PCK in this study, the results of the MPCKI could possibly have favoured the control group of PSTs taught using a teacher-directed approach. However, this was not the case. The conclusion from the results of this mathematics education study is that when assessed using the multiple-choice MPCKI, the closed loop PBL method adopted in this study with PSTs was as effective as teacher-directed instruction. However, we feel the main aim of our study was achieved addressing TEMAG's (2014) recommendations that tertiary providers use evidence-based pedagogical approaches that have a positive impact on learning.

In closing, it is proposed that researchers conducting studies in PBL should, in the first instance, describe the extent to which the PBL method is employed and provide a clear description of the protocols used (Albanese & Dast, 2014; Goodnough & Nolan, 2008; Newman, 2003). This study set out to investigate the effect of the social constructivist, closed-loop PBL method (Barrows, 1986), in comparison to teacher-directed instruction, on PSTs' PCK in a tertiary mathematics education subject. The results suggest that closed-loop PBL is an effective pedagogy for developing PSTs' mathematics PCK - and as such should be pedagogy of interest to pre-service teacher educators.

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Appendix A: Pre-semester Mathematics Pedagogical Content Knowledge Instrument Items

Suppose you wish to know if your students really understand the formula for the area of a rectangle.

Below there are three teaching strategies you might use for this purpose. For each strategy below, indicate whether you *would NOT use, might use*, or *definitely would use* the strategy to determine if they really do understand the formula for the area of a rectangle.

	Would NOT use	**Might use**	**Definitely would use**
Give them the following problem. If a rectangle is 4 cm long and 3 cm wide, what is its area?	[ ]	[x]	[ ]
Simply ask them to tell you what the formula is for the area of a rectangle.	[x]	[ ]	[ ]
Give them the following problem: Sketch two rectangles each having an area of 12 cm^2	[ ]	[ ]	[x]

Appendix B: Post-semester Mathematics Pedagogical Content Knowledge Instrument Items

Suppose you wish to know if your students really understand the formula for the area of a rectangle.

Below there are three teaching strategies you might use for this purpose. For each strategy below, indicate whether you *would NOT use, might use*, or *definitely would use* the strategy to determine if they really do understand the formula for the area of a rectangle.

	Would NOT use	**Might use**	**Definitely would use**
Simply ask them to tell you what the formula is for the area of a rectangle.	[x]	[ ]	[ ]
Take a circle and partition it like a pizza and then cut out the pieces. Arrange those pieces to form a rectangle and ask the students to determine the area of the newly formed rectangle.	[x]	[ ]	[ ]
Using a rectangle which is 4 cm long and 5 cm wide, ask the students to determine the area using only a square centimetre tile.	[ ]	[ ]	[x]

Appendix C: Real-world. Open-ended, Decision-making Problems

The aim of this activity is for you to demonstrate your ability to design a lesson plan on 2D shapes underpinned by the The van Hiele Levels of Geometric Understanding. Scenario: You are on your 15-day prac and your mentor teacher informs you that her Year 5 students can compare and describe most 2-D shapes, but most have misconceptions about the attributes of these 2-D shapes and how to calculate their perimeter and area. Using the rectangle as the context, she is asking you to develop a lesson plan which addresses these misconceptions.

She provides you with the following guidelines. You are to reference the appropriate ACARA strand(s) and sub-strand(s) for these year levels. The design of your lesson should provide the students with the opportunity to:

- revisit their Foundation Year and Year 4 prior knowledge in regards to 'shape';
- be appropriately introduced through real-world, concrete activities to the concepts of geometry from the appropriate year level content descriptor of 'shape';
- apply, in a social constructivist learning environment, the related Year 5 geometry skills; and
- demonstrate and/or explain their understanding to their peers using their own language.

The lesson is to consist of an introduction phase, an enhancing (application) phase and a synthesising phase. You may use any concrete and/or virtual resources, materials, textbooks, or IT available to you. You may also write-up the lesson plan using the example template provided or create your own lesson plan template.