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ABSTRACT

The study reported in this paper was part of a larger study that explored pre-service teachers' perceptions of the effectiveness of a problem-based learning (PBL) teaching approach for developing their mathematics pedagogical content knowledge (PCK) and their ability to enact their PCK in a tertiary mathematics education subject. This paper reports the qualitative semi-structured interviews used to capture the student voice with respect to the impact of the PBL approach used on the development of their mathematics PCK in comparison to their previous experiences with teacher-directed instruction. Overall, responses from the interviews revealed the pre-service teachers considered the PBL method used in this study was a more effective way to learn compared to being taught using a teacher-directed instructional approach, and further, that they will most likely use PBL when they become teachers.

Keywords: problem-based learning, pre-service teachers, pedagogical content knowledge, mathematics education

The National Council of Teachers of Mathematics (2014) asserts that effective teaching, through sound pedagogical content knowledge (PCK), requires teachers to have a deep understanding of the mathematical content they are expected to teach and know their students as learners. They must also be able to choose from, and use, a variety of evidence-based pedagogical strategies in a skillful manner. In Australia, the Teacher Education Ministerial Advisory Group (TEMAG) stated, "the difference between expert teachers and pre-service teachers is this depth of pedagogical content knowledge" (2014, p. 18). Further, they reported that not all graduating pre-service teachers possess adequate PCK to teach effectively. One of the recommendations in the TEMAG report required initial accreditation of teacher education programs to be linked to tertiary providers demonstrating that their programs use evidence-based pedagogical approaches (TEMAG, 2014). The study reported in this paper aimed to provide evidence from a group of pre-service teachers that PBL is a useful pedagogical practice for developing their PCK and their ability to enact their PCK in the context of a semester-long undergraduate mathematics education subject, which is most important for their future students.

Pioneered at McMaster University in the 1960s, PBL was designed to better prepare medical students to think critically and solve complex medical problems. It was developed as a consequence of the general dissatisfaction with medical schools which used traditional, instructor-led models of teaching. The McMaster group's research found that medical students were uninterested with their studies due to the vast amounts of knowledge they were asked to acquire, much of which was perceived to have little application to their future careers. In contrast, the McMaster group found that medical students, during their practicums, were highly engaged when problem solving and working with patients (Barrows, 1996).

PBL's impact in preparing new doctors has become regarded as a pedagogy which offers a great deal for other tertiary programs including schools of education (Savery, 2015; Strobel & van Barneveld, 2009). However, PBL has been so broadly adopted by institutions using variations or degrees of PBL structure, based on the needs of their discipline, that "the meaning of the term problem-based learning has become clouded and confused" (Barrows, 1994, p. vi). Moreover, the findings to date on the effectiveness of PBL are mixed. Most studies and meta-analyses revealed that students exposed to the PBL treatment gained slightly less knowledge but remembered more of the acquired skills (Albanese & Dast, 2014; Newman, 2003; Strobel & van Barneveld, 2015; Walker et al., 2015a). Meta-analyses concluded that "existing overviews of the field do not provide quality evidence with which to provide robust answers to questions about the effectiveness of PBL" (Newman, 2003, p. 5). This result may be due to many researchers not identifying which variation of PBL was used in their study; thus, making it difficult to conduct comparative studies or meta-analyses which produce appropriate findings as the data ends up comparing 'apples to oranges' (Newman, 2003). The teaching intervention employed in the study presented in this paper used a closed-loop PBL approach, which is one of six variations of PBL in Barrows' (1986) taxonomy of PBL methods. Closed-loop PBL was selected for this study because out of the six variations, only closed-loop PBL has the potential to address all four educational objectives: (1) structuring of knowledge for use in clinical contexts; (2) developing an effective clinical reasoning process; (3) developing effective self-directed learning skills; and (4) an increased motivation for learning (see Figure 2).

Literature Review

Pedagogical Content Knowledge

Pedagogical content knowledge is defined as "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8). Shulman (1987) called for the need to explore PCK as the inherent interconnection between content knowledge and pedagogical knowledge.

Marks (1990) indicated that PCK contains elements of both content knowledge and pedagogical knowledge. In such a structure, the teacher must first examine the content for its composition and significance requiring a process of interpretation. 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) by adopting pedagogically useful representations of the content. Pedagogical knowledge can be seen in teachers' use of questioning strategies, knowledge of assessment, or their knowledge of students' learning processes. Ultimately, Marks characterized PCK as a synthesis of a balance of varying degrees of content knowledge and pedagogical knowledge which depend on contextual knowledge demands placed on the teacher such as the year level, the objective, and the level of student ability.

Gess-Newsome (1999) conceptualized PCK as being separate from content knowledge, but mostly was categorized in two distinct models: the integrative model and the transformative model. Under the integrative model, PCK does not exist as a separate category of knowledge, but encompasses the intersection of content knowledge, pedagogical knowledge and contextual knowledge that are combined by the teacher during the course of instruction. In the transformative model, content knowledge, pedagogical knowledge, and contextual knowledge "are inextricably combined into a new form of knowledge" (Gess-Newsome, 1999, p. 11), such that it forms an amalgamation of the knowledge categories arising from their interaction.

Subsequent research, such as Ball et al. (2008), Hill et al. (2008) and Chick and Beswick (2013), are credited with progressing the conceptualisation of PCK. For example, Chick and Beswick (2013) conceptualized a framework for analysing PCK which is grouped into three categories with mathematics teaching as the context. In this framework, PCK is categorized as (a) clearly PCK (as intertwined with pedagogy, student thinking, knowledge of resources, curriculum knowledge and content knowledge, (b) content knowledge in a pedagogical context, and (c) pedagogical knowledge in a content context. Representing mathematics PCK in yet another multifaceted fashion, Michigan State University researchers, Ball et al. (2008) and Hill et al.'s (2008) conceptualisation of PCK subdivided the domain into knowledge of content and students, knowledge of content, and teaching and knowledge of curriculum. On one hand, this view is similar to Chick and Beswick's (2013) framework as this conceptualisation of PCK illustrates a distinction among knowledge of content, teaching, and curriculum. Alternatively, Chick and Beswick describe PCK as a distinct category, clearly PCK, alongside content knowledge in a pedagogical context and pedagogical knowledge in a content context.

The majority of education researchers who have progressed Shulman's (1986) framework agreed that PCK is a unique form of teachers' professional knowledge and is described as recognising how to organize curriculum, content, pedagogy, and knowledge of students' understanding in a form which can be used for decision-making in the classroom in specific situations (Weizman et al., 2008). Loughran et al. (2012) provide this example:

> The combination of the rich knowledge of pedagogy and content together, each shaping and interacting with the other so that what is taught, and how it is constructed is purposefully created to ensure that particular content is better understood by students in a given context, because of the way the teaching has been organized, planned, analysed and presented. (pp. 7-8)

Possessing the ability to enact PCK is fundamental to effective teaching and student academic gains (Hattie, 2012; Tatto et al., 2008; TEMAG, 2014). As described by the international members of the Teacher Education and Development Study in Mathematics (TEDS-M) project (Tatto et al., 2008), enacting mathematics PCK is identified as analysing or evaluating a student's mathematical solutions or arguments as well as providing appropriate feedback, and the ability to guide classroom discourse as well as to explain or represent mathematical discourse or procedures (Döhrmann et al., 2012).

In light of the research presented, this study adopted a conceptual framework for PCK as a special domain of teacher knowledge, formed when content knowledge, pedagogical knowledge and contextual knowledge are used in unison to formulate concepts and content into representations which make them comprehensible to students. Further, this study defined the ability to enact PCK as a process demonstrated when a teacher, as a result of analyzing and interpreting students' solutions or arguments, is able to organize and represent content knowledge in a wide array of methods, which allow it to be developed by students within a classroom context (Döhrmann et al., 2012).

Problem-based Learning

The key component of PBL is that students work together collaboratively in small groups to analyse, research, and find solutions to ill-structured, open-ended, real-world problems which have many potential solutions (Hmelo-Silver & Barrows, 2015). The ill-structured problems are usually the type encountered in workplace practice which have many possible solutions that may not be evident from the outset, as well as containing uncertainty about the strategies or principles needed to solve them (Hung, 2011). The teacher, as the facilitator, has a responsibility to avoid directly transferring his or her own knowledge when guiding the students. Instead, they must attempt to provoke student thinking and provide direction for their investigations. The students' responsibility is to acquire the fundamental essence of the problem, define the gaps in their knowledge, and source and develop the knowledge required to solve the problem. Students also may be required to undertake research, discussion and re-analysis of the problem. The resulting information the students assemble is analysed and then synthesized by the group into new coherent forms of understanding required to solve the set problem.

The objective is to move the students toward self-discovery of the desired outcome(s), thus allowing them to own the knowledge versus being delivered the information and/or solution(s) as in a traditional teacher-directed instructional approach. As an authentic problem is presented, which requires students to consider alternatives and to provide reasoned arguments to support solutions they generate, the students become the owner of the work and assume responsibility for their own learning (Hmelo-Silver & Barrows, 2015). The process is usually completed with a tangible solution to the problem in the form of a presentation alongside reflective discussion as students demonstrate their understanding of the concept or problem (Barrows, 2002). As a social constructivist pedagogical approach, PBL is a "premier example of a student-centred learning environment as students co-construct knowledge through productive discourse practices" (Hmelo-Silver & Barrows, 2015, p. 71).

Problem-based Learning for Developing Pedagogical Content Knowledge

Limited studies exist on PBL's effectiveness in the development of practicing teachers' PCK (for example, Goodnough & Hung, 2008, 2009; Goodnough & Nolan, 2008; Weizman et al., 2008). Each of these studies investigated how the different elements of practicing teachers' science PCK were engaged as they developed PBL learning units for their students during a professional development. In summary, the teachers perceived that as they made curriculum, pedagogy, assessment, and student learning decisions, they examined their own relevant science content knowledge and general pedagogy, resulting in enhanced science PCK. However, the designs of these PBL studies are different from this study, which investigated the attitudes and beliefs of the pre-service teachers regarding their experiences with the closed-loop PBL approach for developing and enacting their mathematics PCK.

Relevant literature on PBL begins to diminish as the search for PBL's effectiveness targets pre-service teachers' perceptions towards being taught using a PBL model (for example, Erdogan & Senemoglu, 2017; Mohamed, 2015; Pepper, 2013). Erdogan and Senemoglu (2017) applied the principles of PBL in a testing and evaluation subject to investigate pre-service teachers' opinions about being taught using a PBL approach. The pre-service teachers highly favoured the active learning, hands-on activities, and interaction among group members which enabled creative and varied ideas to develop as they worked on real-life problems. The students also claimed their critical thinking skills and self-confidence improved during their studies. On the other hand, they indicated the large group size of six or seven had a negative effect on their studies due to the challenges of meeting outside of class time and equally sharing responsibilities. They felt that the success of the group work depended on the self-regulation of the individual group members.

Pepper (2013) introduced PBL into a second-year science education subject to determine pre-service teachers' perceptions of PBL while designing lessons for seventh grade students. The pre-service teachers described the PBL learning approach mainly as engaging, fun, hands-on, interactive, and interesting. Statements provided by the pre-service teachers reflect that they felt more confident about teaching science since completing the PBL activity and that they will likely use PBL in their own classes and see it as valuable in other subject areas, not just science.

In a pilot PBL study, Zamri and Lee (2015) used six weeks from of a 20-week course to investigate PBL's impact on pre-service teachers' PCK for teaching primary school mathematics. The PBL process began with the pre-service teachers being presented with a problem scenario to analyze. Next, they were provided time to identify the issues involved. They were then given opportunities for group discussion and time to investigate relevant resources, plan a solution and demonstrate their solutions in the form of a presentation. The results from student survey responses indicated an overall positive impact on the pre-service teachers' ability to solve real-world problems and consider alternatives to solving the problems. Positive impacts from the PBL treatment were also found regarding their attitudes, activities and perceptions towards PBL in the context of teaching mathematics. Nearly 87% of students were satisfied with their experience and enjoyed the group interactions and environment associated with PBL. Ninety-eight percent indicated that the PBL approach allowed them to take an active role in their learning and were satisfied that PBL improved their ability to locate appropriate resources for teaching.

However, all of these studies lack explanation about the specific design of the PBL program used. It is suggested that researchers embarking on a study using PBL should specify which variation of PBL they intend to use, which degree of student or teacher directedness they utilize based on their discipline, the group design, the facilitator role, the intended learning outcomes, problem design, and the reflective learning that will take place (Hung, 2015; Jonassen & Hung, 2015; Walker & Leary, 2009). Usefully, each of the studies offered insight into pre-service and practicing teachers' perceptions of how their PCK was enacted and transformed while participating in a PBL program.

A further examination of the literature did not reveal any other studies on the effectiveness of PBL at the tertiary level aimed at developing pre-service teachers' mathematics PCK other than the previous study conducted by Martin et al., 2013. As such, there is a gap in the literature regarding closed-loop PBL's impact on developing mathematics PCK in pre-service teachers and their ability to enact their PCK which supports the significance of this study. This study also addressed the PBL program design details lacking in other studies such as (a) the variation of PBL used, (b) the structuredness and complexity of the problems, (c) the self-directness of the learners with successful group collaborations, (d) the role of the teacher as facilitator (e) PBL sessions being embedded in classroom practice, and (f) making elements of the pre-service teachers' PCK explicit.

Considerations When Designing a PBL Program

According to Hung (2011), the design of PBL problems is a matter for consideration. The first consideration is how well the problem is designed for guiding the students to study the content associated with the intended learning outcomes. While there is a large focus on using real-world problems as the foundation of PBL, the underlying nature of the problems should be considered, such as their structure, difficulty, and context based on the nature of the learners (Jonassen & Hung, 2015). Jonassen and Hung challenged PBL researchers to consider problem type and difficulty when designing a PBL program. To suitably identify the type and difficulty of the problems for this PBL study, the typology of problems as conceptualized by Jonassen (2000) was considered useful.

Jonassen's (2000) typology of problems (Figure 1) consists of 10 classes of problems categorized along a continuum.

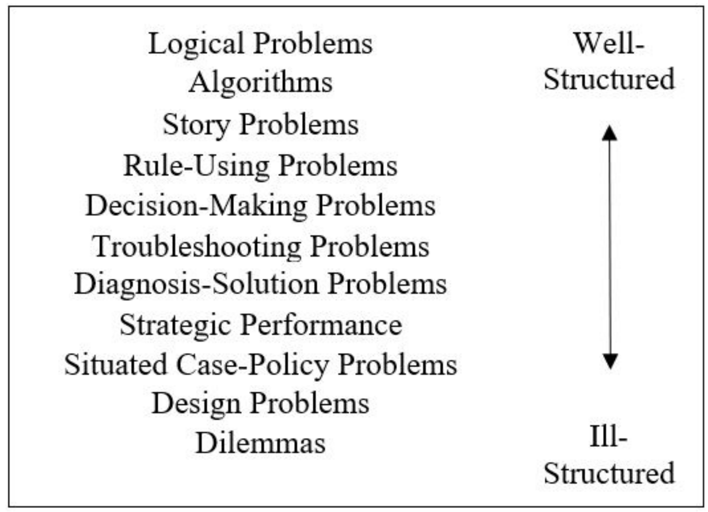

Figure 1. Jonassen's (2000) Typology of Problem Types (Jonassen & Hung, 2015, p. 22)

The problems are assigned to these classes based on the problem's level of difficulty, complexity, and structuredness in relation to the dominant type of problems employed for a particular context. In a later study, Jonassen and Hung (2015) investigated Jonassen's (2000) typology of problems to determine which types of problems are best suited to a PBL program. After considering three problem types: diagnosis-solution, decision-making, and situated cases/policy problems, they hypothesized that "decision-making problems should be used as the problem focus of PBL" (Jonassen & Hung, 2015, p. 31).

Decision-making problems characteristically have several competing alternatives, thus arriving at solutions to this type of problem requires diagnosis, negotiation, and design. Basically, decision-making problems "typically involve selecting a single option from a set of alternatives based on a set of criteria" (Jonassen, 2000,

p. 77); for example, "Which argument would be most effective to plead my case in court?" In the context of this study, an example might be "What lesson activity will best resolve my students' misconceptions regarding what a number raised to the zero power equals?" This type of problem has a number of solutions, but, "the number of factors to be considered in deciding among those solutions, and the implications of each decision, can be very complex" (Jonassen, 2011, p. 98).

In terms of developing a PBL pedagogical approach, Hung (2006); Jonassen (2011) and Jonassen and Hung (2015) posed additional considerations. First, the amount of cognitive scaffolding provided to the groups and individuals was considered. Some of the most successful implementations of PBL have first supported students' self-directed learning and collaborative skills while they are in the process of adapting to their new PBL context (Jonassen, 2011). It should not be assumed that learners are naturally skilled at working in groups, self-directed learning, or at solving complex problems.

> Most learners do not naturally possess these cognitive capabilities; rather, they develop these cognitive skills with sufficient training. Therefore, it is crucial to calibrate the levels of researching and reasoning processes required for solving the problem with the learners' levels of cognitive readiness as well as their self-directed learning skills, or comfort level with PBL. (Hung, 2006, p. 64)

Accordingly, this study utilized the first three weeks of the PBL intervention to scaffold the pre-service teachers' collaborative skills for working productively in groups and with PBL-style problems. The process generally involved using increasing levels of problem complexity and degrees of self-directedness.

Another consideration regarding the development of a PBL program is the instructor in the role of facilitator. A PBL facilitator does not deliver lecture-style content to the students using a traditional, teacher-directed instructional approach. Rather, the instructor is required to use complex facilitation skills and has a responsibility to avoid providing his or her own knowledge of the topic to solve the problems posed. The facilitator models learning strategies and asks meta-cognitive questions focusing on encouraging explanations and recognition of knowledge limitations (Hmelo-Silver & Barrows, 2015; Leary et al., 2013; Walker et al., 2015b). The objective is to move the students toward self-discovery of the desired outcomes, allowing them to own the knowledge rather than being taught the information and/or the solution. In this way, as the authentic problem is presented, and the solution is not immediately apparent, the students become actively engaged, collaborating and assuming responsibility for their own learning around the topic under investigation. One trait of being actively engaged are student-led discussions during and after collaborative group work which are facilitator supported.

The Nature and Effectiveness of PBL in Higher Education

Meta-analyses and reviews of PBL studies (for example, Albanese & Dast, 2014; Strobel & van Barneveld, 2015; Walker et al., 2015b) concluded that teacher-directed, lecture-based instruction may not be the most effective instructional approach in developing practical application and critical thinking skills in higher education students. These studies reported that PBL may be a more effective pedagogical practice at the tertiary level. According to Walker et al. (2015b), PBL leads to favourable outcomes when assessment is at the application level and when the intervention uses the full closed-loop PBL approach. Although the finding was based on a small sample size of closed-loop PBL studies conducted in medical education, Walker et al. concluded that similar learning outcomes would be expected based on the type of PBL implementation used in other disciplines.

Barrows (1986) suggested that a PBL method has the potential to address four educational objectives: (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).

The design and format of the problems is a major variable (represented by a circle in Figure 2). Another important variable is the degree to which learning is teacher-directed or student-centred (represented by a square). Barrows (1986) conceptualized 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" (1986, p. 481). The arrows represent the sequence in which problems are presented. The degree to which each of the four educational objectives (SCC, CRP, SDL, MOT) are addressed by the educational design is assessed by a score of 0-5. The scores indicate the comparative power of each method in relation to the particular objective.

Closed-loop PBL is one of six variations in Barrows' (1986) PBL taxonomy (Figure 2).

		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

●	Complete case or case vignette
◑	Partial problem simulation
○	Full problem simulation (free inquiry)
■	Teacher-directed learning
□	Student-centred learning
◪	Partially student & teacher directed

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

Lecture-based cases are teacher-directed where information is provided by the instructor, during a lecture, prior to case vignettes being presented to the students. Although some group work, hypothesising and diagnosis may still be required with this method, no inquiry or case-building skills are needed. Case-based lectures use essentially the same format as lecture-based cases, except students are provided with the case vignettes prior to the lecture and no self-directed learning takes place.

Next, the case approach provides students with an entire case to study and research. A class discussion follows which is directed by the students and facilitated by the teacher. It is at this stage along the continuum that a sense of student-directed learning is visible. In the modified case-based method, often used in medical schools, more of the students' reasoning skills are challenged but teacher prompting, and restricted inquiry prevent the full implementation of the reasoning process or self-directed learning.

Implementing the 'problem-based' variation of PBL, the teacher, as a facilitator, activates the students' prior knowledge. The facilitator then presents the students with an authentic problem which allows for free inquiry and teacher-guided exploration and evaluation of the problem.

The closed loop (reiterative) PBL approach is the most student-centred in Barrows' (1986) taxonomy using a free inquiry approach with full problem simulation, as occurs in the real world. This variation of PBL is an extension of the problem-based method with the important addition that once students complete their self-directed learning, they are asked to evaluate their research, processes and solution(s) to the problem. They 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 further addresses the students' clinical reasoning processes, their structuring of knowledge for use in clinical contexts, and their development of effective self-directed learning skills. 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). For example, medical students are presented with the symptoms of a sick person. The problem posed of the medical students is to achieve for that sick person a relatively healthy state, and many factors go into determining the best treatment for the patient. In order to solve this problem, the students must possess a fairly deep understanding of human physiology and disease states. The patient's history and genetics also need to be considered. After diagnosing the illness, the medical students must provide an effective treatment for the patient. Barrows states the closed-loop variation is best positioned to enhance the educational objectives for medical students such as acquiring the necessary skills to diagnose and heal effectively.

These objectives correspond with the educational objectives that pre-service teachers are required to achieve, to 'diagnose' student learning needs and enact their understanding to teach effectively. Pre-service teachers need to possess a deep understanding of mathematics content, curriculum, and assessment to determine the cognitive demands of a task for their students (Australian Professional Standards for Teachers, 2018). Next, the pre-service teachers need to analyse the students' mathematical solutions or arguments and identify any learning difficulties and misconceptions they exhibit as a result of engaging in the task. Lastly, the pre-service teachers should be able to enact their PCK to appropriately respond to student misconceptions and learning difficulties by creating learning opportunities and representations which are comprehensible to the students (Shulman, 1986; Tatto et al., 2008). Therefore, this study aimed to investigate the efficacy of the closed-loop PBL pedagogical approach (Barrows, 1986) with pre-service teachers. Based on the research problem that not all graduating pre-service teachers possess adequate PCK to teach effectively, two research questions guided the study:

1. How do pre-service teachers perceive PBL as a teaching approach for developing their mathematics PCK in comparison to their previous experiences with teacher-directed instruction?

2. How do pre-service teachers perceive PBL as a teaching approach for developing their ability to enact their PCK to teach mathematics in comparison to their previous experiences with teacher-directed instruction?

Method

Design

A case study approach was used to answer the research questions. The research used qualitative semi-structured interviews to explore pre-service teachers' lived experiences with PBL. The semi-structured interviews were conducted individually with 16 pre-service teachers to obtain their perspectives of how their mathematics PCK and importantly their ability to enact their PCK for teaching were affected by the PBL approach used during a semester-long mathematics education subject. The study was conducted in accordance with all required ethics protocols.

Participants and Setting

Participants were 16 pre-service teachers seeking a four-year Bachelor of Education degree, who were in their third year of their program at a regional Queensland university in Australia. This group represented 43% of the total number of students studying the subject. The 16 students were a convenience sample (Johnson & Christensen, 2019) who self-nominated for the research study. The Australian Curriculum strands and sub-strands of algebra, measurement, geometry, and probability and statistics provided the content for the subject. Table 1 summarizes the demographic information for the cohort.

# of Students		16
Gender:		
	Females	14/16
	Males	2/16
Age		
	Range	20-45 yrs.
	Mean	28 yrs.
	Median	24 yrs.
Prior Teaching Experience		
	< 10 days	1
	10 – 15 days	3
	16 – 25 days	2
	>26 days	9
Teacher Aide Experience		
		1

Table 1.
Demographic Data for the Cohort of Pre-service Teachers)

Data Collection

The qualitative data were collected post-PBL intervention by audio-taping the semi-structured interviews conducted with each student individually. The interviews (each approximately 15 minutes in duration) were conducted with the 16 pre-service teachers who volunteered during the last week of the semester. Fourteen were interviewed in person and two interviews were conducted by phone. Each interview was conducted one-to-one (student to researcher) in a confidential location. The interview process involved asking variants of six pre-constructed questions (Table 2) and then asking follow-up questions based on the students' response to probe more deeply into their attitudes and beliefs about their experiences with PBL.

Pre-constructed Interview Questions	
1.	Was the PBL method different than the teaching approach used in your other subjects? How was it different?
2.	Do you prefer the problem-based learning/teaching method which required you to work together to research and solve the task, to other learning/teaching methods? Why or why not?
3.	How did PBL affect your understanding of teaching mathematics?
4.	Do you feel the PBL teaching method has been effective in helping you develop your ability to teach mathematics effectively compared to having teacher-directed lectures and teacher-directed tutorials?
5.	Would you use the PBL method when you become a teacher? If so, why?
6.	Is there a way you would have rather been taught in this subject?

Table 2. Interview Questions Posed to the Treatment Group of Pre-service Teachers

Data Handling and Analysis

The context and rich descriptions captured during the semi-structured interviews were transcribed verbatim and stored, using NVivo (QSR International, 2017). To optimize the analysis and interpretation of the pre-service teachers' interviews, the Qualitative Analysis Guide of Leuven (QUAGOL) (Dierckx de Casterle et al., 2012) was used. The QUAGOL, inspired by the constant comparative method (Corbin & Strauss, 2008), is designed as a guide which facilitates a comprehensive process of analysis of qualitative interview data involving two phases (outlined in Table 3). The first phase encompasses a systematic preparation of the coding process. The second phase utilizes a qualitative software program to complete the systematic coding process. The QUAGOL guide provided objectivity to the qualitative analysis process by employing a systematic guide for comprehensively and accurately identifying themes, as well as the interviewees' experiences and inferred meanings.

Phase 1: Preparation of the Coding Process
Stage
1. Thorough (re)reading of the interviews (a holistic understanding of the respondent's experience).
2. Narrative interview report (a brief abstract of the key storylines of the interview).
3. From narrative interview report to conceptual interview scheme (concrete experiences replaced by concepts).
4. Fitting-test of the conceptual interview scheme (testing the appropriateness of schematic card in dialogue).
5. Constant comparison process (forward-backwards movement between-within case and across-case analysis).
Phase 2: Actual Coding Process
Stage
6. Draw up a list of concepts (a common list of concepts as preliminary codes).
7. Coding process – back to the 'ground' (linking all the relevant prose to the appropriate codes).

8. Analysis of concepts (descriptions of concepts, their meaning, dimension and characteristics).

9. Extraction of the essential structure (conceptual framework or storyline).

10. Description of the results (description of the essential findings).

Table 3. QUAGOL Method for Analysing, Interpreting and Summarising Qualitative Data (modified from Dierckx de Casterle et al., 2012, p. 364)

Design and Delivery of the Closed Loop PBL Intervention

Successful implementation of a PBL pedagogical approach relies on (1) students collaborating while investigating and finding fitting solutions to authentic, ill-structured problems, (2) the responsibilities of the students to be self-directed and self-regulated in their learning, and (3) the role of the lecturer as a facilitator of learning (Savery, 2015).

The mathematics education subject was 15 weeks in duration with weekly, 3-hour on-campus workshops with no lecture. The first three weeks of the semester were utilized to scaffold the pre-service teachers' collaborative skills for working productively in groups and with PBL-style problems. Additionally, the participants were instructed independently of the researchers. By not taking the teaching role, the researchers were hoping to demonstrate that the PBL intervention could be successfully implemented by other lecturers. The recruited lecturer, who typically uses a constructivist approach to teaching, was provided with relevant literature on the closed-loop PBL framework and professional development on the practice of facilitating a PBL classroom, the method of preparing groups to work collaboratively in a PBL environment, the art of asking meta-cognitive guiding and clarifying questions, and facilitating discussions (Leary et al., 2013).

Week 1 was used to introduce the subject and its assessments, and to accommodate a revisit of concepts and skills related to place value covered in a previous subject. The strategy to utilize Week 1 in this manner was to begin preparing the pre-service teachers to work and learn in a PBL environment, using content that should be relatively familiar to them. The learning objective for Weeks 2 and 3 was for the pre-service teachers to be able to progress school-aged students understanding of simple geometrical and numerical patterns towards being able to represent the patterns as a general algebraic rule. The strategy to utilize Weeks 2 and 3 in this manner was to scaffold the students' learning of the week's content, while further developing the pre-service teachers' abilities to collaborate and solve moderately ill-structured problems in a student-directed environment. For example, in small working groups the students were asked to analyse a series of similar, but proportionately larger triangles made from toothpicks. As the triangles proportionately grow in size, a pattern emerges as to the number of toothpicks needed to form each triangle. The students were required to determine the pattern and represent that pattern in words and symbols and then as an algebraic formula.

The teaching sequence generally involved using increasing levels of problem complexity and degrees of self-directedness. Furthermore, the decision-making problems needed to achieve both the learning objectives of the mathematics education subject and be positioned so the pre-service teachers' development of the targeted mathematics PCK was facilitated. Consequently, if the problems were not written with clear, specific goals, the pre-service teachers may not have engaged with the correct research or reasoning processes, thus deviating from their intended learning outcomes (Hung, 2011). Hence, the set of criteria directing the pre-service teachers' decision-making was based on ensuring the development of the pre-service teachers' mathematics PCK and the ability to enact their PCK.

The structure used in Weeks 2 and 3 was duplicated four times during the semester. An illustration of the semester's weekly schedule is provided in Figure 3. Weeks 6, 7 and 12-15 were class-free weeks in the semester timetable.

To demonstrate the implementation of the closed-loop PBL approach used with the cohort, the 3-hour workshops from Weeks 4 and 5 will now be detailed.

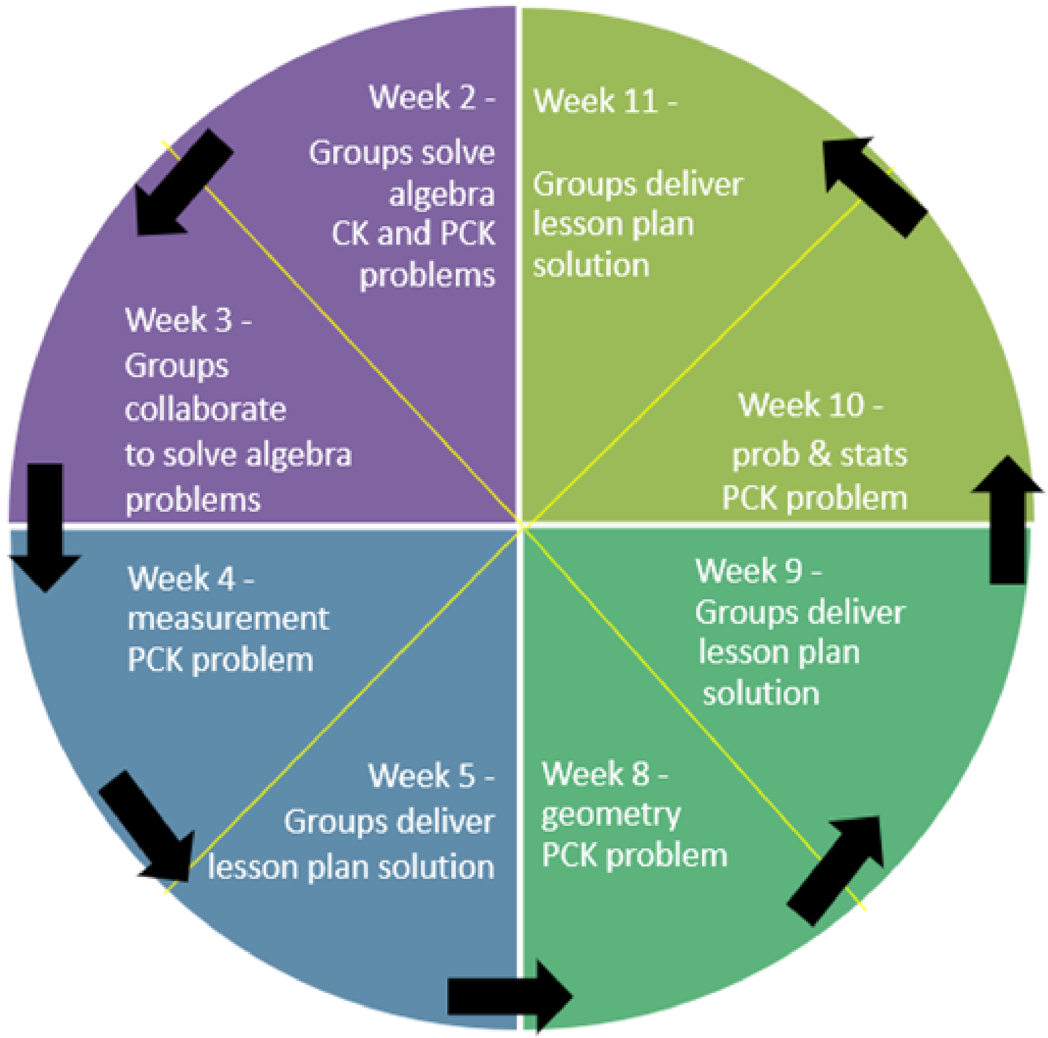

Figure 3. Outline of Semester's Weekly Schedule for the Cohort

The Step-by-step Closed-loop Process

In Week 4, the cohort presented themselves to a classroom for their 3-hour workshop. The room chairs were prearranged into four groups of four students, with each group formed homogenously based on an inventory taken of the teaching levels they prefer to teach when they graduate. This strategy provided more authenticity when the lecturer informed them that they would create a lesson plan in response to one of four scenarios (ill-structured problems) to demonstrate their ability to address difficulties children experience with specific measurement concepts and skills. All four ill-structured problems were based on a particular Australian Curriculum Assessment and Reporting Authority (ACARA) (2018) measurement concept and skill. Figure 4 illustrates one of the four measurement problems presented to the cohort.

The groups were then given the time remaining in their 3-hour workshop to analyse their problem, conduct any necessary research, examine resources, and design their solutions in the form of a lesson plan. Thus, the majority of the workshop was predominantly student-directed, and it was the group's decision how to best utilize the time remaining. If they chose to engage outside the workshop, the following seven days outside of class were also at their disposal. They did not receive a lecture, but they were able to view a recorded

The aim of this activity is for you to demonstrate your ability to design a lesson which has young students *exploring the concept and skills* for measuring **mass.**

Scenario: You are attending your 15-day practicum and your mentor teacher is asking you to design a lesson on the topic of **mass** for her Year 4 class. She informs you the students' prior knowledge in this area is quite limited. She then provides you with the following guidelines:
Since the students' conceptual understanding is limited, you should revisit the related content from the Year 2 and Year 3 ACARA content descriptors.

The design of your lesson should, therefore, provide the students with the opportunity to:

- revisit their Year 2 and Year 3 prior knowledge;
- be **appropriately introduced** through real-world, concrete activities to the concepts related to the measurement of **mass** appropriate for their year level;
- apply, in a social constructivist learning context, the Year 4 measurement skills; and
- demonstrate and explain their understanding to their peers using their own language.

Figure 4. Example of One of the Four Measurement Problems Posed to the Cohort

lecture to source the weekly curriculum and pedagogy content. They were also free to complement their lesson using a PowerPoint presentation if they chose. Relevant concrete materials were available to the groups with no explanation of their function. Other resources made available during the workshop were (a) iPads with internet access, (b) a variety of textbooks aimed at teaching elementary school mathematics, (c) the PBL facilitator as a coach/mentor, and (d) blank lesson plan templates (hard copy and electronic versions) to populate their lesson plan design. Alternatively, they were free to design their own template.

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. These questions were intended to help guide the thinking of the students. Thus, meta-cognitive guiding and clarifying questioning was used, in which the lecturer was neither the author nor transmitter of knowledge, but an assistant to the learner's search for solutions to the problems. This meta-cognitive 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 particular mathematics topics. At the outset, the students were frustrated because their questions were being answered with more questions by the facilitator, even if it was 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 learn. This iterative approach was undertaken so the students would become more confident in identifying the specific information they needed to discover to effectively solve the original problem.

In Week 5, each group's written solutions, presented on a completed lesson plan template, were submitted. During the 3-hour workshop the groups took turns enacting their solutions in the form of a 'lesson' with their peers in a simulated classroom context using their choice of materials and teaching strategies and providing a rationale for the pedagogical approach they chose to underpin their lesson. After delivering their lesson, informal feedback was provided to the group members by their peers and the lecturer, and the group delivering the lesson was also allocated time for self-assessment. To complete the closed-loop PBL process, the pre-service teachers individually responded to a set of reflection questions. These questions requested they revisit the original problem and reflect on the effectiveness of their process in solving the problem, both individually and as a group. They responded to questions such as, "If you were to revisit the original problem, what improvements would you make to your reasoning process?"

Results

The qualitative data were sourced from each pre-service teacher's post-intervention interview responses probing their lived experiences with the PBL intervention. The responses were categorized during the QUAGOL process, and four themes were extracted from the data: (a) effect of PBL on learning, (b) ability to teach more effectively, (c) reasons for using PBL, and (d) dissatisfaction with teacher-directed instruction. From the themes representative statements were extracted. These representative statements are grouped and presented based on how the researchers interpreted the messages in the pre-service teachers' stories in relation to the themes, and subsequently, research question #1 and #2. Each idea will be briefly discussed, and illustrative quotations provided.

Regarding research question #1, many students commented on how PBL affected their understanding of teaching mathematics (levels of PCK). These comments were categorized during the QUAGOL process under three of the four themes (a) effect of PBL on learning, (b) ability to teach more effectively, and (c) reasons for using PBL. Representative statements for each of these three themes included:

> *(a) It [PBL] made me be more engaged in the learning because I was excited to go and teach and make the lesson. We got to actually be a teacher and take the class and teach a lesson. So, it was more real life.*

> *(b) I feel much more capable of teaching maths lessons than I would have before.*

> *(a & b) It [PBL] gave me headaches (laugh). I had to really, really think. Because it enabled you to work together to solve a problem. So, I had to be alert all the time. It gave me new ideas on how to teach, so new perspectives. So, I have a bigger repertoire.*

> *(c) 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.*

> *(c) You got an insight or an aspect of seeing the way other people would teach. So, you've got your own thoughts what you would do and then you see how they would teach it.*

Regarding research question #2, when asked if they felt PBL had been more effective than traditional instruction for developing their ability to enact effective mathematics teaching, 15 of 16 students responded in the affirmative. Specifically, 11 answered “Yes,” three answered “Definitely,” and one responded with “I think it was”. The remaining student did not answer directly; rather, the student responded in a manner which represented an explanation:

> *Teacher-led tutorials and teacher-led lectures bore me. I cannot sit there and listen. I work really fast and if something isn’t coming at me fast enough, I just lose it and I cannot focus. I need to be paced. Problem-based learning does help me to develop providing that I can access the concept at the pace that I’d like to otherwise I just get very, very frustrated.*

When asked to elaborate on why they felt PBL had been more effective than teacher-directed instruction for developing their ability to teach mathematics effectively, students’ responses were categorized during the QUAGOL process under the themes (a) effect of PBL on learning, (b) ability to teach more effectively, and (c) dissatisfaction with traditional instruction. Participants indicated the following reasons for why they thought PBL was more effective than traditional instruction for developing their ability to teach mathematics effectively:

- PBL provides teaching experience.
- PBL requires higher cognitive demand.
- PBL provides immediate feedback on learning.

Representative statements for the identified themes above included

> *(a) Problem-based learning is just so much more…. You are actually doing it.*
>
> *(a & c) Because you’re more hands-on with the materials and the topics and not just sitting there getting taught how to teach.*
>
> *(a) I learn a lot better that way. I recall a lot more information.*
>
> *(a & b) It [PBL] solidifies the approach that I was going to use to teach maths.*
>
> *(b) I actually have just finished my prac and the first subject that I had to teach was Year 7 algebra. Learning in a problem-based learning environment… I think it really improved the way I was able to teach that lesson.*
>
> *(b) 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.*
>
> *(a & b) 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 teacher-directed instruction, in terms of developing their mathematics PCK is further demonstrated by the following representative responses:

> *It [teacher-directed instruction] doesn’t help my learning. It doesn’t make me think about what I should be learning to get the answers. I only like teacher assistance if I am on the wrong track and I was getting the wrong answers, so they could facilitate my understanding.*
>
> *It [teacher-directed instruction] was all about recall and trying to remember things…. I need to know how to put things into practice.*
>
> *With lecturing, I listen but it doesn’t make sense to me. I’ll forget it as soon as I walk out. … I need to actually do it. Otherwise, it won’t make sense to me. So definitely the PBL method definitely did work.*
>
> *Most teachers in lectures and tutorials, we just get given the information and taught how to do it. But we never actually get to figure it out for ourselves and implement it. Because that’s so important to learn.*
>
> *I can’t sit still and have someone tell me everything and expect me to just remember it. I’ll tell you what you need to know to pass, and you try and remember it as best you can. You’re not actually developing in concrete that knowledge.*
>
> *It’s pretty much authoritarian style of teaching. And for me that’s not the best way to learn.*

When you sit there and listen to someone for a few hours you start to tune out, and your mind starts to wander onto other things. Whereas when you are actively engaged in what you are learning, you take a lot more in. You do listen because you need to participate, so you learn a lot more rather than just sitting there listening.

Discussion and Conclusions

Several of the interview questions required the pre-service teachers to compare their views on PBL to their experiences with the teacher-directed approach used in their other subjects. The pre-service teachers almost unanimously agreed that learning using the PBL approach made them more engaged than teacher-directed instruction and that it positively affected their learning and their ability to enact what they had learned about teaching mathematics. None of the students indicated any distress or level of unease using the PBL approach other than one student who stated he "disliked working in groups". None commented negatively on the level of scaffolding they received, and this is attributed to the three weeks that were used initially to familiarize them with the PBL approach that was going to be employed throughout the semester. The interview question asking students about their perception of the PBL approach in relation to how they prefer to learn revealed a nearly unanimous response. Only one student indicated that he was not in favour of the PBL approach because he "disliked working in groups". The rest of the students indicated they thought PBL "was really effective" compared to other subjects where they only "talk about teaching but don't practice it". They found PBL "very beneficial", and they indicated that they preferred "to learn that way". One student stated that she "liked being given the problems and going to find the answers". The conclusion drawn from this small case study was that PBL, even when used in only one semester, can positively impact pre-service teachers' perceptions of their ability to enact their mathematics PCK. In addition, their positivity towards the PBL pedagogical approach, as demonstrated in their interview responses, bodes well for their continuing development of mathematics PCK. In fact, when asked if they would use the PBL method when they become a teacher, nearly all stated they would, with one student clarifying, "yes, but not all the time," and another stating, "I am hoping to. That is certainly my goal to teach in that way." Their reasons why they would use PBL identified its benefits for student learning and included the following statements:

I did benefit from problem-based learning, and I think that children having those experiences in the classroom would benefit from that.

I can see the benefits and I can see that the students are more engaged as well when you are using that method. I was more engaged certainly just by being actively involved and not just sitting there listening. When you are actively engaged in what you are learning, you take a lot more in. You do listen because you need to participate, so you learn a lot more.

This study set out to investigate the effect of a closed-loop PBL method (Barrows, 1986), in comparison to teacher-directed instruction, on pre-service teachers' perceptions for developing their PCK and ability to enact their PCK in a tertiary mathematics education subject. The study is considered an initial attempt to provide clarity surrounding the impact of closed-loop PBL, the most student-centred in Barrows' (1986) taxonomy, on pre-service teachers' perceptions of the PBL method for developing mathematics PCK. The closed-loop PBL pedagogy was shown as being preferable to pre-service teachers when compared to a teacher-directed approach for developing their mathematics PCK. Therefore, it is proposed that closed-loop PBL is a pedagogy, informed by research, which would allow pre-service teachers during their coursework to routinely integrate theory and knowledge of classroom practice before graduation.

The literature on PBL is voluminous. Nevertheless, further investigations on PBL are still needed, specifically in relation to pre-service teachers' and mathematics PCK. Associated with this study's research problem, that not all graduating pre-service teachers possess adequate PCK to teach effectively, PBL's positive impact on their mathematics PCK is still inconclusive in the literature because many researchers did not identify which variation, or degrees of structure of PBL or the type and difficulty of the problems they used in their studies (Barrows, 1994; Walker et al., 2015b). Therefore, it is proposed that researchers conducting studies on PBL should, in the first instance, provide the extent of the PBL method employed as well as a clear description of protocols (Albanese & Dast, 2014; Goodnough & Nolan, 2008; Newman, 2003).

While the need for further research is acknowledged, the researchers believe the main aim of the study was achieved, which was to reveal pre-service teachers' attitudes and beliefs about the effectiveness of closed-loop PBL in a tertiary mathematics teacher education subject. The results from this case study suggest that closed-loop PBL may be a pedagogical approach of interest to pre-service teacher educators in that it can serve as a vehicle for teachers to consider and reflect on their own PCK as they plan and design teaching approaches to match their students' needs in specific education contexts. Fundamentally, adopting closed-loop PBL encourages teachers to examine and reflect on their own content knowledge, concepts, teaching strategies, and ideas associated with a particular learning area and how the subject matter knowledge should be taught which most effectively makes the content comprehensible to students. Thus, educators can utilize closed-loop PBL to enhance their pre-service teachers' content and pedagogical knowledge through solving authentic problems they are likely to face as teachers, which aims to inform and influence the development of their PCK.

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