Measuring problem-based learning's impact on pre-service teachers' mathematics pedagogical content knowledge

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Abstract: *Current educational reforms and initiatives are addressing numeracy outcomes for school-age students as a response to concerns regarding their mathematical achievements. In Australia, the Ministerial Council on Education stated, numeracy remains one of the cornerstones of schooling for young Australians (2008). Ultimately, the responsibility for attending to these educational priorities is placed with teachers. Existing literature suggests that student achievement is directly impacted by 'effective teaching' and that effective teaching begins with effective teacher preparation.*

To address these issues, this pilot study investigated the impact of problem-based (PBL) learning, in a tertiary mathematics education course, on pre-service teachers' mathematics pedagogical content knowledge (PCK) and forms the basis for a larger, subsequent study.

To measure pre-service teachers' mathematics PCK, a Mathematics Pedagogical Content Knowledge Instrument was developed. The instrument was delivered pre-semester and post-semester to a control group (n=15) who received traditional, 'lecture-based' instruction, and a treatment group (n=15) who were instructed using the problem-based learning approach. The data were analysed using a paired samples t-test to compare the pre-semester and post-semester means from both cohorts. The findings indicate the treatment group made larger gains in their PCK when compared to the gains in PCK development of the control group. In teaching terms, the findings suggest an intervention such as problem-based learning may enhance the development of pre-service teachers' PCK when compared to using a traditional teaching approach.

Key words: *problem-based learning; pedagogical content knowledge; pre-service teachers; mathematics education*

Introduction

This pilot study targets pre-service teachers' mathematics PCK. The context of the study takes place in a mathematics curriculum and pedagogy course, aimed at third-year pre-service teachers (PSTs), which is based on the Australian curriculum syllabus strands, Algebra, Measurement, Geometry and Probability & Statistics. The study's conception arose from the long-term concern regarding the inadequacy of pre-service teacher's (PST's) mathematical and pedagogical ability as they enter the workforce (Ball & Wilson, 1990; Council of Australian Governments, 2008; Goulding, Rowland, & Barber, 2002; Ma, 1999; Ministerial Council on Education, 2008; U.S. Department of Education, 2002). These concerns further suggest university faculties of education reevaluate the methods used to deliver their mathematics methods courses and professional development coursework while focusing on the mathematics used in classrooms and in curriculum documents (Ball, Hill, & Bass, 2005).

Pedagogical content knowledge

Pedagogical content knowledge (PCK) is the combination of content knowledge and pedagogical knowledge "that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). Content knowledge refers to the amount and organisation of the concepts, skills and strategies related to the content being taught. A teacher's pedagogical knowledge serves as a framework for the teacher to represent and formulate the content knowledge in a manner that makes it comprehensible to the learners (Shulman, 1986). Generally, pedagogical content knowledge (PCK) represents the incorporation of both content knowledge and pedagogical knowledge that provide teachers with the professional tools to transform their skills and understanding into pedagogical (re)presentations and actions. In terms of PCK Shulman (1986) stresses that teachers should understand the preconceptions and misconceptions that students of different ages and backgrounds bring with them to the learning; and as a result, possess knowledge of strategies most likely to be successful in reorganising the understanding of those students. Therefore, it could be concluded that an 'effective teacher' requires sound pedagogical content knowledge.

The importance of effective teaching and teaching strategies

"One mark of an effective teacher is the ability to use an array of research-based instructional strategies" (Miller, 2003, p. 3). In her brief, Miller's main finding "reveals a 39 percentage-point difference in student achievement between students with 'most effective' teachers and 'least effective' teachers" (2003, p. 2). It is suggested by Miller that by integrating researched-based pedagogical strategies, teachers would be better equipped to bring concepts and understanding to the forefront of student learning.

The Marzano Research Laboratory Investigated pedagogical strategies over a five-year period and employed a meta-analysis involving 300+ volunteer teachers from 38 schools in 14 school districts in the United States (Haystead & Marzano, 2009). Their findings revealed that, on average, when particular instructional strategies are used, there was a 16% learning gain between students' pretest and post test scores. Four of the instructional strategies investigated, complex-cognitive tasks, cooperative learning, feedback and setting goals/objectives, align with the principles and characteristics of a social constructivist, problem-based learning (PBL) approach.

Characteristics of problem-based learning

The first PBL curriculum, pioneered at McMaster University in the 1960s, originated in the medical field in an effort to prepare doctors who could think critically and solve complex medical problems (Barrows, 1986, 1994). PBL's impact on medical students' learning is highly regarded as "significantly more effective than traditional instruction to train competent and skilled practitioners and to promote long-term retention of knowledge and skills acquired during the learning experience or training session" (Strobel & van Barneveld, 2009, p. 55). Due to the success of PBL's impact in preparing new doctors, this teaching approach has become regarded as a pedagogy which offers a great deal in the larger contexts of other professional practices (McPhee, 2002; Strobel & van Barneveld, 2009). Consequently, PBL has been broadly adopted by institutions using variations or degrees of PBL structure, based on the needs of their various disciplines, that "the meaning of the term problem-based learning has become clouded and confused" (Barrows, 1994, p. vi). As a result, this study referenced Howard Barrows' (1986) taxonomy of problem-based learning which allows for the understanding and appreciation of the different variations of PBL. Figure 1 illustrates his taxonomy along a continuum (Barrows, 1986).

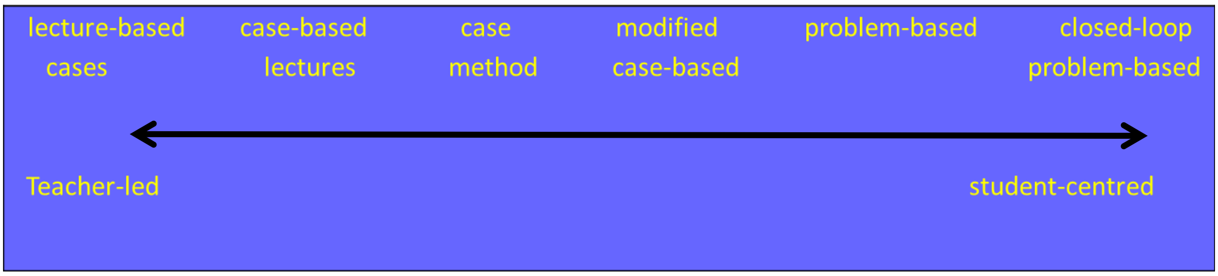

Figure 1: Taxonomy of problem-based learning (Barrows, 1986)

As shown at one end of the continuum, lecture-based cases are teacher directed and information is provided by the instructor prior to the cases being presented to the students. Next, case-based lectures are essentially the same as lecture-based cases except that students are provided with the case vignettes prior to the lecture. Further on the continuum is the case method approach where students are provided 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 on the continuum that a sense of student-directed learning occurs. In the modified case-based method, often used in medical skills, more of the reasoning skills are challenged but cueing and restricted inquiry prevent the full implementation of the reasoning process or for 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 that allows for free inquiry and teacher-guided exploration and evaluation of the problem. At the furthest end of the continuum is the closed loop problem-based approach. This variation of 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) to the problem. They are then asked to return to the original problem to reflect on how they might have improved their reasoning processes on the basis of what they learned during their self-directed learning (Barrows, 1986; Walker & Leary, 2009).

This study, grounded within a social constructivist framework, investigated Howard Barrows' (1986) closed loop variation of PBL and its impact on pre-service teachers' mathematics PCK.

Research method

The participants of the study were students in a four year Bachelor of Education degree, in their third year of the program, on two different campuses of a Regional Queensland, Australian university. The pilot was conducted for fifteen weeks with 30 pre-service teachers who were divided into two cohorts, one from each of the two campuses of the university, forming a control group and an experimental group. Hence, the control group participants were enrolled on one campus and the intervention group on another campus. The learning objectives for both groups were designed to develop PSTs' pedagogical content knowledge of algebra, measurement, geometry and probability & statistics for use in teaching school aged children Prep to Year 7.

The participants of the control group (n=15) were taught by an instructor who used a 'lecture-based cases' PBL approach where the lecture was teacher-led. The tutorial, although organized in groups, was also teacher-led where the instructor was the provider of the majority of course material prior to the cases being presented to the groups. Conversely, the experimental group participants (n=15) were facilitated by the researcher in a workshop environment using Barrows' closed loop PBL approach. In this variation of PBL the cases are presented to the students at the onset of the workshop. Through peer collaboration and research, acquiring the appropriate knowledge to solve the problem becomes self-directed and the intended learning outcomes self-discovered. For comparison purposes the control group and PBL group were presented with the same tutorial tasks throughout the semester.

Following both groups' completion of the pre-semester questionnaire, providing base-line data of their developed PCK, implementation of the closed loop variation of PBL on the experimental group commenced. First, the PSTs in groups of three or four and the teacher acting as a facilitator, were introduced to, and initially analysed, an ill-structured problem relevant to their future profession. More generally, ill-structured problems are complex problems that do not necessarily have a single correct answer but require learners to consider alternative solutions (Hmelo-Silver & Barrows, 2006). The main tutorial task, specifically designed to develop pre-service teachers' PCK, was to collaboratively diagnose children's difficulties with specific maths concepts and skills. Once the task had been clarified, the PBL tutor engaged and guided the PSTs' prior knowledge using key questions while acting as an assistant to their search for evidence and to the application of their reasoned arguments. Next, they researched independently, and/or as a group, any information required to solve the task. This phase of the closed loop PBL process allowed for the participants to discuss and re-analyse the problem. The end product of this tutorial task, due in the following week's PBL session, was to design and present a teaching activity, supported by their research, which theoretically and pedagogically they expected would remediate the children's difficulties. This fortnightly process cycled through each of the four mathematics topics covered in the course namely algebra, measurement, geometry and probability & statistics.

Also as part of the task, each participant was asked to self-evaluate their research processes and solution(s). Additionally, they were asked to self-reflect on the original problem and how they might have improved their reasoning processes on the basis of what they learned during their self-directed learning.

The control group participants, throughout the same time frame, attended a whole-group one-hour lecture. Following the lecture, they collaboratively engaged in the same tutorial tasks as the experimental group, but in a structured teacher-led tutorial environment. The difference occurs in the considerable amount of support the control group participants received and, the extensive amount of specific course material the lecturer provided to them prior to and during their group work.

During the last class of the semester, both the control and treatment group were again requested to complete the questionnaire. These pre and post semester collection points are important components of the data collection scheme because they allow for the appropriate quantitative comparisons of the two groups' level of mathematics PCK before and after the experiment.

The Mathematics Pedagogical Content Knowledge Instrument (MPCKI)

In order to measure PCK and its development in PSTs, indicators of PCK have been investigated. Thus, the conceptual framework of this study's PCK questionnaire draws upon Shulman's previously discussed (1986, 1987) seminal work of teacher knowledge bases, the defined and described components of PCK offered by Magnusson et al. (1999) in their *model of relationships between the components of PCK*, and Weizman et al. (2008) study of PBL's impact on science teachers' PCK.

In terms of measuring the construct, Shulman's conceptualization of pedagogical content knowledge was unique at the time because instead of viewing PCK as either content knowledge or pedagogical knowledge, he associated pedagogy, the art of teaching, with subject area knowledge. Weizman et al. support Shulman's concept of strategic PCK stating it as a "deep, well-organised knowledge about pedagogy and content" and the ability to effectively make use of that content knowledge and pedagogical knowledge in classroom situations (2008, p. 34). The *model of relationships between the components of PCK* offered by Magnusson et al. (1999), and applied by Weizman et al. to measure PCK for science teachers while working in a PBL environment, outlined five components of PCK for teaching: (1) orientations toward teaching, (2) knowledge of the curricula, (3) knowledge of students' understanding (4) knowledge of instructional strategies, and (5) knowledge of assessment (Weizman et al., 2008).

The development of the Mathematics Pedagogical Content Knowledge Instrument (MPCKI) used contributions from three existing instruments (Callingham et al., 2011; International Association for the Evaluation of Educational Achievement. (IEA). 2011; Kwong et al., 2007), is designed to measure PSTs' mathematics PCK.

The item questions in the MPCKI are grounded in scenarios of classroom teaching with particular maths topics. Examples of item questions are shown in Table 1.

Table 1: Examples of items used in the pilot study.

In the number sentence, 17 - 9 = [ ] + 1, one of your students places an 8 in the empty box. For each teacher intervention provided in the table below, indicate to the right which intervention you *would not use*, *might use*, *or definitely would use* to help the student understand this relationship.			
	Would NOT use	**Might use**	**Definitely would use**
Discuss with the student the purpose of the equal sign and about relationships between the left side and the right side of an equation.	[ ]	[ ]	[ ]
Remind the student that what you do to one side of the equation you must do to the other side.	[ ]	[ ]	[ ]
Ask the student to solve a similar, yet less difficult problem such as 6 - 4 = [ ] + 1	[ ]	[ ]	[ ]
Provide the student with a balance scale and blocks to create a representation of the equation.	[ ]	[ ]	[ ]
Advise the student to consider the commutative property of addition.	[ ]	[ ]	[ ]

Data analysis procedures for the MPCKI

Initially, the 58 mathematical pedagogical content knowledge items of the MPCKI were trialed with 240 students and then analysed using the Rasch model. The procedure examined the 'fit' statistics for each item.

A Rasch analysis provides indicators of how well each item fits the underlying construct (Bond & Fox, 2007). Unreliable items do not fit the construct in terms of distance from the mean.

Therefore, the purpose of the analysis was to test the assumption that the items of the MPCKI expressed the same construct, in this case, PCK. In these terms, the standardised information weighted mean square statistic for both Infit and Outfit fell in the .05-1.5 range for all 58 items, that is, these items appeared to be productive (reliable) measures of the theorized construct.

Based on the above, each PCK item shown in Table 1, for example, was scored as 1 for an answer which represented a 'correct' response or as 0 for an answer which might be rational, but not as suitable as the 'correct' choice. Once coded, the data were analysed using a paired sample *t*-test to compare the mean rank between the two groups at the pretest and post test to determine the degree of change in students' level of PCK over the duration of the study.

Results

As Table 2 and Figure 2 indicate, the control group's mean difference for PCK (post-semester minus pre-semester) was .441 – .435. Hence, the control group's PCK mean increased by 0.006 as measured by the MPCKI. The PBL group's mean difference for PCK (post-semester minus pre-semester) was .458 – .417. Hence, the treatment group's PCK mean increased by 0.041 as measured by the MPCKI. Although the difference in the mean scores were greater for the treatment group, the results of the paired sample *t*-test indicated a non-significant difference in both groups between the mean ranks of students' level of PCK at the pretest and the same students' level of PCK at the post test.

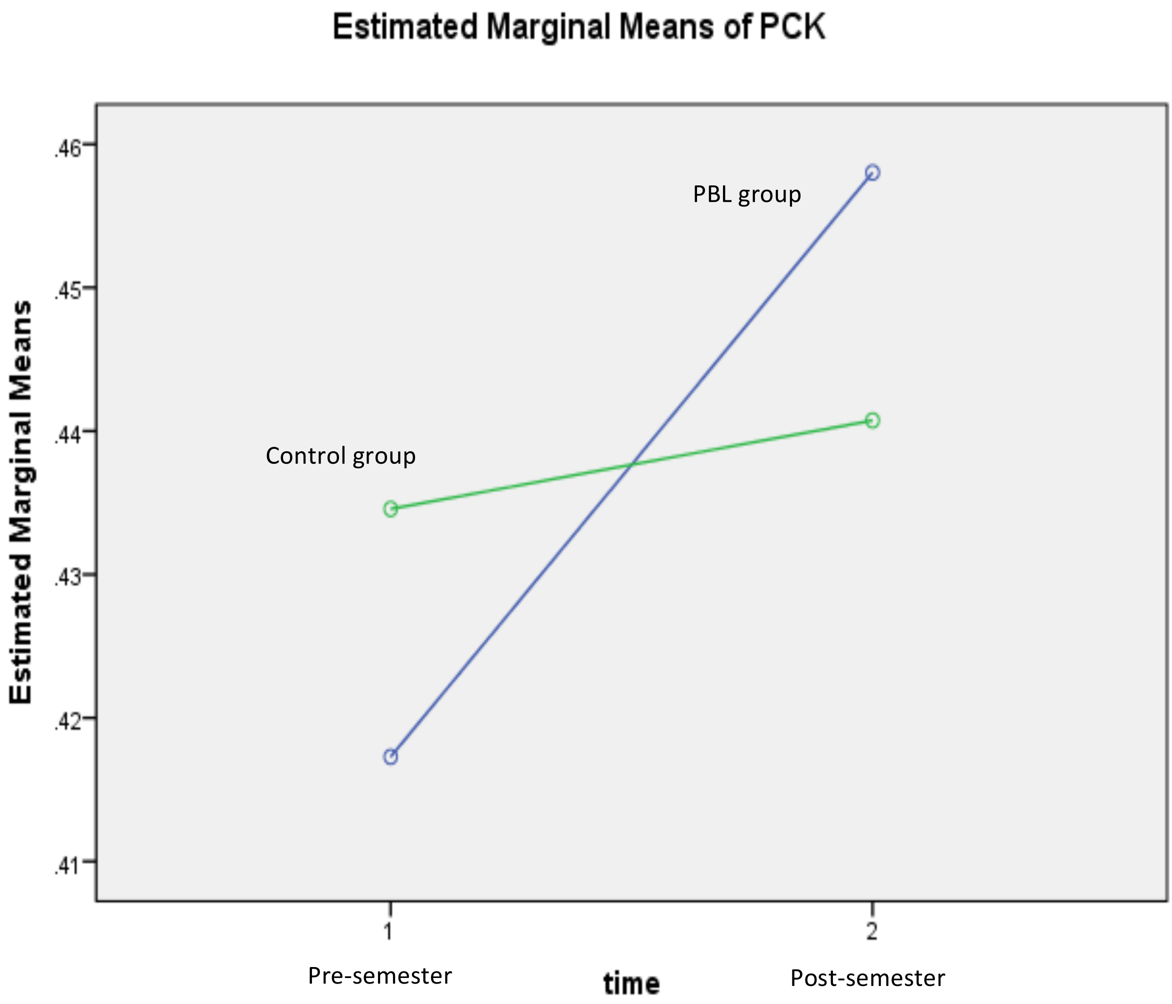

Figure 2: Change in PCK

Table 2: Estimated Marginal means of PCK

Measure	sub-group	time	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
PCK	PBL	1	.417	.020	.376	.458
		2	.458	.021	.416	.500
	Control	1	.435	.020	.394	.476
		2	.441	.021	.398	.483

Outcomes and significance

Although not statistically significant, the results are promising indicators that applying the PBL instructional method with PSTs, in a mathematics education course, an effective process was set in motion which appeared to increase mathematics PCK.

A limitation of this pilot study is the small sample size, which means that outcomes cannot be inferred as reliably would be the case with a large sample.

The evidence and outcomes of this pilot forms the basis for the larger, subsequent study and seeks to contribute to the limited body of evidence as to whether closed loop PBL may or may not assist PSTs to develop mathematics PCK. As the problem-based learning model dictates, Shulman suggests a research-based conception of teaching where “principled skills and well-studied cases are brought together in the development and formation of strategic pedagogical knowledge” (1986, p. 12). Support of this argument is also provided in previous studies of the use of problem-based and case-based methods (Hmelo-Silver, 2004).

In closing, if teacher knowledge and teaching methods are important elements of teacher effectiveness (National Commission on Teaching and America’s Future, 2010; Office for Standards in Education, 2005); and, if effective teaching begins with effective teacher preparation, then university teacher preparation programs should focus their efforts on ensuring pre-service teachers graduate possessing strong pedagogical content knowledge.

References

Ball, D., Hill, H., & Bass, H. (2005). Knowing mathematics for teaching: Who knows mathematics well enough to teach third grade, and how can we decide? *American Educator, 29*(3). http://www.aft.org/pdfs/americaneducator/fall2005/BallF05.pdf

Ball, D., & Wilson, S. (1990). *Knowing the subject and learning to teach it: Examining assumptions about becoming a mathematics teacher*. Paper presented at the annual meeting of the American Educational Research Association, Boston. http://ncrtl.msu.edu/http/rreports/html/pdf/rr907.pdf

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical education, 20*(6), 481-486. doi: 10.1111/j.1365-2923.1986.tb01386.x

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, Illinoise: Southern Illinoise University School of Medicine.

Bond, T. G., & Fox, C. M. (2007). *Applying the rasch model: Fundamental measurement in the human sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Callingham, R., Beswick, K., Chick, J., Goos, M., Kissane, B., Serow, P., . . . Tobias, S. (2011). *Beginning teachers' mathematical knowledge: What is needed?* Paper presented at the AAMT - MERGA Conference 2011, Alice Springs, N.T.

Council of Australian Governments. (2008). National numeracy review report. Commonwealth of Australia, Barton, ACT.

Goulding, M., Rowland, T., & Barber, P. (2002). Does it matter? Primary teacher trainees' subject knowledge in mathematics. *British Educational Research Journal, 28*(5), 689 - 704. http://lq6tx6lb4h.scholar.serialssolutions.com/?sid=google&auinit=M&aulast=Goulding&atitle=Does+it+matter%3F+Primary+teacher+trainees%27+subject+knowledge+in+mathematics&id=doi:10.1080/0141192022000015543a&title=British+educational+research+journal&volume=28&issue=5&date=2002&spage=689&issn=0141-1926

Haystead, M., & Marzano, R. (2009). Meta-analytic synthesis of studies conducted at Marzano research laboratory on instructional strategies. Retrieved 13 November 2010, from http://files.solution-tree.com/MRL/documents/Instructional_Strategies_Report_9_2_09.pdf

Hmelo-Silver, C. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266.

Hmelo-Silver, C., & Barrows, H. (2006). Goals and strategies of a problem-based learning facilitator. *The Interdisciplinary Journal of Problem-based Learning, 1*(1), 21-39. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1004&context=ijpbl

International Association for the Evaluation of Educational Achievement. (IEA)., Australian Council for Educational Research, (ACER). (2011). Teacher Education Study in Mathematics (TEDS-M): Released Items. East Lansing: Teacher Education International Study Center: College of Education, Michigan State University.

Kwong, C. W., Joseph, Y. K., Eric, C. C., Khoh, L. S., Gek, C. K., & Eng, N. L. (2007). Development of mathematics pedagogical content knowledge in student teachers. *The Mathematics Educator, 10*(2), 27-54.

Ma, L. (1999). *Knowing and teaching elementary mathematics: Teachers' understanding of fundamental mathematics in China and the United States*. Mahwah, NJ: Lawrence Erlbaum Associates

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examing pedagogical content knowledge: The construct and its implications for science education*. New York: Kluwer Academic Publishers.

McPhee, A. (2002). Problem-based learning in initial teacher education: Taking the agenda forward. *Journal of Educational Enquiry, 3*(1). http://www.ojs.unisa.edu.au/index.php/EDEQ/article/viewFile/550/420

Miller, K. (2003). School, teacher, and leadership impacts on student achievement. Retrieved December 20, 2010, from http://www.mcrel.org/topics/TeacherPreparation/products/149/

Ministerial Council on Education, E. C., Development and Youth Affairs, (MCEECDYA). (2008). Melbourne declaration on educational goals for young Australians. Retrieved December 28, 2011, from http://www.mceecdya.edu.au/verve/_resources/National_Declaration_on_the_Educational_Goals_for_Young_Australians.pdf

National Commission on Teaching and America's Future. (2010). Who will teach? Experience matters. Washington DC.

Office for Standards in Education. (2005). The national literacy and numeracy strategies and the primary cuuriculum. London.

Ryan, J., & McCrae, B. (2006). Assessing pre-service teacher's mathematics subject knowledge. *Mathematical Teacher Education and Development, 7*, 72-89. http://www.merga.net.au/documents/MTED_7_Ryan.pdf

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. http://coe.utep.edu/ted/images/academic_programs/graduate/pdfs/matharticles/Knowledge%20Growth%20in%20Teaching%20Shulman.pdf

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22. http://her.hepg.org/content/j463w79r56455411/fulltext.pdf

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to convenional classrooms. *The Interdisciplinary Journal of Problem-based Learning, 3*(1), 44-58. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1046&context=ijpbl

U.S. Department of Education. (2002). *No Child Left Behind (NCLB) Act* (PL 107-110; Part B - Sec. 2201). United States: Retrieved from http://www2.ed.gov/policy/elsec/leg/esea02/index.html.

Walker, A., & Leary, H. (2009). A problem-based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary journal of problem-based learning, 3*(1), Article 3.

Weizman, A., Covitt, B. A., Koehler, M. J., Lundeberg, M. A., Oslund, J. A., Low, M. R., . . . Urban-Lurain, M. (2008). Measuring teachers' learning from a problem-based learning approach to professional development in science education. *The Interdisciplinary Journal of Problem-based Learning, 2*(2). http://dx.doi.org/10.7771/1541-5015.1081