IUMPST: The Journal, Vol 4 (Curriculum)), May 2005. [www.k-12prep.math.ttu.edu]

PREPARING ELEMENTARY TEACHERS TO TEACH MATHEMATICS: HOW FIELD EXPERIENCES IMPACT PEDAGOGICAL CONTENT KNOWLEDGE

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Abstract

Student achievement and attitudes toward mathematics are influenced by the teacher, emphasizing the importance of quality teacher preparation. This study explored different preparations and the impact on pre-service teachers' pedagogical content knowledge. The sample included 96 pre-service teachers enrolled in a math course at one Midwestern university. Results suggest that field experience combined with other aspects of mathematical teacher preparation impact pre-service teachers' pedagogical content knowledge for mathematics.

Introduction

With an increase of research in mathematics education, attention on the National Council of Teachers of Mathematics (1989, 1991, 2000) Standards, and accreditation guidelines from the National Council for the Accreditation of Teacher Education (NCATE), reform in mathematics education continues to emerge (Grouws & Schultz, 1996). As K-12 teachers shift instructional practices to reach toward mathematics instruction envisioned by NCTM, many teacher preparation programs are responding in an effort to prepare pre-service teachers to support classroom learning and higher-level thinking in mathematics.

Improving teacher preparation is among the most prominent reforms suggested for education (Ginsberg & Rhodes, 2003). Past reform efforts lacked the impact necessary to improve mathematics instruction as "ordinary" mathematics classes dominate American classrooms (Ball, Lubienski, & Mewborn, 2001). Two explanations for impeding change include a misrepresented view of mathematics, one that consists primarily of rules (Ball et al., 2001; Romberg, 2002), and the role of colleges and universities in teacher preparation (Ball, 2000; Ball et al., 2001).

Accreditation by NCATE brings forth a major reform effort for higher education institutions to improve teaching by creating standards that incorporate current school needs into coherent teaching programs (Holm & Horn, 2003). Using the standards as a foundation has potential to create a context for learning, and a knowledge base to equip teachers with the essential knowledge, skills, and dispositions.

Review of the Literature

In many traditional teacher education programs, preparation for teaching elementary school includes separate courses in learning pedagogy, educational psychology, mathematics and other subject matter. For mathematics teaching preparation, one typically begins with a mathematics prerequisite; pre-service teachers for whom the prerequisite is not met have an additional mathematics requirement. Many times, this results in enrollment in an additional mathematics course offering little or no relation to school mathematics. Most teacher education programs include a combination of mathematical content courses, or content knowledge, and a course centered on pedagogy, also commonly referred to as math methods. To develop subject-matter knowledge in mathematics, pre-service teachers are required to complete from 1-4 math content courses, followed by a mathematics methods course, or in some cases, a general methods course which integrates more than one subject area. The overlying goal of a methods course is to understand how children learn various mathematical concepts and skills and how to teach particular mathematical ideas to children. When and how field experiences occur varies greatly from program to program. Despite the separation of three such experiences in traditional teacher education programs, a perusal of the literature suggests there are common characteristics for each individual entity: mathematics content courses, mathematics methods instruction, and an early field experience.

Integrating Content and Pedagogy

There is supporting evidence that confirms an interconnection between content and pedagogy (Lampert & Ball, 1998). As teacher education programs make efforts to strengthen the preparation of teachers, the balance of content and pedagogy remains a concern. Shulman (1986) suggested the use of the construct of pedagogical content knowledge, described as the combination of what one knows about mathematics, about students, about general pedagogy, and about learning mathematics.

Shulman’s focus on pedagogical content knowledge led to more attention on how teachers acquire knowledge in teacher education, as well as the impact of pedagogical content knowledge on teachers’ quality of teaching (Ball, D.L., Hill, H.C. & Bass, H., 2002). This focus can also be connected with the implementation of teaching standards, such as NCTM (1989, 1991). NCTM’s (1991) Professional Standards state the importance of “teachers knowing mathematics, knowing students, and knowing teaching” (p. 124).

With standards in place, the next shift involved testing for teaching licensure, which typically includes a subtest of mathematics. Many of these assessments, however, are limited to measuring candidates’ computational abilities rather than on the content knowledge used in teaching. For example, Wilson, S., Floden, R. & Ferrini-Mundy, J. (2001) reviewed teacher education studies and found that teachers’ content knowledge test scores did not correlate with teacher performance, suggesting that more than content knowledge is needed to teach. Although standards and assessments remain in place across the United States, there still remains a lack of consensus over what teachers must know in order to effectively teach mathematics (Ball et al., 2002).

Accompanying a lack of agreement on content knowledge needed for teaching is a limitation of studies that adequately describe the impact of teacher preparation programs on pre-service teachers’ pedagogical content knowledge. Unfortunately, to date, large-scale studies on pedagogical content knowledge have not been conducted as the field lacks methodology to enable such studies. Through qualitative research, however, investigations of the development of pedagogical content knowledge assist in understanding the complexities of this domain of knowledge.

Perhaps the most substantial contribution to developing a theoretical framework related to pedagogical content knowledge, were Ball’s (1990) and Ma’s (1999) studies where particular mathematics topics were situated in teaching and used as survey items with pre-service teachers. These studies revealed weak mathematical content knowledge. Furthermore, the particular mathematics concepts held by teachers do not necessarily represent the knowledge needed for teaching mathematics. These studies also suggested that students' learning is dependent on more than one factor: the teachers' content knowledge and the interaction between this form of knowledge and the students' thinking about the mathematical content (Ball et al., 2002).

A clearer understanding of the regularities of teaching directly relates to this form of knowledge known as pedagogical content knowledge. Ball et al. (2001) recommended that an examination of the practice of teaching mathematics itself was necessary; one which included studies of teachers' roles in designing mathematical tasks, in selecting textbooks, in predicting trouble areas for students, and in determining what children know. Ball et al. (2002) further expanded upon limitations of Shulman's (1986) original definition of pedagogical content knowledge to include how teachers hold mathematical knowledge needed for teaching and referred to this as the specialized "content knowledge needed for teaching."

Recently the National Research Council (1996) defined effective teachers as those who display pedagogical content knowledge. The expanded definition of Shulman's (1986) pedagogical content knowledge known as "the content knowledge needed for teaching" provides an additional argument for redesigning the mathematical sequence in teacher education programs. With traditional teacher preparation programs' focus on separate domains of mathematical teacher preparation, bridging content and pedagogy to develop pre-service teachers' pedagogical content knowledge is unlikely. With the overlapping teacher education goals of content, pedagogy, and developing pre-service teachers who are reflective practitioners, comes the need to bridge these three separate entities of teacher education into one coherent plan.

Wilson et al. (2001) found three studies that acknowledge the interaction between content and pedagogy. These studies implied that pre-service teachers' consideration of content knowledge in subject specific methods courses allows for reorganization of knowledge by classifying how the content should be taught. Most models of integration efforts include purposeful course development that emphasizes the blending of content with pedagogy within a methods course designed for pre-service teachers. Typically, these courses follow constructivist theory, with the intent of having students gain an understanding about learning and teaching.

The distinction between learning mathematical content and acquiring methods for effective mathematics instruction has become less clear (Cooney, 1994). Interpretive studies of math methods courses show many overlapping features with the math content courses for elementary school teachers. For example, both courses emphasize the pre-service teacher as a learner with the goal of developing "mathematical habits of mind" (CBMS, 2001). Engaging pre-service teachers in meaningful explorations involves carefully selected content that connects to school mathematics. Within the mathematics education community is the general acceptance of the need to focus on students' understanding of mathematical concepts in teaching (Heibert & Carpenter, 1992; NCTM, 2000). Through the learning process and rich discourse, pre-service teachers come to understand how children learn and are given opportunities to think about the applications in an actual classroom.

Field Experiences in Mathematics

Field experiences are more commonly linked to methods courses rather than content courses. Purposeful connections between fieldwork and coursework in a methods course have been implemented in many programs in an effort to improve teacher preparation. Foss and Kleinsasser (1996) suggest the need for reorganization of the design, one that focuses on reform with an emphasis on constructing conceptions conducive to learning mathematics. They believe that pre-service teachers should be asked to provide a rationale for their teaching and show the ability to justify their actions through class discussion and debates. Collaboration between the methods instructor, cooperating teachers, and the pre-service teachers is recommended prior to any actual teaching (Cooper, 1996; Foss & Kleinsasser, 1996).

Another powerful consideration for combining the field experience with the methods class emerges in the development of course assignments. Through involvement with case studies of children, assessment interviews, and focused observational activities, Vacc and Bright (1999) discovered that beliefs about mathematics teaching were influenced, moving toward more constructivist views.

Other research examines pre-service teachers' participation in action research. Ohana (2003) and Lampert and Ball (1998) outlined students' involvement in a methods course, math-related fieldwork, and the investigation of a research question. Mewborn (1999) suggested a more inquiry-based model integrating methods with the field experience, therefore, using pre-service teachers' inquiries about aspects of mathematics teaching and learning to determine the course agenda. The field component included a more traditional field experience design, however, in that pre-service teachers first observed exemplary math teachers and later gained responsibility in math instruction for the classroom.

Other designs for integrating methods courses with fieldwork note the value of school-based methods courses (Berliner, 2000; Lowery, 2002). School-based methods courses allow pre-service teachers opportunities to experience authentic learning, with the "real" classroom context providing access to teaching and learning. As a result of a semester in a school-based methods course, pre-service teachers made positive gains in pedagogical content knowledge (Lowery, 2002). In Hedrick, McGee and Hittag's (2000) study, they found that one-on-one tutoring experiences provided positive learning opportunities for pre-service teachers, particularly when pre-service teachers had completed or were concurrently enrolled in specific-subject methods courses that matched the subject matter of the tutorial sessions.

Methods instructors should reframe the goals of the methods course to encompass the development of habits of mathematical thinking (Ebby, 1999). Integrating math methods with a field experience means establishing learning goals that develop through field experiences. Purposeful connections between university coursework and "real" classrooms empowers methods instructors to aid in pre-service teachers' understanding (Cooper, 1996). Providing pre-service teachers with opportunities to apply what they are learning in the methods course is a common goal for field experience design. Cooper (1996) recommends experiences involving children learning with manipulatives to witness firsthand the results.

A less familiar arrangement in mathematics teacher preparation involves integrating a field experience with a math content course. Baggett and Ehrenfeucht (2001) studied mathematics content courses for both pre-service and practicing teachers. The laboratory format resulted in fewer topics covered than traditional Colleges of Arts/Sciences courses, although more time was allocated toward developing conceptual knowledge. The field component involved application of the content lessons in the practicing teacher's classroom with both experiences in co-teaching and observation. Ultimately, blurring the distinction between theory and practice may lead to deeper understandings of the teaching—learning process of mathematics and more developed pedagogical content knowledge.

Content, Pedagogy and Field Experiences

Few studies currently exist to document attempts to integrate mathematics content, pedagogy, and field experiences. In one of the earliest integrated designs, Feiman-Nemser (1990) described how two professors worked together to team-teach a mathematics content and methods course, with a focus on conceptual understanding of mathematics. The field component entailed pairing each prospective teacher with a mentor classroom teacher. Assignments, which developed as part of the mathematics block, were carried out in the classroom setting. Although findings from the study indicate improvement in pre-service teachers' ability to understand procedural relationships, skepticism about instructional practices remained the same.

Benbow (1995) reviewed a mathematics preparation design that included the integration of mathematics content and methods in one course and a structured field experience. This study provided insights into three critical aspects: the nature of pre-service teachers' beliefs about mathematics, the nature of their practices in the mathematics classroom, and a potential design for restructuring teacher preparation programs.

More recently, Hart (2002) described the impact of an alternative certification route that combined six credit hours of mathematics with six credit hours of math methods and fieldwork. Through integrated coursework, which was developed around school mathematics topics and a problem solving approach, Hart discovered that pre-service teachers' beliefs about mathematics teaching were impacted. In addition, results from the Praxis I and Praxis II examinations provide evidence of sufficient content and pedagogical knowledge.

The review of the literature suggests a need for research in this area exists. Although a plethora of studies present some promising characteristics of separate courses included in more traditional teacher preparation, the fragmentation of the design is believed to hinder pre-service teachers' development, rather than support it. More recently, the integration of mathematics preparation courses has been explored, although limited research is available to support or disclaim this design. There is little known about what constitutes an effective program for preparing students to teach elementary school mathematics.

Design

During the fall of 2003, three math methods courses were offered at a small Midwestern university, all with the same instructor. One group of pre-service teachers represented the institution's new program design where students were concurrently enrolled in a math content course, methods course, and weekly field experience. Both of the math courses were the first of two such "blocks" required for all K-8 education majors. This group was represented as CMF (content-methods-field). A second group (MF) was involved with two of the three components, excluding the mathematics content course, which was completed prior to enrollment in the methods course.

For the CMF and MF groups, the field component was supervised by the same methods instructor. The field experience involved approximately 20 hours of one-to-one sessions with a third grade elementary student. The primary goal of the field experience was to help pre-service teachers understand how children learn and think about mathematics topics, mainly Number and Operation concepts.

The former teacher preparation program, which was being phased out, represented the third and fourth groups. Traditionally, there was a gap between enrollment in two sequenced content courses and the students' enrollment in the math methods course. No field experience opportunity specific toward mathematics existed, although the former program required pre-service teachers to complete 50 clock hours of fieldwork. The observational field hours were linked to a general teacher education course that focused on classroom management and learning theories. This group is referred to as M Only (for Methods only); both content courses and the 50 hours of fieldwork had previously been completed.

The fourth group, C Only (for Content only) served as the control group. Participants were former program students completing the traditional sequence as mentioned above, but were just beginning the 3 course sequence. It is important to note that the same mathematics instructor was involved in teaching the participants in both the CMF group and the C Only group.

This provided an opportunity for investigation of the new teacher education design for pre-service elementary teachers which involves learning mathematical content, pedagogy, and fieldwork in a 5.5 credit-hour block.

Participants

The sample included 96 pre-service teachers enrolled in a mathematics methods course and/or the first of two mathematics content courses during a 16-week semester. Without random assignment for the four groups of pre-service teachers, demographic questions were analyzed to rule out variability among groups. The revised Essential Elements of Elementary School Mathematics (EEESM) measure (White, 1986) was administered during the first week of the semester to all participants in an attempt to measure content knowledge.

Using a one-way analysis of variance, and an alpha level of .05, no significant difference was detected for the number of high school courses, the EEESM content mean scores, or the ability self-rating on a 1-5 scale. Chi-square analysis was used to describe variability for gender, academic major, and class standing. Table 1 presents the data to support the similarities among the four groups in this study.

Table 1

Demographics for the Four Groups of Pre-service Teachers

Group(n)	**Gender** **M F**	**Major** **ELED** **M.S. Math** **Other**	**Class Standing** **SO JR SR**	**ACT Score**	**No. of HS Math**	**No. of College Prereq.**	**EEESM Mean Score**	**Ability Self-rating**
C (*17*)	2 15	12 0 5	5 3 8	19.250	3.35	0.882	.637	2.94
CMF (*28*)	3 25	22 1 5	4 19 5	19.154	3.54	1.500	.622	3.04
MF (*15*)	4 11	11 9 3	3 11 1	22.200	3.80	0.400	.671	3.13
M (*36*)	4 32	30 4 2	0 1 35	19.792	3.44	0.778	.634	3.08

For three demographic areas, the number of prerequisites, ACT math scores, and class standing, significant differences were detected. The prerequisite algebra courses required prior to enrollment in the first mathematics content course are requirements by the mathematics department and are determined based on the number of high school mathematics courses completed, ACT mathematics score, and/or placement test results. Pre-service teachers may be required to begin at the lowest level, Elementary Algebra, followed with two additional Algebra courses. The number of prerequisite requirements ranges from 0, which signifies satisfactory past mathematical achievement, to 3, representing a deficiency in mathematical background. Contrary to the belief that more mathematics classes correlate with greater achievement, the prerequisite courses discussed in this study represent the opposite.

The CMF group had a higher mean for prerequisite mathematics courses than any other group, suggesting that general mathematics ability at the time of college entry was deficient in comparison to the other three groups. Additionally, the MF group's mean ACT score was significantly different from the CMF group. In the area of class standing, the M only group had a greater percentage of upperclassmen, reflecting the transition in program design.

With no significant differences in the EEESM mean scores, it is believed that the four groups' mathematical abilities were similar at the start of the study.

Instrumentation

The Essential Elements of Elementary School Mathematics test (White, 1986) was revised by the researcher to include 17 of the original 50 items intended to measure conceptual knowledge of mathematics most commonly associated with elementary school mathematics. The items were written in a way to emphasize conceptual understanding over computational skills. For the EEESM test, a panel of judges with various backgrounds used a 4-point rating scale for each of the 50 items based on relevance to the EEESM. Validity was established through high ratings of 3 and above for 88% of the items. The items included for this study were concepts associated with numbers and place value, basic operations on numbers including their properties and uses, and problem solving.

With 17 items instead of 50, the projected reliability coefficient was found to be .695. In this study, reliability for the measure was found to be at an alpha of .428.

The Content Knowledge for Teaching Mathematics measure (CKTM) represented a set of survey-based teaching problems thought to model various components of the specialized knowledge of mathematics which is needed for teaching (Ball et al., 2002; Hill, H.C., Schilling, S.G., & Ball, D.L., 2003). The CKTM survey had 27 multiple-choice items integrating pure content knowledge, content knowledge situated in teaching, and knowledge of students' thinking. IN addition to an overall PCK score, two constructs were analyzed: Knowledge of Content and Knowledge of Students and Content.

The test was developed through the Study for Instructional Improvement/Learning Mathematics for Teaching (SII/LMT) project using Item Response Theory to produce items of varying difficulty. This form of instrumentation differs substantially from the aforementioned EEESM content knowledge test. The CKTM measure extends well beyond the mathematical knowledge one holds for oneself, to include content knowledge used for particular tasks of teaching.

Results

Research questions: How has the type of mathematical preparation impacted pr-eservice elementary school teachers' pedagogical content knowledge (PCK) in mathematics. Does the type of preparation affect Knowledge of Content and Knowledge of Students/ Content, as measured by the Content Knowledge for Teaching Mathematics measure? Is there a significant difference in overall PCK?

In order to determine the extent of PCK, the newly developed Content Knowledge for Teaching Mathematics (CKTM) measure was given to all participants near the conclusion of the semester. Scores for participants ranged from 5 to 23. Using Item Response Theory, items were normalized so an "average" teacher would correctly answer approximately 50% of the items (Hill et al., 2003). In this study of pre-service teachers, scores below .500 were highly anticipated due to their lack of teaching experience. Interestingly, percentage scores for overall PCK ranged from .185 to .852, with several individual scores exceeding the .500 level.

A one-way analysis of variance was selected as the statistical test. Mean percentage scores and standard deviations for the total CKTM measure are presented for each group in Table 2. Additionally, in an attempt to determine how the inclusion of a field experience impacted pedagogical content knowledge, Table 3 shows a comparison between field experience groups, CMF and MF, and non-field experience groups, M only and C only.

Table 2

Mean Percentage Scores and Standard Deviation for the Content Knowledge for Teaching Mathematics (CKTM) Posttest

Group	M	SD	n
Content only	.417	.099	17
CMF	.505	.140	28
MF	.530	.087	15
Methods only	.431	.123	36

Note. The difference among the four group means (.417 vs. .505 vs. .530 vs. .431) was significant, F (3, 93) = 3.577, $p < .01$.

Table 3

Mean Percentage Scores and Standard Deviations for the CKTM by Field Experience

Group	M	SD	n
Field Experience (CMF/MF)	.513	.125	43
Non-Field Experience (M only/C only)	.427	.116	53

Note. A significant difference was found between those groups associated with a mathematics field experience (.513) and those groups without a mathematics field experience (.427), F (1,94) = 12.029, $p < .01$.

The Newman-Keuls post-hoc test was used to determine where the significance was located. The significant difference was found to be between the MF group and the Methods only group, q (3, 92) = 3.719, $p < .05$, as well as between the MF group and the Content only group, q (4,92) = 4.245, $p < .05$. Although the MF group had the highest mean score for PCK, it did not differ significantly from the CMF group.

In an attempt to further explain how different designs for preparing pre-service teachers to teach mathematics impact PCK, an analysis was conducted for each of two constructs, Knowledge of Content and Knowledge of Students and Content. For Knowledge of Content (KC) content knowledge is "specialized" differing from mathematical knowledge one holds for oneself (Ball et al., 2002; Hill et al., 2003). Most of the items were situated in teaching mathematics, with focus on particular tasks of teaching such as representing an expression with a model. The CKTM measure used content questions that extend beyond knowing an answer for oneself.

For this construct, participants' scores across groups ranged from 1 correct answer to 13 correct answers for 15 items. No significant difference among the four groups was detected on the KC subscale. Furthermore, the groups associated with the mathematical field experience (CMF and MF) held similar KC scores when compared to groups for whom no field experience (M and C) was offered. Tables 4 and 5 present the results for the KC subscale.

Table 4

Mean Percentage Scores and Standard Deviations for the Knowledge of Content Subscale of the CKTM Measure

Group	M	SD	n
C only	.382	.151	17
CMF	.483	.180	28
MF	.467	.117	15
M only	.429	.163	36

Note. The difference among the four means (.382 vs. .483 vs. .467 vs. .429) was not significant, F (3, 92) =1.615, $p > .05$.

Table 5

Mean Percentage Scores and Standard Deviations for the Knowledge of Content Subscale

Group	M	SD	n
Field Experience	.478	.161	43
No Field Experience	.414	.161	53

Note. There was no significant difference detected for the Knowledge of Content scale between field experience group and non-field experience group, F (1, 94) = 3.660, $p > .05$.

Although the first subscale of the CKTM failed to detect significant differences among groups, there is a fine distinction between Knowledge of Content and the second domain, Knowledge of Students and Content. Because few “pure” knowledge of students’ thinking items could be developed, the original domain was revised to be named Knowledge of Students and Content (Ball et al., 2002; Hill et al., 2003). This suggests a relationship exists between the teacher’s own content knowledge and the knowledge needed for inferring a student’s thinking. For this subscale, participants’ scores ranged from 1 to 10 correct responses out of 12 possible. Results for the Knowledge of Students and Content (KSC) subscale are displayed in Tables 6 and 7.

With the Newman-Keuls test, the significant difference was found to be between the CMF group (.531) and the M only group (.435), q (3, 92) = 3.408, $p < .05$; the MF and M only group, q (4, 92) = 6.176, $p < .01$; and the MF group and the C only group, q (3, 92) = 5.253, $p < .01$. The MF and CMF groups were found to be similar for the Knowledge of Students and Content subscale.

Table 6

Mean Percentage Scores and Standard Deviations for the Knowledge of Students and Content Subscale

Group	M	SD	n
C only	.461	.086	17
CMF	.531	.130	28
MF	.609	.094	15
M only	.435	.150	36

Note. The difference among the four means (.461 vs. .531 vs. .609 vs. .435) was significant, F (3, 92) = 7.713, $p < .01$.

Table 7

Mean Percentage Scores and Standard Deviations for Field Experience vs. No Field Experience on the Knowledge of Students and Content Subscale

Group	M	SD	n
Field Experience	.558	.124	43
No Field Experience	.443	.134	53

Note. A significant difference was detected between field experience groups and non-field experience groups, F (1, 94) = 18.434, $p < .01$.

With the large difference noted between the MF and M only mean scores, the researcher used Glass's formula for effect size, and determined an effect size of 1.16 for the mean KSC scores. With results exceeding 1.0, the effect size of the field experience is considered to be substantial (Glass, G., McGaw, B., & Smith, M.L., 1981). This information suggests that the field experience impacted MF participants' Knowledge of Students and Content scores.

The CMF and MF groups spent 20 hours in a field-based setting. The majority of this time was spent working one-to-one with an elementary school student on mathematics. Similar to the findings between field experience groups and non-field experience groups for overall pedagogical content knowledge, the two groups for whom a field experience was required scored significantly higher on the KSC subscale than the other two groups.

Summary

In an effort to improve the fragmentation of traditional models of preparation, Ball (2000) recommended finding a model to integrate content knowledge and pedagogy in the context of teaching. To date, the development of a model that more effectively prepares pre-service teachers to teach mathematics is nonexistent.

The Methods only group's low mean percentage score for pedagogical content knowledge suggests that field experiences integrated with a mathematics methods course holds greater potential to impact pedagogical content knowledge. Even with prior field experience work comprising a minimum of 50 hours of fieldwork, low mean scores on the CKTM suggest that past experiences had little impact on pedagogical content knowledge for mathematics.

The impact of the mathematics field experience, combined with methods or methods/content, perhaps, shows the greatest promise in preparing elementary teachers to teach mathematics. Although pre-service teachers' time in the field was considerably less than in the content course and the methods course, significant differences between field experience groups (CMF/ MF) and non-field groups (Content only/Methods only) were found in two areas: the Knowledge of Students and Content construct, and pre-service teachers' overall pedagogical content knowledge.

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