Teachers' subject matter knowledge as a teacher qualification:

A Synthesis of the quantitative literature on students' mathematics achievement

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For many years, educational scholars and policy makers have been concerned with the factors that influence teaching and learning. The qualifications of teachers have been assumed to be one of the critical factors. Even though there are debates on how to define a qualified teacher, teachers' subject matter knowledge has been long considered an important influence on teaching and learning.

However, studies that examined the influences of teachers' subject matter knowledge on student achievement have produced mixed findings. Several reviews of empirical studies on the relationship between teachers' subject matter knowledge and the quality of teaching have found that the studies fail to yield consistent findings (Ashton & Crocker, 1987; Darling-Hammond, 2000; Wilson, Floden, & Ferrini-Mundy, 2001). Even though in some studies, a positive connection between teachers' subject matter knowledge and student achievement was found (e.g., Darling-Hammond, 2000; Mandeville & Liu, 1997; Rowan, Chiang, & Miller, 1997), some studies found a non-significant effect of subject matter knowledge on student achievement, and others report a negative association (e.g., Koch, 1972; Reed, 1986).

This paper examines the reasons for these disparities. That is, the focus of this paper is not on the question of whether teachers' subject matter knowledge influences student learning. Such an influence is assumed. It is a question of why research has drawn different relationships between teachers' subject matter knowledge and student learning. That is, the main focus of our study is to find different kinds of variables that might contribute to variations in the strength and direction of the relationship by examining quantitative studies that relate mathematic teachers' subject matter knowledge to student achievement in mathematics.

This paper has three main sections. The first section reviews all quantitative studies that have investigated the relationship between teachers' mathematics subject matter knowledge and student learning we have found. In this section, we describe variations in the following three domains (a) measurement, (b) data analytic techniques, and (c) the samples of subjects we assume that these variations may influence study outcomes. In the second section, we present a meta-analysis of a sub-set of these studies, which rely on correlation coefficients to examine hypotheses. Then, we summarize the results and draws implications based on what we have learned from our analysis.

LITERATURE REVIEW

Selection of Studies for the Review

Studies for this review were drawn from the broader TQ-QT project's database. The TQ-QT project is a synthesis of studies investigating the relationship between indicators of teacher qualifications (TQ) and the quality of teaching (QT) using studies conducted in the United States since 1960. See Wu et al. (2002) for more details on the full project. From this TQ-QT database, studies for this review were selected if they investigated the relationship between indicators of teachers' subject matter knowledge and student achievement. Specific criteria for selection of studies are as follows.

First, each study must have at least one measure of subject matter knowledge. In the TQ-QT project we have developed a list of indicators of subject-matter knowledge. We chose the following search terms to identify the applicable studies in the overall TQ-QT database: 'teacher knowledge', 'content knowledge', 'subject-matter knowledge', 'GPA in subject', 'major or degree in subject', 'degree level in subject', 'certified in subject', 'numbers of courses taken', 'credit hours of course taken', 'NTE', 'Praxis', 'certification test', 'knowledge test', and 'teacher test'. Second, each study must have reported on at least one student achievement outcome as an indicator of student learning. Third, each study must have reported at least one link between indicators of teachers' subject matter knowledge and student mathematics outcomes. Fourth, each should be a quantitative study. Fifth, the subject matter was limited to mathematics for this search.

This selection process identified a total of 41 studies. These include 8 journal articles, 1 book chapter, 7 research reports, 1 conference proceeding, and 24 dissertations. 41 studies were examined for the brief literature review but some studies were omitted from the meta-analysis.

Hypotheses for Inconsistent Findings on the Relationships

Interest in the role of subject matter knowledge as a component of teacher knowledge on teaching and learning has been increased since Shulman (1986) pointed out subject matter knowledge as a "missing paradigm" in the study of teaching. Since then, researchers have explored what subject matter knowledge looks like and whether and/or how subject matter knowledge affects both teaching practices and student learning. Even though the importance of subject matter knowledge is generally believed for teaching and learning, findings of empirical studies on the relationship between teachers' subject matter knowledge and the quality of teaching have been inconsistent as mentioned above.

Many variables may contribute to inconsistencies and variations in study findings but we focus on variations in the following three domains (a) measurement, (b) data analysis techniques, and (c) the samples of subjects. In the next section, we will describe these variations addressing our hypotheses for our meta-analysis.

Measurement Variations

Variation in indicators of subject matter knowledge

Because subject matter knowledge is a broad construct, researchers choose indicators of subject matter knowledge based on their operationalizations of this construct. The use of different indicators may act as an important moderator. Due to the intangible nature of knowledge, researchers need to create variables that are visible and practical in order to investigate relationships and different indicators of subject matter knowledge were used in the studies.

These measures fall into two general categories. The first type is educational background indicators, including GPA in mathematics courses, number of courses taken in mathematics, major or degree in mathematics, degree level in mathematics, certification in mathematics, or composite variables that combine more than two educational background variables. The second category is tests, including large-scale teacher tests such as NTE area tests and state certification tests and research based local tests such as the Glennon Test of Basic Mathematics Understanding developed by other researchers (e.g., Bassham, 1962) and researcher-made tests (e.g., Begle, 1972). Table 1 shows all of the indicators that we found and how many studies used each indicator at both elementary and secondary levels.

Table 1

Number of studies using various indicators of subject matter knowledge

		Grade Level of Teacher	
Category	Indicator	Elementary (1-6)	Secondary (7-12)
Educational background	Coursework in mathematics	4	11
	Degree or major in mathematics	3	9
	Degree level in mathematics	0	4
	Certified in mathematics	0	7
	GPA in mathematics	0	3
	Composite variables	2	3
Teacher test	Large scale tests	3	1
	Research based local tests	9	4

Note. Because some studies examine several indicators of teacher subject-matter knowledge at both elementary and secondary levels, the counts in Table 1 add up to more than our total number of studies.

Two-thirds of the indicators used in the studies fall into the first category- educational background variables. Within the educational background category, the most often used variable is a measure of the coursework taken in mathematics. A third of studies in this category used teachers' coursework in mathematics. Another set of widely-used variable includes major or degree in mathematics; 26 % of the studies in this category used major or degree to represent teachers' subject matter knowledge. As shown in Table 1, educational background variables were used more often in studies that examined grade seven through twelve teachers to measure teachers' subject matter knowledge.

The second main approach shown in Table 1 is the use of test scores. The studies used the National Teacher Examination specialty test, State certification tests, tests developed by other researchers, or researcher-made tests. We found that 25 % of the studies in our sample used one or another type of test to measure teachers' subject matter knowledge. Research based local tests are the most often used to measure teachers' subject matter knowledge. Whereas secondary school studies used educational background variables more often, teacher tests were used more often in studies that examined grade one through six teachers to measure teachers' subject matter knowledge.

Thus, the variations in indicators of subject matter knowledge may influence inconsistent study findings on the relationship between teachers' subject matter knowledge and student mathematics achievement.

Measurement variations on the same indicator

There are also variations within these general categories of indicator. There are many tests and many ways of tallying up coursework. As a case, we examine the ways in which coursework taken in mathematics was measured in the studies. Table 2 shows the different approaches to measuring teachers' coursework in mathematics.

Table 2

Number of studies by approaches for using teachers' coursework in mathematics

Coursework	Amount of courses		Level of courses
	number of courses	Credit hours	
N of studies	4	6	5

The first approach shown in table 2 is to measure the amount of math courses taken, regardless of the level of courses. That is, the amount of courses were counted regardless of whether the courses were introductory or advanced courses. In most studies, coursework taken in mathematics was measured as the amount of courses by counting total number of courses or total credit hours across all courses.

The second approach in Table 2 is to measure the amount of coursework, differentiating by the level of the courses. Five studies examined whether teachers who took advanced mathematics courses or more advanced mathematics courses have students with higher achievement in mathematics. For example, Chaney (1995) classified teachers as those who took courses only at the calculus level or below versus those who took advanced courses in mathematics, and then examined whether eighth grade students performed better if their mathematics teachers had taken courses beyond the level of calculus.

Within the second approach, researchers used different ways to measure teachers' coursework in related to level of the courses. Two studies measured teachers' coursework in related to the level of courses asking whether or not they took advanced courses. A study measured it asking how many advanced courses teachers took. Other two studies developed their own rating scales to measure teachers' coursework in related to the level of courses. For instance, Rouse (1967) developed a scale with 9 values to measure the extent of teachers' college mathematics preparation. While 1 of value means no mathematics courses, 9 of value means that teachers took one or more of the most advanced mathematics courses.

Thus, it may be that study findings are different when researchers choose different approaches using the same measure. For example, it may be that using different approaches to measure the amount of coursework makes a difference in study findings. There may also be differences in findings between studies that used the amount of coursework and studies that used the level of coursework as indicators of subject matter knowledge.

Different scaling of data

Studies chose different scaling of the data using the same measure. For example, while 8 studies used continuous variables, measuring exact count of numbers of courses or credit hours, 5 studies created categorical coursework variables by grouping number of courses or credit hours. One study used both continuous and categorical variables to examine the relationship between teachers' subject matter knowledge measured by teachers' coursework in mathematics and student mathematics achievement. In addition, the studies that used categorical variables used different categories because there are no clear cut-points to make categories.

Using different scaling of the data may influence study findings. For example, Monk (1995) investigated the effect of subject matter knowledge measured by teachers' coursework in mathematics and student mathematics achievement using both continuous and categorical variables. While positive effects of subject matter knowledge on student achievement were found in his study, Monk reported that the magnitudes of the positive effects varied. Using a continuous variable, he found that an increase of one mathematics course was associated with a 1.2% increase in the junior students' mathematics test scores. The addition of courses beyond the fourth course had a smaller effect (0.2 % increase) on student performance when he used a categorical variable (0-4 vs. 5 up).

Thus, it may be that using different scales to measure teachers' subject matter knowledge influence inconsistent study findings. These researchers' choices of scaling were related to their choices of data analytic techniques we will discuss in the next.

Variations in Data Analytic Techniques

Studies also used very different data analytic techniques to examine the influence of teachers' subject matter knowledge in relation to student mathematics achievement. The major data analytic techniques used in our sample are as follows: (a) correlation analysis, (b) regression, (c) hierarchical linear modeling, and (d) group comparison techniques such as analysis of variance and analysis of covariance. Table 3 shows how many studies used each data analytic technique. Because many studies use several data analytic techniques, the counts in Table 3 add up to more than our total number of studies.

Table 3

Number of studies by data analytic techniques

Category	Measure	Data analytic technique			
		Correlation	Regression	HLM	Comparison
Educational background	Coursework	9	6	2	4
	Degree or Major	3	6	1	1
	Degree level	1	4	1	0
	Certified in mathematics	1	3	2	3
	GPA in mathematics	2	1	0	1
	Composite variable	4	2	0	1
Test scores	Large-scale tests	6	3	1	1
	Research based local	8	2	0	2

Note. Because many studies use several data analysis techniques to examine the relationships, the counts in Table 3 add up to more than our total number of studies.

Thus, study findings on the relationship between teachers' subject matter knowledge and students' mathematics achievement may vary by the type of data analytic technique used in the study.

Variations in Subjects: Grade Level of Teachers ands Students

Teachers and students who participated in the studies we found ranged in grade from 1 through12. This fact means that the studies are concerned with different mathematical content. That is, the relationships between teachers' subject matter knowledge and students' mathematics achievement may depend on what grade was taught.

Findings in the following two studies support this hypothesis. Chiang (1996) studied the relationship between teachers' educational training and student mathematics achievement using NELS 88 data. One variable representing teachers' subject matter preparation was whether the teacher held dual degrees in mathematics – undergraduate and graduate degrees in mathematics. He used it to examine whether teachers who had dual degrees in mathematics had students with higher mathematics achievement. He found that while teachers with two degrees in math were not more effective in increasing student achievement in the 10^{th} grade mathematics classes and any degree in mathematics was equally effective, in the 12^{th} grade mathematics classes, teachers holding dual produced higher student achievement. Monk (1994) also found that the effects of subject matter knowledge measured by number of undergraduate mathematics courses on student achievement in mathematics were different for the sophomore and junior students. He reported that the magnitude of the effect was larger at the junior level.

Thus, we hypothesize that study findings may differ by grade level taught.

RESEARCH QUESTIONS

Given the literature review, our main purpose of the meta-analysis is to identify variables that moderate the relationship of teachers' subject matter knowledge and student mathematics achievement. Our specific questions are as follows.

1. What is the overall strength of the relationship between teachers' subject matter knowledge and student learning?

2. Does the strength of the relationship differ by types of indicators of teachers' subject matter knowledge?

3. Does the strength of the relationship differ by grade level taught?

4. Does the strength of the relationships differ by other measurement variations such as types of subject matter knowledge tests, ways in which teachers' coursework were measured, and unit of analyses?

META-ANALYSIS

Methods

Of 41 relevant studies our meta-analysis is based on the 27 studies including 4 journal articles, 1 conference paper, 4 reports, and 18 dissertations. We will discuss the omitted studies and combined studies in this section. The characteristics of the 27 studies included in this research synthesis are in Appendix I.

Omitted Studies

A number of potential studies were omitted from this research synthesis for two reasons. First, some did not report enough information to obtain a correlation coefficient, which was the selected effect-size metric in this meta-analysis (e.g. Darling-Hammond, 2002; Hurst, 1967). For example, Cox (1970) used analysis of covariance to test the effect of teachers' level of competence in mathematics on student achievement in arithmetic controlling for student Intelligent Quotient (IQ) and pre-test achievement. It was not possible to obtain a correlation coefficient from this study.

Second, we omitted studies that used incomparable statistical designs such as hierarchical linear modeling (HLM), and multiple regression with no correlations reported. Nine studies that used HLM or regression did not allow us to compute an effect size comparable to a correlation coefficient (e.g., Chaney, 1995; Ziegler, 2000).

Combined Studies

Two studies in which the same dataset was used were combined together as one study. Rowan, Chiang, and Miller (1997) used the same dataset (NELS:88) that Chiang (1996) used in his dissertation. Most of the reported correlation values were identical in the two studies. Therefore, we combined those two studies and extracted the correlation values from Chiang's (1996) study because Rowan et al. (1997) did not report one of the correlation values that we were interested in.

Coding

Indicators of teachers' subject- matter knowledge

The indicators of teachers' subject-matter knowledge (SMK) were characterized into two main categories: Educational background variables and teacher tests. Educational background variables included 1) GPA in mathematics, 2) coursework in mathematics, 3) degree or major in mathematics, 4) degree level in mathematics, 5) certificate in mathematics, and 6) some combinations of educational background variables.

Table 4 shows the numbers of correlations for each indicator of teachers' subject-matter knowledge across the 27 studies. The counts of correlations are not as same as the numbers of studies (27) used in this meta-analysis because some studies reported on multiple samples and multiple indicators of teachers' SMK

Table 4

Numbers of correlation for teachers' subject-matter knowledge (SMK) and grade

SMK	Grade	Types of SMK	# of R
Educational Background Variables (K=38)	Elementary (K=10)	GPA	0
		Coursework	6
		Major/Degree	3
		Certification status	0
		Combinations of background variables	1
	Secondary (K=28)	GPA	2
		Coursework	9
		Major/Degree	10
		Certification status	2
		Combinations of background variables	5
Teacher tests (K=26)	Elementary (K=16)	Large-scale based	12
		Research based –local	4
	Secondary (K=10)	Large-scale based	8
		Research based –local	2

Other coded variables

A number of other characteristics of studies were coded. These included publication type (journal article, report, conference paper, and dissertation), unit of teachers used in the data-analysis, unit of students used in the data-analysis, topic area within mathematics, whether the reliability of the teacher test was reported or not, measures of coursework (number of coursework versus credit hours of coursework), and scale of measurement for coursework (categorical versus continuous). Table 5 shows the number of correlations for each level of each coded variable.

Table 5

Other coded variables

Variables	Levels of the variable	# of R
Publication type	Journal	7
	Report	39
	Dissertation	17
	Conference paper	1
Unit of teachers	Individual level	54
	Classroom level	7
	School level	3
Unit of students	Individual level	42
	Classroom level	18
	School level	4
Topic area within mathematics	General mathematics	22
	Arithmetic	16
	Algebra	20
	Geometry	5
	Other	1
Whether reliability of teacher test is reported or not	Reliability reported	8
	Reliability unreported	17
Measures of coursework	Number of courses	8
	Hours of courses	7

Effect Size

The main index used to represent the association between teachers' subject matter knowledge was the Pearson product-moment correlation coefficient (r). If a zero-order correlation coefficient was reported in the primary study, we used the reported correlation coefficient value as our outcome. However, when we could not directly get correlation coefficients from primary studies, we extracted them in several ways:

1) When a study reported raw data, we directly computed the correlation coefficient (e.g. Carezza, 1970; Koch, 1972; Lampela, 1966; Smith, 1964; Soeteber, 1969).

2) When a study reported means (M_i) and standard deviations (*SD*s) for two groups that represented different levels of teacher knowledge, we first obtained Cohen's d as

$$d = \frac{M_1 - M_2}{S_{pooled}}, \qquad (1\text{-}1),$$

where S_{pooled} is the pooled within-groups *SD* (that appears in the two-sample *t* test) and then converted *d* to *r* via

$$r = \sqrt{\frac{d^2}{d^2 + 4}} \quad . \qquad (1\text{-}2).$$

The signs of correlation estimates were assigned to be positive when the group presumed to represent a higher level of teacher knowledge had a higher mean (e.g., Fagnano, 1988).

3) When a study reported a *t* value for a two group comparison, we converted the *t* value to *r* as follows:

$$r = \sqrt{\frac{t^2}{t^2 + df}}, \qquad (1\text{-}3)$$

where $df = n_1 + n_2 - 2$ (Rosenthal, 1994). Again here the sign of *r* was made positive when the group presumed to have more knowledge scored higher (e.g. Prather, 1991).

4) When a study reported on more than two groups and reported an ANOVA table, we computed eta^2 and used eta as an alternative to the correlation value if eta^2 appeared to be comparable (i.e., if the groups showed a linear relation or higher means for groups presumed to have higher teacher subject matter knowledge). Even though some researchers have recommended avoiding squared indices of effect size such as eta^2 because they lose the directionality of effect sizes (Rosenthal, 1994), we used eta, and directionality of the data was examined using the reported means of all the groups (e.g. Reed, 1986).

Because correlation coefficients can range only from –1 to +1, their distributions can violate the normality assumption for several statistical methodologies. Therefore, all the correlation coefficient values were transformed using Fisher's (1925) *z*, which ranges from negative infinity to positive infinity, and is computed as follows:

$$z_i = .5 * \ln((1 + r_i)/(1 - r_i)), \tag{1-4}$$

where *ln* is the natural logarithm. The conditional variance of z_i is

$$v_i = \frac{1}{n_i - 3}, \tag{1-5}$$

where n_i is the sample size used in each study. Then, all the estimates (e.g., means and confidence limits) computed based on Fisher's *z* were then transformed back into the *r* metric via

$$r(z) = \frac{e^{2z} - 1}{e^{2z} + 1}. \tag{1-6}$$

Thus, after reversing Fisher's *z*, the effect-size estimates can be simply interpreted as common correlation coefficients. Below, for simplicity, we refer to all of the effect measures obtained as correlations, regardless of how they were initially computed.

Analyses

Our analyses follow random-effects models (Raudenbush, 1994) rather than fixed-effects models. The distinction between fixed and random effects is a sophisticated data analysis problem (Raudenbush, 1994). Cooper (1998) suggests that the meta-analyst should choose a random-effects model in cases where the effect sizes in a data set are likely to be affected by a large number of uncontrollable influences such as differences in the teachers and schools sampled, the specific measures used of each variable, and so on. Also, Raudenbush (1994) indicated that, if the outcome of a process cannot be predicted in advance due to a multiplicity of potential moderators, it would be reasonable to consider a study's true effect size as random.

We will first examine the overall mean correlation and its 95% confidence interval. In this overall analysis, we will include all the correlations obtained from 27 studies in spite of dependencies among multiple outcomes from several studies. Then, we will examine the effects of potential moderator variables on the relationship between teachers' subject-matter knowledge and student learning using both weighted regression analyses and ANOVA-like categorical analyses (Raudenbush, 1994).

Results

Description of Studies

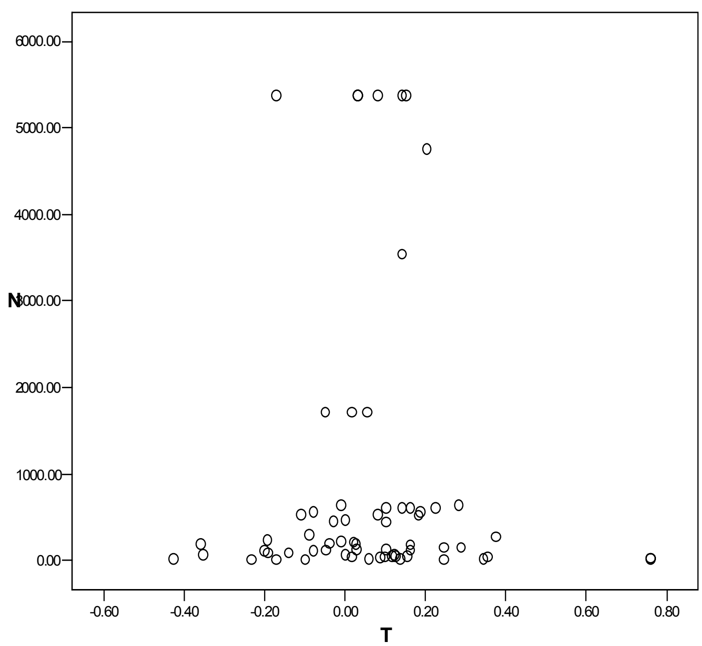
The 27 studies included in this research synthesis allowed for the computation of 64 effect sizes. Studies often have multiple samples (which provide different independent correlation coefficients) as well as multiple correlation coefficients for single samples, depending on how many measures were obtained of teachers' subject-matter knowledge and of student learning. When multiple samples were identified, we treated each sample independently. For example, Begle (1972) reported separate correlation coefficients for male teachers and female teachers. So, we treated Begle's male and female teachers as two independent samples. When multiple outcomes were reported in studies, we used the most fine-grained subsets for our effect size computation. The largest number of correlations was obtained from Begle and Geeslin (1972), which produced 9 correlations from multiple samples and multiple outcomes. Therefore, the total number of correlations used in this research synthesis is 64.

Assessing the Presence of Publication Bias

Publication bias arises when the probability that a study is published depends on the statistical significance of its results. It represents the degree to which studies in the meta-analysis truly represent the broader population in which researchers are interested. One way to assess whether publication bias is likely to be problematic for a set of studies is to examine the funnel plot. Since correlations from smaller studies show more variability than those from larger studies, a plot of correlations against sample sizes should look like a funnel if there is no publication bias. The following funnel plot is fairly symmetric and it has a funnel shape except one correlation larger than .7.

Figure 1

*Plot N*T overall*



Overall Homogeneity Test

We first test homogeneity of all effects using the fixed-effects model. The studies appear not to all come from a single population with a common correlation (Q(63)=824.49, p<.0001).

Hence, as we assumed, a random-effects model is more appropriate to describe the average size of the relationship between teachers' subject-matter knowledge and student learning across all the samples. Under the random-effects model, the estimated average correlation is .06 with a 95% confidence interval (CI) ranging from .06 to .07 and with a standard error of .004. This result indicates that the relationship between teachers' subject-matter knowledge and student learning is statistically different from zero. The estimate of the between-studies variance component is .03.

Moderator Analysis

Since the purpose of our study is to explore the effect of different moderators on the relationship between teachers' subject-matter knowledge and student achievement, we conducted a number of moderator analyses. Also, our initial set of 64 effect sizes suffers from dependence because of multiple outcomes from different indicators (e.g., Carezza, 1969; Chiang, 1996). The moderator analyses will often reduce the dependence among the multiple correlations from individual studies by classifying them into separate subsets.

Educational background variables versus teacher knowledge tests

One possible moderator is whether teachers' subject-matter knowledge was measured by educational background variables or a teacher knowledge test. To examine the effect of the measure of teachers' subject-matter knowledge on the relation of teachers' SMK to student achievement, we conducted a weighted regression analysis with a dummy variable (0 = educational background variable, 1 = teacher knowledge test). The model for this regression analysis is shown in Table 6.

Table 6 shows the relationship between teachers' SMK is significantly different depending on whether teachers' knowledge in mathematics is measured by either educational background or teachers' SMK ($Q_{model}(1)=34.89$, $p<.0001$). The measures of teachers' subject matter knowledge explain some of the variation in the strength of the teachers' SMK to student achievement. However, all the variation is not explained by the difference between these two types of measures of teachers' knowledge in mathematics.

More specifically, the parameter estimates from the fixed-effects model with the dummy variable are shown in Table 6. The mean difference of the relationship between teachers' subject matter knowledge and student achievement depending on the measures of teachers' subject matter knowledge (educational background variable versus. teachers' knowledge test) are -.05, which is significant. Also, the estimate of the mean correlation is .08 when we measure teacher knowledge with educational background variables, while the estimate of the mean correlation is .03 when teachers' knowledge in mathematics is measured by a knowledge test.

Grade level

Another possible moderator is grade level of teachers and students. To examine the effect of grade level on the relation of teachers' SMK to student achievement, we conducted a weighted regression analysis with a dummy variable (0 = elementary level, 1 = secondary level). The model for this regression analysis is also shown in Table 6. Result shows the test for the model (Q_m) is significant, but much variations is still unexplained (Q_e), indicating that the relationship between teachers' subject matter knowledge and student learning varies significantly depending on the grade level assessed (elementary versus. secondary).

The mean difference in the relationship between teachers' subject matter knowledge and student achievement depending on the grade level is .04. Also, the estimate of the mean correlation is .03 at the elementary level, while the estimate of the mean correlation is .07 at the secondary level.

Indicators of Teachers' subject- matter knowledge and grade level

Since previous research has shown that the effect of teacher's subject matter knowledge differs depending on grade level (Chiang, 1996), we examined the interaction of the two dummy variables. Models 3 and 4 suggest an interaction effect by grade level and different measures of teachers' subject matter knowledge on the relationship between teacher knowledge in mathematics and student achievement.

Table 6

Models by predictors (SMK & Grade)

	Estimate	S.E	Z	LLIM	ULIM
Model 1	$Q_{model}(1)=34.89$ $p<.0001$, $Q_{between}(62)=789.60$ $p<.0001$				
β_0	.08*	.02	15.84	.07	.09
β_1 (SMK_D)	-.05*	.03	-5.75	-.07	-.03
Model 2	$Q_{model}(1)=18.36$ $p<.0001$, $Q_{between}(62)=806.13$ $p<.0001$				
β_0	.03*	.01	3.17	.01	.05
β_1 (Grade)	.04*	.01	4.29	.02	.06
Model 3	$Q_{model}(2)=45.65$ $p<.0001$, $Q_{between}(61)=778.85$ $p<.0001$				
β_0	.06*	.01	5.79	.04	.08
β_1 (SMK_D)	-.05*	.01	-5.58	-.07	-.03
β_2 (Grade)	.03*	.01	3.01	.01	.05
Model 4	$Q_{model}(3)=86.06$ $p<.0001$, $Q_{between}(60)=738.43$ $p<.0001$				
β_0	-.003	.01	.04	-.02	.03
β_1 (SMK_D)	.06*	.02	2.91	.02	.09
β_2 (Grade)	.10*	.01	6.61	.07	.12
β_3 (SMK_D*Grade)	-.14*	.02	-6.17	-.17	-.09

*p<.01

Model 1: $r_i = \beta_0 + SMK\_D * \beta_1 + e_i$,

Model 2: $r_i = \beta_0 + Grade\_D * \beta_1 + e_i$,

Model 3: $r_i = \beta_0 + SMK\_D * \beta_1 + Grade\_D * \beta_2 + e_i$,

Model 4: $r_i = \beta_0 + SMK\_D * \beta_1 + Grade\_D * \beta_2 + SMK\_D * Grade\_D * \beta_3 + e_i$, where SMK_D is 1 if teacher knowledge is used for measuring teachers' subject matter knowledge and is 0 otherwise. Also, Grade_D is 1 for elementary school teachers and students, and is 0 for secondary school teachers and students.

Since teachers' SMK and grade and their interaction did not fully account for all between study differences, we estimated the mean correlations under the random-effects model. The random-effects model assumes there is a population of effects varying randomly around an average true effect. An estimate of this uncertainty is incorporated into the mean correlation and its standard error. Table 6 shows the average correlation of teachers' SMK with student achievement depending on grade level and type of SMK.

The average correlation between SMK represented by educational background at the elementary level is -.05 with a large standard error of .09. The average correlation between SMK represented by educational background at the secondary level is .05 with the standard error of .04. Both of them are not significantly different from zero. However, the average correlation between SMK represented by teacher tests at the elementary level is .11 with astandard error of .06. The average correlation between SMK represented by educational background at the elementary level is .1 with standard error of .04. Both of them are significantly different from zero.

The results indicate that SMK measured by teacher tests yields a positive relationship with student achievement at the both elementary and secondary levels. Also, the average values of the correlation are almost same regardless of grade level (.11 at the elementary level and .10 at the secondary level). The mean of the correlations between SMK represented by educational background and student achievement are essentially zero at both the elementary and secondary levels.

Table 7

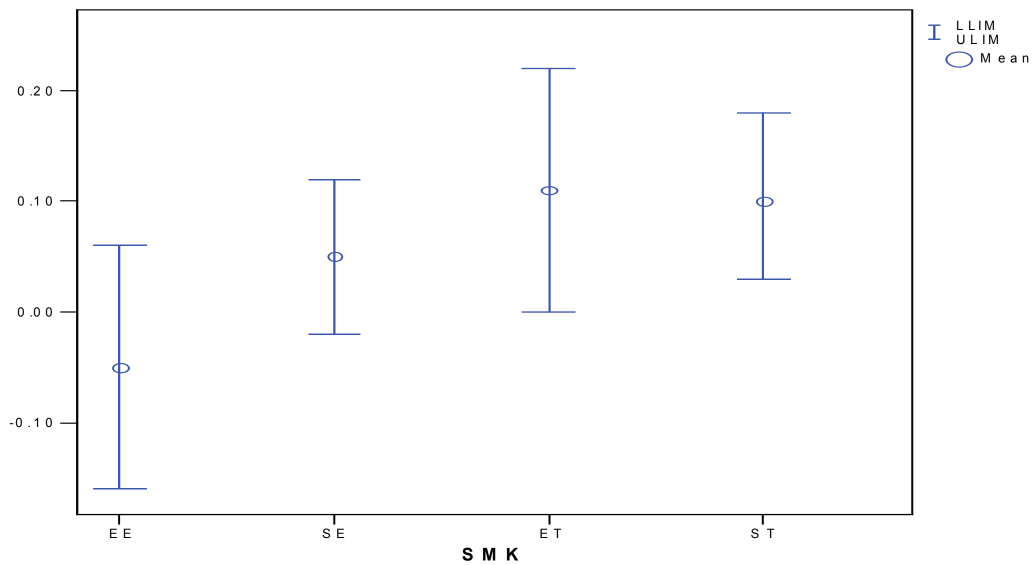
The average correlations of teachers' SMK with student achievement depending on Types of SMK and grade level

SMK	Educational background				Teacher tests			
	Mean	S.E	95% CI		Mean	S.E	95% CI	
Grade			Lower	Upper			Lower	Upper
Elementary	-.05	.09	-.16	.06	.11*	.06	.003	.22
Secondary	.05	.04	-.02	.12	.10*	.04	.03	.18

* p<.05

Figure 2

Confidence interval for SMK by grade level under the random effects



EE: Educational background variables at the elementary level
ET: Teacher tests at the elementary level
SE: Educational background variables at the secondary level
ST: Teacher tests at the secondary level

One other regression model with four predictors – SMK, grade, SMK*grade, unit of teacher and publication year – is shown in the appendix II. In this regression model, the Q_{model} is significant and Q_{error} is significant. It indicates that these four predictors explain between study variations. However, unexplained variations still exist in this model.

Categorical Analyses

In order to examine the effect of different moderators on the relationship between teachers' knowledge in mathematics and student learning, we also conducted several categorical data analyses.

Measures of teachers' SMK and grade level: All grade levels

We examined the effect of different kinds of measures of teachers' SMK across all grade levels. As shown in Table 8, since $Q_{between}$ is significant, differences between five different measures of teachers' subject matter knowledge – GPA, coursework, degree/major, test, and combinations of other indicators - explain some of the variation in correlations across all grade levels. However, there is still considerable unexplained variation and a significant Q_{within}, which indicates the predictor, types of measure of teachers' subject matter knowledge, does not give a full explanation of all the variation in the relationship between teachers' SMK and student achievement. Of the five indicators of teachers' SMK, the two groups labeled "combination of other indicators" (e.g., GPA + coursework) and certification status yielded the highest mean correlations. We found negative but insignificant correlations between teachers' subject matter knowledge and student achievement when GPA and coursework were used to represent teachers' knowledge in mathematics.

Measures of teachers' SMK and grade level: Elementary level

As shown in Table 7, since $Q_{between}$ is significant, four different measures of teachers' subject matter knowledge – coursework, degree/major, test and combination – do explain some variations of correlation in elementary school. However, there are still unexplained variations in correlation.

Measures of teachers' SMK and grade level: Secondary level

For the secondary studies the five different measures of teachers' SMK – GPA, coursework, degree/major, test and combination – do explain some variation in the correlations. However, again unexplained variation still remains.

Table 8

Fixed-effects Categorical Model by Measures of Teachers' Subject Matter Knowledge

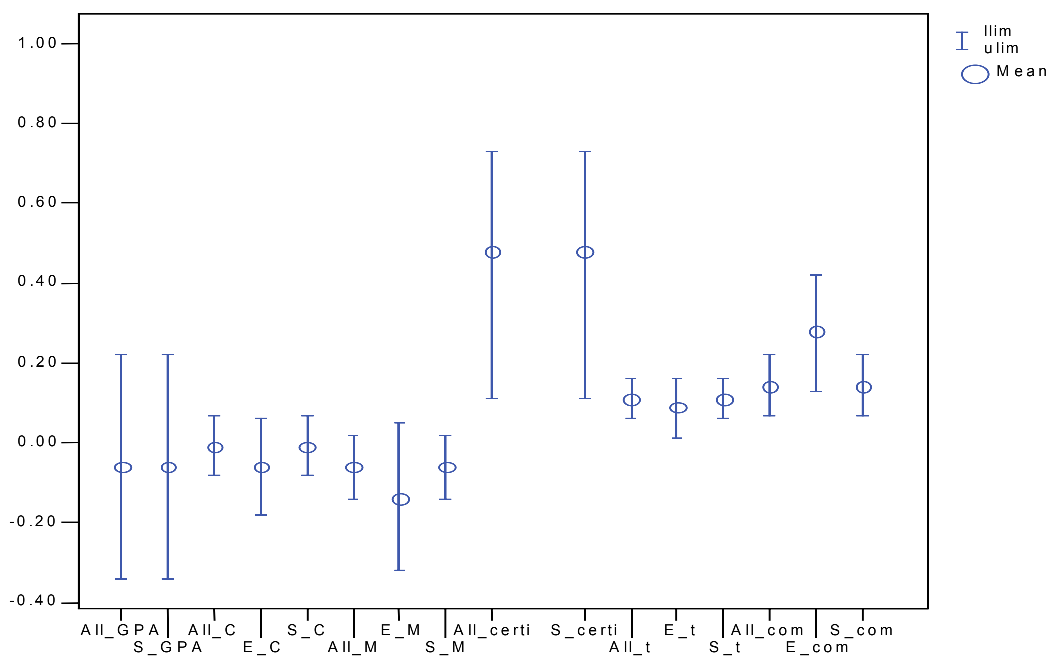
Q overall(63)=824.491 p<.0001

	K	Q	P	Mean	CI(95%) Lower	CI(95%) Upper
SMK (all grades)	Qbetween(5) =120.627 p<.0001 Qwithin(58) = 703.865 p<.0001					
GPA	2	1.11	0.29	-0.06	-0.34	0.22
Coursework	15	447.53	<.0001	-0.01	-0.08	0.07
Major/degree	13	55.57	<.0001	-0.06	-0.14	0.02
Certification status	3	11.69	0.002	0.48*	0.11	0.73
Tests	25	176.76	<.0001	0.11*	0.06	0.16
Combination	6	11.22	0.05	0.14*	0.07	0.22
SMK (elementary)	Qbetween(4) =43.814 p<.0001 Qwithin(59) = 166.650 p<.0001					
GPA	0	--	--	--	--	--
Coursework	6	32.24	<.0001	-0.06	-0.18	0.06
Major/degree	3	6.69	0.04	-0.14	-0.32	0.05
Certification status	0	--	--	--	--	--
Tests	16	139.10	<.0001	0.09*	0.01	0.16
Combination	1	0	--	0.28*	0.13	0.42
SMK(secondary)	Qbetween(5) =125.116 p<.0001 Qwithin(58) = 470.554 p<.0001					
GPA	2	1.11	0.29	-0.06	-0.33	0.22
Coursework	9	412.92	<.0001	0.03	-0.06	0.12
Major/degree	10	30.68	<.0001	-0.03	-0.13	0.06
Certification status	2	8.82	<.001	0.41	-0.19	0.78
Tests	10	9.14	0.42	0.15*	0.13	0.16
Combination	5	7.89	0.1	0.13*	0.07	0.19

Figure 3 shows confidence interval plots for SMK for all grades, the elementary level, and the secondary level. For all the categories of SMK, the mean correlation values at the elementary level are relatively low with wide range of confidence interval, while the mean correlation values at the secondary level is relatively high with narrow confidence intervals. In addition, the mean correlation values between teacher test and student achievement is a bit high with small range of confidence interval.

Figure 3

Confidence interval plots for SMK



All: all grades, E: elementary level, S: secondary level

GPA, C: coursework, M: major, Certi: certification status, T: test, Com: combinations

Other measurement variations

Variations in correlations between teachers' subject matter knowledge and student achievement will be explained by other aspects of measurement variations so we did fixed-effect categorical analysis with six moderator variables. Variables used to for this moderator analysis are 1) sources of teacher's knowledge test and student achievement test (researcher-made test versus. large-scale test), 2) types of measures for coursework (number of courses versus. credit hours), 3) scale of the measure of coursework (Continuous scale versus. categorical scale), 4) whether reliability is reported or not for teacher test, 5) unit of the teacher data (individual, classroom, or school), and 6) unit of students (individual, classroom, or school). Table 9 shows effects of other measurement variations on the relationship between teacher knowledge in mathematics and student

Table 9. *Measure variations*

	k	Q	p value	Mean	SE of mean
Source of measures (Teacher test)	$Q_{total}(24)$ =175.52 $Q_{between}(2)$ =11.27** $Q_{within}(22)$=164.25**				
Large-scale based	5	18.29**	<.001	.13*	.05
Research-based local	20	145.97**	<.001	.10*	.03
Measure of coursework	$Q_{total}(14)$ =585.29 $Q_{between}(1)$ = 429.23** $Q_{within}(13)$ = 156.06**				
Number of courses	8	90.27**	<.001	-.09	.05
Credit hours	7	65.78**	<.001	.06	.01
Level of coursework	$Q_{total}(14)$ =585.29 $Q_{between}(1)$ = 14.96** $Q_{within}(13)$ = 570.33**				
General mathematics	12	367.51**	<.001	.004	.03
Higher level mathematics	3	202.82**	<.001	-.12	.15
Whether reliability is reported or not	$Q_{total}(24)$ =175.52 $Q_{between}(1)$ = 40.59** $Q_{within}(23)$ = 134.93**				
Reported	8	117.58**	.02	.08*	.04
Unreported	17	17.35**	<.0001	.16*	.02
Unit of teacher data	$Q_{total}(63)$ =824.49, $Q_{between}(1)$ =44.22**, $Q_{within}(62)$=780.27 **				
Individual	61	798.63**	<.0001	.05*	.03
School	3	1.33	.51	.14*	.02
Unit of student data	$Q_{total}(63)$ =824.49, $Q_{between}(2)$ =44.36**, $Q_{within}(61)$=780.13 **				
Individual	24	495.79**	<.0001	.07*	.02
Classroom	37	283.00**	<.0001	.03	.04
School	3	1.33	.51	.14*	.02

** p<.01

Source of the measures. For teacher knowledge test, the source of the measure explains some variation of correlation ($Q_{between}(1)$ =11.27 p<.0001). However, unexplained variance remains in the effect size by this moderator. The means of correlation under random-effects model are .13 and .10 for large-scale based test and research based local test. The mean correlation for large-scale based test yields a bit higher correlation value.

Measures of coursework. The kinds of measure of coursework, either number of courses taken or credit hours of mathematics, explains the variation in correlation between teachers' subject matter knowledge and student achievement ($Q_{between}(1) = 429.23$, $p<.001$). However, this does not fully explain variation among the correlations ($Q_{within}(13) = 156.06$, $p<.001$).

Types of coursework. Two different types of coursework, general mathematics courses or higher level mathematics courses, explain some variations in the correlation between teachers' subject matter knowledge represented by coursework in mathematics and student achievement ($Q_{between}(1) = 14.96$, $p<.001$). However, again this moderator does not fully explain differences in these correlations ($Q_{within}(13) = 570.33$, $p<.001$).

Whether reliability of teachers' subject matter knowledge is reported or not. Whether reliability of teachers' subject matter knowledge is reported or not does explain variations in the correlations ($Q_{between}(1) = 40.59$, $p<.001$). Even though this cannot fully explain the variations of effect size, the studies that report reliability have lower positive correlation values than those that do not report reliability ($Q_{within}(23) = 134.93$, $p<.001$). The mean correlation of SMK and student learning under the random-effects model is higher when the study did not report reliability for teacher tests than that when study did report reliability information for teacher tests.

Unit of analysis. The unit of the teacher data explains some between study differences, but it also does not fully account for the variation in correlations between studies ($Q_{between}(1)$ $=44.22$, $p<.0001$). The average correlation under random-effects model is lower at the individual teacher level than at the school level. Unit of students also explain some of between study differences, but it also does not fully account for the variations between studies ($Q_{between}(2)$

=44.36, p<.0001). The average correlation under random-effects model is the lowest at the classroom level.

Other moderators

Two other moderators – publication type and content of mathematics - are tested. Table 10 shows the categorical analyses by publication type and content areas in mathematics. Even though both moderators explain some variations between studies, unexplained between studies differences remain.

Table 10

Publication type and topic areas in mathematics

	Q	K	P value	Mean	SE of mean
Publication type	$Q_{total}(63)$ =824.49, $Q_{between}(3)$ =44.22** , $Q_{within}(60)$=780.27 **				
Journal	13.83**	7	.03	.12	.06
Dissertation	674.35**	39	<.001	.08	.04
Reports	92.10**	17	<.001	.01	.03
Conference paper	--	1	--	--	--
Topic areas	$Q_{total}(63)$ =824.49, $Q_{between}(4)$ =10.16*, $Q_{within}(58)$ = 57.58**				
General math	526.44**	22	<.001	.10**	.04
Arithmetic	179.74**	16	<.001	.04	.04
Algebra	90.46**	20	<.001	.02	.001
Geometry	17.69	5	<.001	.11	.16
Other	0	1	--	--	--

* p<.05 **p<.01

CONCLUSION

While scholars emphasize the importance of teachers' subject matter knowledge for teaching and learning, the results of empirical studies have been inconsistent. Based on our literature review, we identified several potential moderators that may influence study findings on the relationship between teachers' subject matter knowledge and student mathematics achievement. We conducted a meta-analysis based on 27 primary studies in order to examine the effects of different moderators on the relationship between teachers' subject matter knowledge and student learning. In particular, we focused on measurement variations (i.e., of the different indicators of teachers' subject matter knowledge) to explain the diverse results on the relationship between what teachers know in mathematics and student learning. The following findings emerged in the meta-analysis.

(1) Under the random-effects model, teachers' subject matter knowledge was positively related to student mathematics achievement but the magnitude of the estimated mean correlation coefficient across the 27 studies was very small ($r = .06$).

(2) The strength of the relationship between teachers' subject matter knowledge and student mathematics achievement was moderated by different types of indicators of subject matter knowledge. Under the random-effects model, the estimated mean correlation was .02 when subject matter knowledge was measured by educational background variables, but the estimated mean correlation was .11 when subject matter knowledge was measured by teacher tests.

(3) The relationship of teachers' subject matter knowledge to student mathematics achievement is moderated by grade level taught. Under the random-effects model, while the estimated mean correlation was .05 at the elementary level (grade 1-6), the estimated mean correlation was .07 at the secondary level (grade 7-12).

(4) There was an interaction effect between grade level taught and types of indicators of teachers' subject matter knowledge. Under the random-effects model, while the estimated mean correlation was -.05 at the elementary level when subject matter knowledge was measured by educational background variables, the mean correlation was .05 at the secondary level when subject matter knowledge was measured by educational background variables. However, the

estimated mean correlations were similar at elementary level and secondary level when subject matter knowledge was measured by teacher tests. As a result, the indicators of teachers' subject matter knowledge show different strengths of the relationship between the extent of teachers' knowledge in mathematics and student achievement depending on the grade level of students.

(4) Other characteristics of measures such as sources of teacher knowledge tests, types of coursework measures, whether reliability is reported or not for teacher knowledge tests, and unit of analysis also account for some part of the variation in correlations between teachers' subject matter knowledge and student achievement.

(5) None of moderators fully explains the variations among the correlations between teachers' subject matter knowledge and student achievement. The results of our meta-analysis indicate other moderator variables may predict the unexplained variations of correlation between teachers' subject matter knowledge and student achievement.

LIMITATION

Our meta-analysis has several limitations investigating the relationship between teachers' subject matter knowledge and student mathematics achievement and the variables that moderate the relationship. The first limitation is that we did not include all the quantitative studies that have examined the relationship between teachers' subject matter knowledge and student achievement. A number of studies using multiple regression and hierarchical linear model (HLM) were omitted for our meta-analysis. Due to these omitted studies, this meta-analysis can only be generalized to correlational studies. In addition, because some studies that examined teacher subject matter knowledge represented by degree level in mathematics and student achievement were omitted (e.g., Goldhaber & Brewer, 1997; 2000), we could not examine how degree level as a measure of teachers' subject matter knowledge related to student achievement in this meta-analysis.

Second, we did not include qualitative studies that examined the relationship between what mathematics teachers know and the quality of teaching (e.g., Stein, Baxter, & Leinhardt, 1990). Those qualitative studies focused more on the influence of teachers' subject matter knowledge on their instructional practices rather than on student mathematics achievements and found a more clear and positive connection using different measures of subject matter knowledge such as interview with teachers and task completion. Unfortunately, we cannot incorporate qualitative research into quantitative meta-analysis. The inferences from this meta-analysis should be interpreted with the valuable information provided by qualitative research in this area.

Third, in this study we only investigated teachers' subject matter knowledge as related to student achievement test scores, which is just one indicator of student learning influenced by teachers' subject matter knowledge. There are other indicators of student learning such as students' interests toward mathematics and communication with peers in mathematics classrooms that can be influenced by teachers' subject matter knowledge. Thus, teachers' subject matter knowledge should also be appreciated in relation to other indicators of student learning as well as teachers' instructional practices.

Fourth, there are other moderators that were not examined in our meta-analysis to explain variations in study findings because information was not available or not enough for our meta-analysis. One of potential moderators is feature of student mathematics achievement tests. While we examined whether measures of teachers' subject matter knowledge influence study outcomes, we did not examine the influence of different types of student achievement tests. For example, while some studies used large-scale standardized tests to measure student achievement, several studies used teacher-made tests. It may be that the correlation between teachers' subject matter knowledge and student mathematics achievement is higher when student tests are aligned with what teachers taught (e.g., Moody, 1968). What the tests assess could also be a feature of student achievement tests. While a student achievement test or a sub-test assesses students' computation skills, another test assesses students' thinking skills. Depending on what the tests assess, the relationship between teachers' subject matter knowledge and student achievement test scores may differ (e.g., Mandeville & Liu, 1997). Another potential moderator is students' achievement level. It would be different in study findings depending on where students were selected. That is, whether students were selected from high achieving schools or low achieving schools depending on school locations would influence study findings (e.g., Bassham, 1962; Reed, 1986).

IMPLICATATION

This research has implications for tow audiences: 1) educational researchers or policy makers who make inferences about the relationship between teachers' subject matter knowledge and student learning and 2) methodologists who want to carry out research synthesis in education or social science.

As found in this meta-analysis, the relationship between teachers' subject matter knowledge and student learning differs depending on measurement variations. Thus we argue that educational researchers and policy makers should carefully examine different aspects of measurement such as scales, types of measures, and unit of analysis before making inferences from the findings.

Methodologists who carry out meta-analyses should consider a number of important moderators to explain study variations found in primary studies. In particular, most outcomes in educational areas are influenced by a number of factors. It is important for meta-analysts to find the most important predictors to explain the variations in the findings. In addition, for future research one important issue will be to find ways to incorporate various research designs into meta-analysis. In particular we intend to synthesize with the current studies other research studies using different data analytic techniques such as HLM and multiple regression.

Appendix I: Characteristics of all studies included in meta-analysis

Study	Pub_year	Source	U_S	U_T	N	Areas	Grade	Grade_D	SMK	SMK_D	R
Bachman	1968	2	1	1	210	2	7	1	7	0	-0.04
Bachman	1968	2	1	1	194	2	7	1	7	0	0.16
Bassham	1962	1	1	1	648	1	6	0	6	1	0.27
Begle	1972	3	1	1	620.5	3	9	1	6	1	0.16
Begle	1972	3	1	1	620.5	3	9	1	6	1	0.22
Begle	1972	3	1	1	620.5	3	9	1	6	1	0.1
Begle	1972	3	1	1	620.5	3	9	1	6	1	0.14
Begle & Geeslin	1972	3	2	1	72	3	4	0	3	0	-0.34
Begle & Geeslin	1972	3	2	1	462	3	4	0	3	0	-0.03
Begle & Geeslin	1972	3	2	1	544	3	4	0	3	0	-0.11
Begle & Geeslin	1972	3	2	1	310	3	7	1	3	0	-0.09
Begle & Geeslin	1972	3	2	1	224	3	7	1	3	0	0.02
Begle & Geeslin	1972	3	2	1	102	3	7	1	3	0	-0.14
Begle & Geeslin	1972	3	2	1	78	3	7	1	3	0	0.12
Begle & Geeslin	1972	3	2	1	230	4	10	1	3	0	-0.01
Begle & Geeslin	1972	3	2	1	74	4	10	1	3	0	0
Begle & Geeslin	1972	3	2	1	102	4	10	1	3	0	-0.19
Brown	1988	2	2	1	200	1	1-6	0	2	0	-0.35
Brown	1988	2	2	1	200	1	1-6	0	2	0	0.03
Caezza	1969	2	1	1	537	1	2	0	6	1	0.08
Caezza	1969	2	1	1	571	1	3	0	6	1	-0.08
Caezza	1969	2	1	1	458	1	4	0	6	1	0.1
Caezza	1969	2	1	1	533	1	5	0	6	1	0.18
Caezza	1969	2	1	1	483	1	6	0	6	1	0
Chiang	1996	2	1	1	5381	1	8	1	6	1	0.14
Chiang	1996	2	1	1	5381	1	8	1	2	0	0.03
Chiang	1996	2	1	1	5381	1	8	1	3	0	0.08
Chiang	1996	2	1	1	5381	1	10	1	2	1	-0.17
Chiang	1996	2	1	1	5381	1	10	1	3	0	0.03
Chiang	1996	2	1	1	5381	1	10	1	6	0	0.15

Dicks	1990	2	1	1	646	2	1-6	0	6	1	-0.01
Eigenberg	1977	1	2	1	25	3	J/h	1	1	0	-0.23
Eigenberg	1977	1	2	1	25	3	J/h	1	2	0	-0.17
Eigenberg	1977	1	2	1	25	3	J/h	1	6	1	-0.1
Fagnano	1988	2	2	1	4764	2	8	1	2	0	0.2
Hawk	1985	1	1	1	569	3	6-12	1	7	0	0.18
Hawk, Coble, & Swanson	1985	1	1	1	44	5	6-12	1	7	0	0.09
Koch	1972	2	2	1	52	2	6	0	6	1	0.02
Kim	1992	2	4	4	3551	1	8	1	2	0	0.14
Lampela	1966	2	2	1	140	2	4-6	0	6	1	0.1
Lampela	1966	2	2	1	140	2	4-6	0	6	1	0.03
Mandeville & Liu	1997	1	4	4	132	1	7	1	7	0	0.16
Moody	1968	2	2	1	26	4	5	0	5	0	0.64
Moore	1965	2	2	1	284	2	4	0	6	1	0.36
Moore	1965	2	2	1	245	2	6	0	6	1	-0.19
Peskin	1964	2	2	1	54	2	7	1	6	1	0.34
Peskin	1964	2	2	1	58	4	7	1	6	1	0.12
Prather	1991	2	2	1	38	1	8	1	5	0	0.64
Prekeges	1973	3	1	1	1722	2	456	0	6	1	-0.05
Prekeges	1973	3	1	1	1722	2	456	0	2	0	0.02
Prekeges	1973	3	1	1	1722	2	456	0	2	0	0.05
Teddelie, Falk, & Falkowski	1983	4	4	4	35	1	3	0	6	1	0.33
Turgoose	1996	2	2	1	160	1	6	0	6	1	0.24
Turgoose	1996	2	2	1	160	1	6	0	7	0	0.28
Reed	1986	2	2	1	60	1	8	1	2	0	0.15
Reed	1986	2	2	1	60	1	8	1	5	0	0.12
Rouse	1967	2	2	1	129	2	4	0	2	0	-0.05
Rouse	1967	2	2	1	128	2	6	0	2	0	-0.08
Rouse	1967	2	2	1	128	2	8	1	2	0	-0.2
Smith	1964	2	2	1	54	3	8	1	2	0	0.1
Soeteber	1969	2	2	1	34	3	9-12	1	1	0	0.06
Soeteber	1969	2	2	1	34	3	9-12	1	2	0	0.14
Soeteber	1969	2	2	1	34	3	9-12	1	3	0	-0.4

Soeteber	1969	2	2	1	22	3	9-12	1	6	1	0.24

Pub_year: Publication year
Sources: 1. Journal article, 2. Dissertation, 3. Reprots, and 4. Conference paper.
U_T (Unit of teachers) : 0. School, 1. Individual.
U_S (Unit of students) : 0. School, 1. Individual, and 2. Classroom.
N (Number of samples in the correlation).
Subject: 1. General mathematics, 2. Algebra, 3. Arithmetic, 4. Geometry.
Grade: grade level.
Grade_D (Dummy variables of grade level): 0. Elementary, 1. Secondary.
SMK (Indicators of teachers' subject-matter knowledge): 1. GPA in Mathematics, 2. Coursework in Mathematics, 3. Major/Degree in Mathematics, 5. Certification status, 6. Teacher tests, and 7. Combinations of educational background.
SMK_D (Dummy variables of SMK): 0. Educational background, 1. Teacher tests.
R: Correlation values

Appendix II: Regression model with five predictors

Table 11

Weighted regression model with five predictors

Q_{total} (63) =824.49 Q_{model}(5)=124.93 p<.0001 Q_{error}(58)=699.56 p<.0001

	Estimate	SE	SE	z	LLIM	ULIM
Intercept	6.3*	3.87	1.11439	5.65332	4.1158	8.4842
SMK_D	0.04*	0.06	0.01728	2.31517	0.00614	0.07386
Grade_D	0.15*	0.06	0.01728	8.68188	0.11614	0.18386
Grade_D & SMK_D	-0.12*	0.07	0.02016	-5.9533	-0.1595	-0.0805
Pub_year	-0.003*	0.002	0.00058	-5.2091	-0.0041	-0.0019
U_T	-0.05	0.06	0.01728	-2.894	-0.0839	-0.0161

Model:

$$r_i = \beta_0 + SMK\_D * \beta_1 + Grade\_D * \beta_2 + SMK\_D * Grade\_D * \beta_3 + Pub\_year * \beta_4 + U\_T * \beta_5 + e_i$$

,where SMK_D is 1 if teacher knowledge is used for measuring teachers' subject matter knowledge and SMK_D is 0 if educational background variable is used for measuring what teachers know in mathematics. Grade_D is 1 for elementary school teachers and students, and Grade_D is 0 for secondary school teachers and students. And, U_T is 0 for individual teacher level and U_T is 1 for school level teacher.

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