Cross-national study of lower secondary mathematics teachers' content knowledge in the USA and Russia

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The quantitative study focused on comparative analysis of middle school mathematics teachers' content knowledge in two countries. The sample consisted of lower secondary mathematics teachers from the US (grades 6-9, N=102) and Russia (grades 5-9, N=97). The instrument was designed to assess teacher content knowledge based on the cognitive domains of knowing, applying, and reasoning, as well as addressing the lower secondary mathematics topics of Number, Algebra, Geometry, Data and Chance. The results suggest that there are significant differences in teacher knowledge between the countries in content as well as in cognitive domains. The study results may inform the field on priorities placed on lower secondary mathematics teachers' knowledge in USA and Russia.

Keywords: Comparative studies, teacher knowledge, lower secondary mathematics.

Introduction

The motivation for the study is based on the 8th-grade mathematics portion of the TIMSS-2011 results (Mullis et al. 2012). We identified two countries ranked closely to each other: Russia - in the 6th position and the USA – in the 9th position. At the same time, a difference in the US and Russian students' scores was revealing: the average score of Russian students in the content domain was 539 and of the US students 509, with Russian students gaining higher scores on Number (534 vs. 514), Algebra (556 vs. 512) and Geometry (533 vs. 485) whereas US students outscored Russian students in the domain of Data and Chance (527 vs. 511). Russian students also outperformed the US students in each cognitive domain: Knowing (548 vs. 519) Applying (538 vs. 503), and Reasoning (531 vs. 503). These data triggered the following research question: to what extend the US and Russian lower secondary mathematics teachers' knowledge differ by content and cognitive domains?

Cross-national studies of teacher knowledge

Conducting cross-national studies allow comparing, sharing, and learning about issues in an international context which in turn help researchers understand their own context, teaching practice, teacher knowledge, and student learning (Stigler & Perry, 1988). During the last decade, the number of cross-national studies on teacher education is increasing in order to understand differences in student performance on international tests such as TIMSS, PISA (Wang & Lin, 2005). Scholars have addressed these differences focusing on characteristics such as teachers' perceptions of effective mathematics teaching (Cai, Ding, & Wang, 2013), teacher knowledge (Tatto & Senk, 2011; Tchoshanov et al., 2015), among others.

Few cross-national studies focused on teacher knowledge. A large-scale study conducted by the University of Michigan examined the mathematical content and pedagogical content knowledge of pre-service teachers from 17 countries including USA and Russia (Tatto & Senk, 2011). The nature of mathematics teacher knowledge, conceptual representation, and curriculum materials were examined by Ma (1999) to explain differences in students´ performance in the U.S. and China. An, Kulm, and Wu (2004) studied the PCK of middle school teachers in the U.S. and China. They found that mathematical PCK differs since Chinese teachers emphasize developing procedural and conceptual knowledge through traditional teaching practices while their counterparts in the U.S. focus on promoting creativity and inquiry through activities designed to develop student´s understanding of mathematical concepts. Sorto et al. (2009) administered surveys that measured teachers' content knowledge in Costa Rica and Panama and found that teachers in both countries focus more on knowing rules and procedures than on making connections and reasoning.

Recently, the field of mathematics education is expanding its knowledge-base in understanding the role of teacher characteristics in student learning and achievement. The major shift in the field had happened with Shulman's (1986) work on teacher knowledge that proposed an alternative approach to the educational production function perspective, which was concerned with examining proxies of teacher knowledge such as coursework/certification and its impact on student achievement (Charalambous & Pitta-Pantazi, 2016). Research on teacher knowledge initiated by work of Shulman (1986) has focused on teacher knowledge as a major predictor of student learning and achievement. In the last decade, the field benefited from numerous studies (Hill, Ball, & Schilling, 2008; Baumert et al., 2010) that substantially advanced the conceptualization of teacher knowledge.

Capitalizing on Shulman's (1986) work, scholars examined different categories of teacher knowledge. Content or subject-matter knowledge and pedagogical content knowledge are the most important categories of teacher knowledge. Bransford, Brown, and Cocking (2000) state that content knowledge requires "a deep foundation of factual knowledge, understanding of the facts and ideas in the context of a conceptual framework, and organization of the knowledge in ways that facilitate retrieval and application" (p. 16). Hill, Ball, and Schilling (2008) consider a special kind of teacher knowledge that combines content and pedagogical content knowledge - mathematical knowledge for teaching. It is knowledge "that allows teachers to engage in particular teaching tasks, including how to accurately represent mathematical ideas, provide mathematical explanations for common rules and procedures, and examine and understand unusual solution methods to problems" (p. 378).

Some scholars (Izsak, Jacobson, & de Araujo, 2012) examined different facets of teacher knowledge without explicitly emphasizing its connection to student learning. Other scholars stressed the importance of the kind of knowledge a teacher possesses because it impacts his/her teaching (Steinberg, Haymore, and Marks, 1985). Another line of research (e.g., Baumert et al, 2010; Hill, Ball, & Schilling, 2008; Tchoshanov, 2011) specifically targets the effects of different types of teachers' knowledge on student achievement.

Recently, scholars have advanced the field by examining teacher knowledge in variety of domains including Number Sense (Ma, 1999; Izsac, Jacobson, & de Araujo, 2012), Algebra (McCrory et al., 2012), Geometry and Measurement (Nason, Chalmers, & Yeh, 2012), and Statistics (Groth & Bergner, 2006). However, the field lacks cross-national research that provides a comprehensive analysis of the various facets of teacher knowledge (including content and cognitive domains) and its connection to student performance.

Methodology

The proposed study is based on the assessment framework used by TIMSS (Mullis et al. 2012). In this section, we will describe the study participants, the instrument as well as data collection and data analysis procedures.

The sample of this study consisted of lower secondary mathematics teachers from the US (grades 6-9, N=102) and Russia (grades 5-9, N=97). The US teacher-participants were selected from urban public middle schools in the Southwestern part of the country. Teacher sample demographic information was self-reported by participating teachers. In terms of gender distribution, 55% of teacher participants were females and 45% - males. Most of the US participants (64%) had 1-5 years of teaching experience. Additionally, 62% of the teacher sample received their teaching certificate through traditional teacher preparation programs and 38% of participating teachers were certified through alternative programs. The Russian teacher-participants were selected from urban public secondary schools in the Volga region. Russian participating teachers had attained a secondary mathematics teacher preparation Specialist's degree[1], which allowed them to teach in secondary schools (grades 5-11). The majority of participating teachers were females (89%). The sample was composed of 78% of teachers who have more than 10 years of teaching experience.

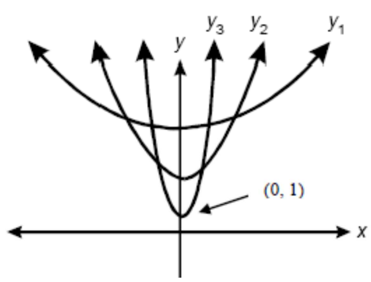

Figure 1. Diagram to the TCKS item in Algebra domain

The instrument used in this study was the Teacher Content Knowledge Survey which was developed using TIMSS framework (Mullis et al. 2012). It was designed to assess teacher content knowledge based on the three cognitive domains: Knowing, Applying, and Reasoning. The TCKS survey consisted of 33 multiple-choice items topics addressing main objectives of lower secondary mathematics curriculum: Number, Algebra, Geometry, Data and Chance. The alpha coefficient technique was utilized to evaluate the reliability of the teacher content knowledge survey. "The value of the coefficient of *.839* suggests that the items comprising the TCKS are internally consistent" (Tchoshanov,

[1] In Russia, the secondary school consists of lower and upper levels: the lower secondary school includes grades from 5 to 9, and grades 10-11 are part of the upper secondary school.

2011). Examples of the TCKS items in Algebra domain across different cognitive types (Knowing, Applying, and Reasoning) are presented below.

Use the diagram above (see Figure 1) to answer the questions that follow.

1. Knowing

Which of the following equations best describes the function y_3?

A. $y = ax^2 + bx + c$
B. $y = ax^2 + bx + 1$
C. $y = ax^2 + 1$
D. $y = x^2 + 1$.

2. Applying

The function y_3 is translated *4* units left and *7* units down. Which of the following equations best describes the new function?

A. $y = ax^2 + 11x + 28$
B. $y = ax^2 + 4x + 7$
C. $y = ax^2 + 8ax + c$
D. $y = x^2 + 28x + 11$.

3. Reasoning

The diagram shows a family of functions in the form $y = ax^2 + bx + c$. Which of the following statements best describes the changes in the values of the coefficients as the graphs transform from y_1, to y_2, to y_3?

A. a is increasing, $b = 0$, and c is increasing
B. a is increasing, $b = 0$, and c is decreasing
C. a is decreasing, b is increasing, and $c = 0$
D. a is decreasing, b is decreasing, and $c = 0$.

Each teacher was given 90 min to complete the survey. Along with teachers' scores on the TCKS, teachers' demographic information such as gender and ethnicity, years of teaching experiences, as well as other proxies for teacher content knowledge (i.e., mathematics coursework) were also collected. In correspondence with the research question, data analysis was performed using non-parametric techniques (chi-square test of goodness of fit). This statistic was selected to measure the variance between independent groups of the same (not normal) distribution with arbitrary sample sizes of each group. The selection of this test was also based on the ordinal (ranked) nature of data for content and cognitive domains of teacher knowledge and student performance.

Results

In this section, we first analyze teacher knowledge data by content domain, then we examine teacher data by cognitive domain, and finally we discuss parallels between student and teacher performance within and between countries. The results reported on teacher content knowledge show that the US teachers' highest mean score was obtained on Number domain – 623 and lowest on Geometry domain - 514 (see Table 1). Russian teachers' highest mean score was obtained on Algebra domain – 728 and lowest on Data and Chance domain – 387 (see Table 2). Moreover, we found that the US teachers' highest mean score was obtained, as expected, on Knowing domain – 734 and lowest on Reasoning domain - 495 (see Table 3). Russian teachers' highest mean score was obtained, as expected, on Knowing domain – 760 and lowest, unexpectedly, on Applying domain - 504 (see Table 4). Moreover, we identified that there is no significant difference between Russian and US teachers' knowledge on Number and Geometry domains (*Chi-square 0.347 p>.05 and Chi-square 1.293 p>.05*) (see Table 5).

Content Domain	Mean	SE	SD	Conf. level (95%)
Number	623	20.3129	205.1512	40.296
Algebra	563	23.2356	234.6679	46.093
Geometry	514	25.4349	256.8802	50.456
Data and Chance	593	20.9738	211.8252	41.606

Table 1. US teachers´ means scores by content domain

Content Domain	Mean	SE	SD	Conf. Level (95%)
Number	656	106.5819	319.7456	23.873
Algebra	728	82.8841	248.6523	30.648
Geometry	586	72.7004	218.1013	45.505
Data and Chance	387	125.0891	306.4044	35.844

Table 2. Russian teachers´ means scores by content domain

Cognitive Domain	Mean	SE	SD	Conf. level (95%)
Knowing	734	19.7673	197.6733	39.2226
Applying	505	20.7101	207.1015	41.0934
Reasoning	495	23.8130	238.1303	47.2502

Table 3. US teachers´ means scores by cognitive domain

Cognitive Domain	Mean	SE	SD	Conf. level (95%)
Knowing	760	14.2486	135.1745	28.3117
Applying	504	12.7961	121.3950	25.4257
Reasoning	593	17.7406	168.3028	35.2503

Table 4. Russian teachers´ means scores by cognitive domain

Content Domain	Number	Algebra	Geometry	Data and Chance
Russia	656	728	586	387
USA	623	563	514	593
Chi-square	0.347	6.311*	1.293	8.003**
p-value	0.5558	0.0119	0.2555	0.0047

Table 5. Russian and US teachers' knowledge by content domain

However, there is a statistically significant difference between Russian and US teachers' knowledge on Algebra domain (in favor of Russian teachers; *Chi-square 6.311 p<.05*) and Data and Chance domain (in favor of US teachers; *Chi-square 8.003 p<.05*) (see Table 5). This finding closely parallels the US and Russian *students' performance* on TIMSS on Algebra domain (in favor of Russian students) and Data and Chance domain (in favor of US students).

Also, this study reported that there is no significant difference between Russian and US teachers' knowledge on Knowing and Applying cognitive domains (*Chi-square 1.707 p>.05 and Chi-square 0.008 p>.05*) whereas there is a statistically significant difference on Reasoning domain (in favor of Russian teachers; *Chi-square 19.117 p<.05*) (see Table 6).

Cognitive Domain	Knowing	Applying	Reasoning
Russia	760	504	593
USA	734	505	495
Chi-square	1.707	0.008	19.117**
p-value	0.1914	0.9287	0

Table 6. Russian and US teachers' knowledge by cognitive domain

This finding parallels the US and Russian students' performance on TIMSS' cognitive domain.

Discussion and Conclusion

This study confirms the differences between Russian and the U.S. lower secondary in-service teachers' knowledge in the content domain as it was reported by the TEDS-M study that was focused on pre-service teachers (Tatto & Senk, 2011). At the same time, this study expands the examination of in-service teachers' knowledge to the cognitive domain.

Teacher preparation could be considered as the main factor contributing to the differences between Russian and US teachers' knowledge. Overall, there is a tangible difference in secondary teacher preparation curriculum between the two countries: in average, Russia offers about 240 credit hours in teacher preparation programs compare to 120 credits in the USA. Furthermore, cross-national curriculum analysis shows that Russian teachers have more extensive content preparation compare to their American counterparts. A number of contact hours for mathematical content knowledge, as well as pedagogical content knowledge and specialized mathematics knowledge offered at selected teacher preparation programs (e.g., the University of Texas at El Paso, USA and Kazan Federal University, Russia) in two countries, is presented in table 7.

Country	Mathematics Content Knowledge (Academic Mathematics)	Pedagogical Content Knowledge (Mathematics Pedagogy)	Specialized Mathematics Knowledge (School Mathematics)
Russia	1857	278	380
United States	442	72	87

Table 7. Contact hours in Mathematics related disciplines in teacher education programs in Russia and United States

Numbers depicted in the table are compatible with the findings of the TEDS-M study (Tatto & Senk, 2011). Close examination of secondary teacher preparation curriculum in Russia shows that more emphasis is placed on an analytic and algebraic component of mathematics and less emphasis - on statistic and probability component compare to the US curriculum. Moreover, item analysis of standardized tests for the lower secondary schools in USA and Russia revealed the difference in selection and composition of algebra problems as well as problems related to data and chance in the test: while in Russia more emphasis is placed on algebraic problems and less emphasis on data and chance problems, in the USA – the emphasis is equally distributed among algebraic problems and data and chance problems. We observed another noticeable difference in the role of proof in the academic mathematics component of the teacher preparation program which could explain the difference in the reasoning domain of the teacher knowledge: Russian curriculum places a heavy emphasis on proof across the mathematics coursework including school mathematics whereas the US curriculum uses proof in selected mathematics courses primarily in academic mathematics coursework.

We are cognizant of the limitations concerning the convenient sampling technique that influences generalizability of the study results. Moreover, there is no cluster matching between teachers participating in the study and students tested in TIMSS. However, the study main results suggest that student performance on international tests could be explained by teacher knowledge. The study also presents opportunities for comparing, sharing, and learning about issues in cross-national context in US and Russian teacher education, training, and development. Moreover, the reported cross-national study on teacher knowledge may inform the field on priorities placed on lower secondary mathematics teachers' knowledge in USA and Russia by content and cognitive domains.

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