Nervous about Numbers: 
Math Content Knowledge and 
Math Anxiety of Teacher Candidates

Mary Reid a Steven Reid a Jim Hewitt a
a Ontario Institute for Studies in Education of the University of Toronto

Abstract

This study analyzed the math content knowledge (MCK) and math anxiety (MA) levels of 99 elementary teacher candidates (TCs) before and 97 TCs after a math methods course. Through a mixed methods research design, MCK and MA were measured via quantitative instruments, while qualitative data was gathered through semi-structured interviews. Findings revealed a strong negative correlation between MA and MCK. A major factor that contributed to TCs’ anxiety was their perceived inadequate math knowledge. As TCs developed their MCK throughout the course, anxiety levels significantly decreased. Due to the interplay between MCK and MA, it is recommended that pre-service education programs implement mandatory math content courses designed to increase TCs’ MCK and confidence. This will promote increased math competencies and reduced math anxiety of future TC graduates.

Introduction

This study examined the constructs of math content knowledge (MCK) and math anxiety (MA), and how the two phenomena interplay in pre-service math education. Reid and Reid (2017) defined MCK as “the basic math knowledge possessed by individuals considered to be mathematically literate” (p. 853). A deep conceptual understanding of MCK is essential for the development of math knowledge for teaching (Ball, Thames, & Phelps, 2008; Thames & Ball, 2010). However, the literature reveals that a great percentage of elementary teacher candidates (TCs) and in-service teachers possess high levels of MA, which can impede math teaching effectiveness (Shield, 2005; Vinson, 2001). According to Chang and Beilock (2016), MA is defined as an emotional feeling of nervousness and apprehension about one’s own ability to understand math, perform math functions, and/or explain problems. Common behaviours of highly math anxious teachers include: allocating less time to teaching math, ineffectively explaining, describing and modelling math concepts, and gravitating towards teacher-directed rote methods (Dunkle, 2010; Finlayson, 2014; Karp, 1991; Relich, 1996). The purpose of this study was to examine the relationship between elementary TCs’ MA and MCK over the span of a course on math teaching methods. It may be assumed that TCs who have limited MCK and higher MA may feel less confident about their math teaching skills. This in turn could encourage behaviours of math avoidance and pedagogical practices that are rigid and inflexible (Beilock & Maloney, 2015).
Further research is necessary to examine the relationship between MA and MCK in the context of math teacher preparation in order to gain a deeper understanding of the interplay between and within the two constructs.

**Literature Review**

**Math Content Knowledge of Elementary Teacher Candidates and In-Service Teachers**

Math content knowledge (MCK) of elementary teachers (teacher candidates [TCs] and in-service) has been widely researched over the last three decades. Strong content knowledge is an important construct that supports the development of math teaching capacities (Philipp et al., 2007; Thames & Ball, 2010). Ball, Thames, and Phelps (2008) argue that without a solid foundation of MCK, successful math instruction and student learning of the content would be questionable. Ma’s (1999) landmark study of American and Chinese teachers revealed disconcerting evidence of deficiencies in American teachers’ MCK for teaching. Overall results demonstrated that Chinese teachers overwhelmingly understood and explained math concepts better than their American counterparts. For example, fewer than 20% of the American teachers were able to explain the conceptual knowledge of regrouping, while 86% of Chinese teachers demonstrated a firm grasp of this concept. A foundational understanding of number sense is necessary for more complex reasoning and problem solving (Biddlecomb & Carr, 2011; Dehaene, 2011). Ma (1999) discusses in great detail how Chinese teachers’ profound understanding of math contributes to their students’ success in the discipline. She speculates that a salient difference between the two groups begins at an early age, where Chinese elementary math teachers possess specialized understanding of the discipline allowing them to teach concepts in a comprehensive way, even in the earliest grades.

Recent studies corroborate Ma’s (1999) research, validating the need to support deeper levels of MCK among elementary TCs and/or in-service teachers (Conference Board of Mathematical Sciences, 2012; Heibert, 2013; Reid & Reid, 2017; Thames & Ball, 2010). Reid and Reid (2017) illustrated the challenges TCs face when solving Grade six and seven numeracy problems involving percent, fractions, decimals, order of operations, and integers. Their findings suggest that many TCs were over reliant on memorized procedural steps and lacked conceptual understanding, which further compromised the development of knowledge required to teach math. Inadequate MCK has led researchers to propose a variety of recommendations in teacher education, which include: demonstration of minimal math competencies through proficiency tests or additional math courses (Reid & Reid, 2017); increased hours devoted to MCK development during initial teacher education (Gresham, 2007), and admission requirements of at least one undergraduate math course for elementary TCs (Kajander et al., 2013).

**Post-secondary Math Courses**

The recommendation by Kajander et al., (2013) to require at least one undergraduate math course prior to pre-service admission would pose a major challenge in many jurisdictions, as most North American elementary TCs lack such qualifications. Statistics show that most elementary teachers are humanities majors and many drop math after Grade 11 in high school. In fact, more
than 50% of Canadian high school students drop out of science and math as soon as they possibly can, leaving them with minimal requirement credits at Grade 10 or 11, thereby negatively impacting on future occupational opportunities in the field of STEM (Amgen Canada Inc. & Let’s Talk Science, 2013). The widespread absence of math degrees and post-secondary math courses among elementary teachers raises alarming statistics. The most recent national survey of science and math education found that a mere 4% of elementary teachers have a degree in math or math education (Banilower et al., 2013). In Ontario, teacher survey data from Education Quality Accountability Office (EQAO) show that only 2% of Grade three and six teachers have a math major or specialist in their undergraduate degree; in addition, 83% of Grade three teachers and 80% of Grade six teachers have not taken any post-secondary math courses (EQAO, 2016a; EQAO, 2016b). Although higher levels of math courses do not automatically equate to better math teaching or less anxiety, the possession of strong content knowledge is necessary to help students acquire deep math understandings (Reid & Reid, 2017).

**Math Anxiety in Elementary Education**

When compared to other university majors, research reveals that MA was most prevalent in elementary education majors (Hembree, 1990; Kelly & Tomhave, 1985). Among teachers, MA has been identified as one of the possible sources of MA in students, in which highly math anxious teachers transmit their fear and avoidance of math onto their students (Beilock, Gunderson, Ramirez, & Levine, 2010; Bekdemir, 2010; Harper & Daan, 1998; Hembree, 1990; Vinson, 2001). The root cause of MA is most likely from harmful math experiences during elementary school and the anxiety continues into upper grades in which “teacher behavior is the major factor to which these experiences are attributed” (Bekdemer, 2010, p. 326). Hadley and Dorward (2011) found a positive relationship between elementary teachers’ MA and anxiety about math teaching and this further impacted negatively on student math achievement. McAnallen (2010) and Stuart (2000) posit that MA develops when math is taught through ineffective teaching methods, such as not being able to explain concepts when students are confused. McAnallen also discovered that students’ lack of conceptual math understanding contributed to increased anxiety levels. In consideration of MCK and its connection with MA, Brady and Bowd (2005) suggest TCs who achieved higher levels of formal math education possessed less MA. They reported a negative correlation between TCs’ formal math education and MA. An important way to build MCK and overcome MA is to engage in productive struggle, that is, to put forth a concerted effort to understand and solve math problems that are not immediately obvious (Hiebert & Grouws, 2007). Further, embracing a growth mindset would foster TCs’ beliefs that effort takes precedence over innate math ability (Dweck, 2015). The literature clearly shows the importance of confronting MA and developing positive environments for TCs. The purpose of the current study is to shed light on possible remedies by improving MCK.
Methodology

The methodological approach in this study falls under a pragmatic paradigm of mixed methodology benefiting from the analysis of both quantitative and qualitative data. Creswell and Clark (2007) explain that mixed methods research is ideal when “the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone” (p. 5). For this study’s intentions and goals, both qualitative and quantitative data were required to provide a comprehensive understanding of teacher candidates’ (TCs’) development in math content knowledge (MCK) and its relationship with math anxiety (MA). The researchers valued TCs’ personal math experiences, which could only be gathered through qualitative approaches. They recognized the complexity of the meanings behind each experience and appreciated the richness of the qualitative data. Notwithstanding, the researchers also felt it was necessary to gather quantifiable evidence of TCs’ MCK and MA in order to gain a more complete picture of how these phenomena interact. By using diverse approaches, this study gave primacy to the importance of the research problem - what is the relationship between MA and MCK development? - and valued both quantitative and subjective knowledge.

The participants in this study were drawn from two initial teacher education math classes taught by one of the researchers (see below for further details). She set out three major goals for her TCs in these courses. The first of these goals was for TCs to make sense of math in a deep conceptual way. By emphasizing multiple ways of understanding concepts, TCs would be encouraged to examine their own math reasoning and the reasoning of others. She focussed a great deal of her teaching to ensure that TCs had a solid conceptual understanding of the math. The second goal involved positively changing TCs’ beliefs and attitudes about math by building on their interests and making math class enjoyable, meaningful, engaging, and something to look forward to. Her third objective was to improve the pedagogical skills of the student teachers. She designed the course to include the modelling of constructivist approaches. In every math class, TCs would experience the following: metacognitive reflections, hands on manipulatives, research and theoretical applications, examination of student math work, and math games.

Instrumentation data collection

A recognized instrument designed by Betz (1978), the Revised Math Anxiety Scale (RMAS), was used in this study. The RMAS has established validity factors and a high reliability factor of 0.92. TCs completed the RMAS at the beginning and at the end of the math methods course to determine if levels of MA changed during the course. It took approximately six minutes for TCs to complete the RMAS. The highest possible score on the RMAS is 50, which indicates the least amount of anxiety. The lowest possible RMAS score is 10, which signifies the highest level of anxiety. Of most importance, the RMAS results were examined by the instructor as a diagnostic tool to identify TCs with high anxiety, so more support could be provided to those TCs.

This study also measured MCK of TCs through a Grade six math pre- and post-test. Items for the math tests were obtained from the Education Quality Accountability Office (EQAO). The
math tests included five open-ended questions and 10 multiple choice questions; pre- and post-tests consisted of different questions at the same level of difficulty. The 10 multiple choice items were scored as correct or incorrect, giving a maximum score of 10. The five open-ended items required the researchers to use EQAO’s four-level scoring rubric with level three and above as meeting the provincial standard. The scoring criteria included TCs’ understanding of concepts and accurate application of the procedures. In addition, the researchers looked for responses that demonstrated effective problem solving processes based on understanding the relationships between concepts, identification of important elements, and appropriate solutions to the problem. Responses that were blank or irrelevant (e.g., “I don’t know how to do this”) were scored as zero. Therefore, the highest level that was given to an open-ended question was four, and the lowest level was zero, with the highest total score attainable of 20 (i.e., level 4 x 5 questions).

The Grade six pre-test and the RMAS scale were administered on the first day of math class. Individual results of the pre-test and RMAS scale were returned to TCs during the second math class. Test items were reviewed as a class and TCs were encouraged to reflect on their math content and anxiety results. TCs were made aware of the post-test near the end of the course.

Both instrumentation data sets were easily quantified so that comparisons were calculated between pre- and post-tests. Comparing the pre- and post-results enabled researchers to quantifiably measure any changes throughout the duration of the math course, as well as measure any existing correlations between MA and MCK. The instrumentation data on its own would not have been adequate in understanding this study’s research focus on TCs’ math emotions, behaviours, feelings, and interpretations of experiences. These conceptualizations could only be captured through qualitative data methods. For this reason, the mixing of the two approaches maximized this study’s objectives.

**Semi-structured interviews**

Semi-structured individual interviews provided optimal opportunities to gain an in-depth understanding of TCs’ math experiences as related to MA and MCK. In this study, interviews were conducted with six TCs who possessed high or low math anxiety levels. An external third party conducted two face-to-face interviews (one at the beginning and one at the end of the course). The goals of these interviews were to understand TCs’ MA (high or low) and how it related to their MCK. The interviews were audio-recorded and transcribed by the researchers after the submission of final grades.

**Inter-rater reliability**

The researchers independently reviewed the interview transcripts and arrived at an initial set of codes. Researchers then agreed upon the final set of codes used to analyze all transcripts. Inter-rater reliability was applied throughout this study. Simply put, inter-rater reliability refers to the degree of agreement or consensus among individual raters (Kurasaki, 2000). The qualitative interviews were independently coded by the researchers and an inter-rater reliability agreement of 88% was obtained. Inter-rater reliability was also applied to the scoring of the quantitative content.
test instrument. The five open response questions were scored independently by one researcher and a colleague. The scoring rubric was used to determine the level for each question. Inter-rater reliability was calculated in each of the open-ended questions for the pre- and post-content test, and ranged from 86% to 94%. The assessments were further reviewed and reassessed until 100% agreement was attained for each open response question.

Participants
As previously stated, the participants in this study were drawn from two initial teacher education math classes taught by one of the researchers. This specific population consisted of TCs studying to become teachers at the elementary level (kindergarten to Grade six). The total amount of time spent in class was 36 hours from September to mid-April. Each math class focused on elementary math with a total of 99 TCs enrolled across two cohorts; 97 TCs took part in the post data gathering.

Sampling
In order to gain a deeper understanding of how MA connected with TCs’ MCK development, “purposeful sampling” from the study’s participant population of 99 TCs was used (Creswell & Clark, 2007, p. 112). The researchers intentionally selected TCs with either high or low MA in order to explore both ends of the anxiety spectrum. Based on the RMAS results on the first day of math class, six TCs were invited to participate in two in-depth interviews throughout the year. The six participants were comprised of three TCs with low anxiety (scoring more than 45), and three TCs with high anxiety (scoring less than 15).

Results
This section presents the results of TCs’ math tests, math anxiety (MA) scales, and interview data. In order to examine what changes occurred in TCs’ math content knowledge (MCK), the researchers initially analyzed the pre- and post-test results. Tables 1 and 2 reveal TCs’ improvements in the open-ended problems from pre- to post-test, with greatest gains in the categories of patterning and algebra, and measurement. In the pre-test, more than half (54%) of the TCs were unable to solve the measurement problem and almost half (48%) did not solve the patterning and algebra problem. Several candidates responded to these questions indicating they did not know how to solve the question. The multiple choice items proved to be less challenging as results were generally higher than the open-ended items (see Table 3).
### Table 1:
Percentage of TCs at All Levels for Open Ended Items of MCK Test

<table>
<thead>
<tr>
<th>Results in %</th>
<th>Number Sense &amp; Numeration</th>
<th>Measurement</th>
<th>Patterning &amp; Algebra</th>
<th>Data Management &amp; Probability</th>
<th>Geometry &amp; Spatial Sense</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Level 4</td>
<td>52</td>
<td>80</td>
<td>5</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>Level 3</td>
<td>23</td>
<td>16</td>
<td>7</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Level 2</td>
<td>12</td>
<td>4</td>
<td>14</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>Level 1</td>
<td>7</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Blank or irrelevant content</td>
<td>6</td>
<td>0</td>
<td>54</td>
<td>3</td>
<td>48</td>
</tr>
</tbody>
</table>

| At or Above Ontario Provincial Standard (Levels 3 & 4) | 75 | 96 | 12 | 68 | 20 | 88 | 65 | 100 | 33 | 78 |

*Note.* Results are reported in percentage. Each of the five open-ended questions was scored on a four level rubric, with level three and four as meeting provincial standard. Greatest gains occurred in patterning and algebra, and measurement. Provincial standard scores (levels three and four) increased by 68% for patterning and algebra, and 56% for measurement.

### Table 2:
MCK Test Open Ended Items Based on Four Level Scoring Rubric

<table>
<thead>
<tr>
<th>Results in %</th>
<th>Number Sense &amp; Numeration</th>
<th>Measurement</th>
<th>Patterning &amp; Algebra</th>
<th>Data Management &amp; Probability</th>
<th>Geometry &amp; Spatial Sense</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>N=99</td>
<td>N=97</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>3.08</td>
<td>3.75</td>
<td>0.89</td>
<td>3.14</td>
<td>1.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.21</td>
<td>0.53</td>
<td>1.19</td>
<td>1.03</td>
<td>1.29</td>
</tr>
</tbody>
</table>

*Note.* Each of the five open-ended questions was scored on a four level rubric, with level three and four as meeting provincial standard. The lowest mean of 0.89 occurred in the pre-test measurement question and the highest mean of 3.99 occurred in the post-test data management and probability question. Greatest mean gains were in patterning and algebra, and measurement, with a mean increase of 2.6 and 2.25, respectively.
Overall, Table 3 illustrates that TCs substantively increased their MCK scores over the math methods course, signifying important skill development. Total mean scores increased by 37.14 percent. When comparing the standard deviations between the pre- and post-test results, the pre-test revealed a larger variance from the mean in both the multiple choice and open-ended items. The range of responses on the MCK test was much greater in the pre-test than in the post-test. On the post-test, many students scored a level four, the ceiling score of the test. Therefore, the standard deviation was smaller in the post-test.

Table 3:
MCK Test Total: Multiple Choice (out of 10) and Open Ended Items (out of 20)

<table>
<thead>
<tr>
<th></th>
<th>Pre N=99</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post N=97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple Choice</td>
<td></td>
<td>7.01</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.53</td>
<td>0.72</td>
</tr>
<tr>
<td>Open Ended</td>
<td></td>
<td>9.18</td>
<td>6.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>16.19</td>
<td>8.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(53.96%)</td>
<td>(91.1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27.33</td>
<td>4.52</td>
</tr>
</tbody>
</table>

Note. TCs increased their MCK scores over the math methods course, signifying improvement. Total mean scores increased by 37.14 percent. Multiple choice items were out of 10, and the open ended questions were out of 20, with a total attainable score of 30.

TCs who possessed higher levels of MA performed less favourably in their math test. This was manifested in the comparison analysis of the RMAS and MCK test results. Descriptive data for RMAS are shown in Table 4. The highest possible score on the RMAS is 50, which indicates the least amount of anxiety. The lowest possible RMAS score is 10, which signifies the highest level of anxiety. A mean of 28.76 in semester one, then 33.8 in semester two provides a mean difference of 5.04 or 10.1 percent. This difference suggests that over the course of the academic year TCs experienced a moderate decline in their MA.

Table 4:
Math Anxiety Results Using the RMAS Instrument

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre N=99</td>
<td>28.76</td>
<td>10.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post N=97</td>
<td>33.8</td>
<td>9.49</td>
</tr>
</tbody>
</table>

Note. The highest score for the RMAS is 50 indicating low anxiety, while the lowest score is 10 indicating high anxiety. A mean increase of 5.04 suggests a moderate decrease in MA over the course.

The RMAS and the MCK test results were analyzed to determine the relationship between TCs’ MA and MCK by calculating the Pearson product-moment correlation coefficient (Table 5).
Results revealed statistically significant correlations. Overall, scores showed that TCs with higher levels of MA had lower math scores and, conversely, TCs with low levels of MA scored higher in their MCK assessments. According to the correlation coefficients computed, TCs’ MA was strongly related to their content knowledge results ($r^2= 0.7981$, semester one, and $r^2=0.6135$, semester two). Therefore, TCs who possessed stronger competencies to solve math tasks were more likely to feel less MA in their ability to problem solve in math. On the other hand, TCs who felt high MA were more likely to perform poorly when solving math problems.

<table>
<thead>
<tr>
<th>Table 5: Correlation between MCK Test and RMAS Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Content Knowledge Test (N=99)</td>
</tr>
<tr>
<td>Pre-RMAS</td>
</tr>
<tr>
<td>$r=0.89$</td>
</tr>
<tr>
<td>$r^2=0.798$</td>
</tr>
</tbody>
</table>

Note. Pearson product-moment correlation coefficient was calculated to determine the correlation between MA and MCK. Results suggest a statistically strong correlation in the pre-test $r=0.89$, $r^2=0.798$ and continued strong correlation in the post-test, $r=0.78$, $r^2=0.6135$.

Due to the statistically strong relationship between MCK and MA, it is worth discussing the coefficient of determination, or $r^2$, as this demonstrated statistically significant linear regression lines (see Figures 1 and 2). A stronger correlation occurred in semester one than in semester two. The coefficient of determination represents the percent of the data that is closest to the regression line. The pre-test results, $r = 0.89$, then $r^2= 0.7981$, and the post-test results, $r=0.78$, then $r^2=0.6135$, illustrated the very strong correlation between the two variables of MA and MCK. As the shortcomings of TCs’ MCK were addressed through the course, MA decreased. Based on the strong correlations between RMAS and MCK, another correlation analysis was performed comparing the RMAS and MCK test differentials over the year. The difference between RMAS differential (Post RMAS – Pre RMAS) and MCK test differential (Post MCK test – Pre MCK test) was analyzed through the Pearson product-moment correlation coefficient resulting in $r = 0.6733$ and $r^2 = 0.4533$, a moderate to strong correlation value. Therefore, an association exists between changes in MCK and changes in MA. On average, the larger the increase in a student’s MCK, the larger the decrease in their MA.
Figure 1: Pre-Content Knowledge Results vs. Pre-RMAS Results

Figure 1. Linear regression line demonstrates a strong coefficient of determination ($r^2=0.7981$) between pre-MCK test and pre-RMAS scores. Pearson product-moment correlation coefficient was used to calculate the coefficient of determination, or $r^2$, which represents the percent of the data that is closest to the line.

Figure 2: Post-Content Knowledge Results vs. Post-RMAS Results

Figure 2. Linear regression line demonstrates a strong coefficient of determination ($r^2=0.6135$) between the post-MCK test and post-RMAS scores. Pearson product-moment correlation coefficient was used to calculate the coefficient of determination, or $r^2$, which represents the percent of the data that is closest to the line.
Interviews

Results of the interview data unveiled two major themes that supported TCs’ MCK and diminished MA. These themes were: 1) quality of instruction during the course, and 2) understanding one’s own anxiety levels. The interviews included discussions about course experiences that helped TCs’ development as math teachers and barriers that hindered the learning process.

Quality of Instruction During the Course

The quality of instruction proved to be an important factor in supporting TCs’ math development. Students stated it was most valuable when the instructor explained math concepts comprehensively through various representations, as this helped them better conceptualize the math being taught. They reported appreciating lessons that modelled effective methods which could easily be replicated in a classroom. Examples of effective approaches included: the use of manipulatives such as algebra tiles, fraction pieces; working on authentic math problems; deconstruction of various strategies; and examination of actual student work. “When we were able to see the various ways children understand and solve problems, it allowed me to think about the processes that they go through.” Students noted that it was of most importance when the instructor spent time debriefing how and why such strategies were effective, in order for TCs to set their own pedagogical goals.

TCs described the significance of the pace of teaching during the course. TCs with lower MCK and higher anxiety reported that they valued material presented at a pace that allowed for questioning, collaborative problem solving, and reflection. “I believe that the greatest learning happened for me when we are able to collaborate, discuss and think out loud.” However, some TCs felt that they had insufficient time to further develop their skills due to low levels of MCK. Students stated that it was helpful when the instructor provided additional math content to review prior to class. Furthermore, optional math sessions during lunch and after classes were offered, so TCs had multiple opportunities to understand the content. However, not all TCs who required the additional support took advantage of this; perhaps such avoidance behaviours were indicative of their MA. “As I have no memory of using manipulatives to learn math as a child, I had no idea how to use such tools to teach math to my students. I still don’t know how to use them beyond the examples that were modelled in class.” For those TCs who did attend extra sessions and put forth the time to improve their MCK, they considered themselves adequately prepared for in-class math activities. Hence supplementary support outside of class was very helpful and it was not confounded by time constraints that often occurred during in-class remediation.

Understanding One’s Own Anxiety Levels and Building Confidence

When TCs were made aware of their anxiety scores after they completed the RMAS, they reported being more mindful of their anxiety levels, especially during in-class math activities. As a result of reflection and discussion about anxiety, TCs with high anxiety described measures they took in combatting such emotions, through behaviours such as deep breathing, reviewing math tasks thoroughly before attempting to solve it, and asking questions to clarify confusions about
concepts. TCs were also appreciative of their MCK test results which allowed for the identification of strengths and areas for growth. “I don’t have any content knowledge. When we were doing the questions on the assessment test I could see kind of what I’m supposed to remember in terms of formulas but I couldn’t put it together.” Highly anxious TCs identified the benefits of understanding their anxiety and setting goals to improve their MCK, which led to reduced anxiety. This theme was substantiated by the quantitative data in which MCK tests and MA scales had a strong correlation, and this relationship was stable throughout the courses. Essentially, effective reduction in MA was realized and understanding of math concepts and problem solving ability improved. “I had an ‘ah-ha’ moment during open arrays and 2-digit multiplication. I had forgotten how to use the algorithm, and looking at it through arrays made me feel very confident to bring this into the classroom.”

A safe learning space was deemed important by TCs to reflect on their MA and build confidence. Safe learning spaces included: embracing growth mindset; engaging in productive struggle; and building a community of mathematicians. Students noted the importance of community norms that cultivated a growth mindset culture. They felt that their math ability was not innately predetermined and their effort and perseverance during challenging math activities had positive outcomes on their MCK and MA. Productive struggle was evident in the group of highly anxious TCs as they clearly identified that they required more time to first learn the math content before considering how to teach math beyond procedural methods. Importantly, TCs explained how their MA was reduced when they did not feel embarrassed about their confusion or misconceptions during collaborative problem solving activities. “For the first time, I actually worked hard to figure out the problem … I didn’t give up. I wasn’t embarrassed because we were all taking the time together.” Furthermore, MA reduction was also attained through the cultivation of a psychologically safe learning environment wherein TCs felt supported in their math development free from ridicule or censure.

**Discussion and Recommendations**

This study’s key question investigated the relationship between math anxiety (MA) and math content knowledge (MCK). The quantitative data revealed significant improvements in teacher candidates’ (TCs’) MCK occurred in parallel with a reduction of their MA. MCK test scores and MA scale results were strongly correlated (pre-test r=0.89, and post-test r=0.78). Further, the qualitative data also highlighted the interplay between their MA and MCK as TCs built not only their MCK during the course, but also their confidence in solving challenging questions. As the researchers further analyzed the various data sources, the development of a compulsory MCK course surfaced as the major theme for improved math outcomes for TCs. The following recommendations would support the development and implementation of a MCK course and are further described below: 1) MCK course and rationale; 2) content of the MCK course; and 3) partnerships with university math departments.
MCK Course and Rationale

This study supports a wide range of literature that reveals the strong correlation between MCK and MA. The literature illustrates that poor performance in math is directly correlated to higher anxiety (Akinsola, 2008; Battista, 1986; Cohen & Green, 2002; Hembree, 1990). With this evidence in mind, the researchers of this current study recommend the need for TCs to develop comprehensive MCK as part of their program requirements.

Although this study’s results indicate that the math methods course supported MCK improvements of TCs to at least a Grade six level, it is important to note that the instructor offered additional MCK assistance beyond class time. As noted previously, these supports included additional math sessions over lunch and after class, as well as offering TCs the math content to review prior to class. These extra supports added to an already heavy workload for the math methods instructor and were not provided across all cohorts. Hence, the researchers advocate for a separate course devoted solely to TCs’ MCK development.

With an additional course recommended to improve the MCK of TCs, therein lies a programming challenge. Teacher education degrees are often described as intense and overcrowded, with a long list of curriculum, policy, research, and practicum requirements. Simply removing an existing course and replacing it with a MCK credit cannot be an option in many jurisdictions due to accreditation requirements. Therefore, the researchers suggest to strategically add a non-credit MCK course prior to program commencement. Alternatively, the MCK course could be implemented during first term, placing the math methods course to second term after the completion of the MCK credit. This sequence will allow for optimal learning of pedagogical content in the math methods course, due to established MCK proficiency.

The researchers considered various options to ensure achievement of minimal MCK competencies, such as high-stakes admission or exit tests. High-stakes admission tests can disadvantage specific populations or discourage some students from applying to teacher education programs. This type of entry requirement would counteract goals in diversifying teacher representation within the profession. Alternatively, some educational jurisdictions have introduced a high-stakes exit test taken at the end of the program. TCs must pass the test to graduate and be certified as teachers. However, this practice places tremendous stress and possibly amplifies already existing MA in TCs. Another option involves a compulsory test at the beginning of the program, followed by a remedial course for those TCs who fail. Unfortunately, this option raises concerns that failing the test and taking the remedial course might stigmatize TCs.

The recommendation that the researchers propose involves the delivery of a MCK course for almost all TCs. As noted in the literature review, highly anxious individuals avoid math experiences, even those that are meant to be supportive (Beilock & Maloney, 2015). Avoidance behaviour was also evident during this study when some TCs did not engage in extra math opportunities. Throughout the academic year, the instructor offered TCs open-ended rich math
tasks to work on outside of class time. However, it was noted that several anxious TCs did not participate, as this was voluntary. By mandating a compulsory MCK course, avoidance behavior would be remedied and expanded math learning would be the norm for all incoming elementary TCs. This course would become part of the teacher education culture of fostering mathematicians. The concept of ‘almost all’ is proposed by offering an optional test that can be taken prior to program commencement for TCs who have a strong math background, e.g., university math specialist. However, based on the typical profile of elementary teachers noted in the literature review, relatively few possess a math background (Banilower et al., 2013; EQAO, 2016a; EQAO, 2016b).

Content of the MCK Course

The researchers recommend that the focus of the MCK course include elementary math concepts up to and including Grade eight, by addressing common misconceptions and building new math knowledge. Due to time constraints, the course content should primarily emphasize numeracy, as this is the foundation of math. All five math strands (i.e., number sense and numeration, measurement, geometry and spatial sense, patterning and algebra, and data management and probability) are interwoven and interconnected, however, number sense and numeration is the strand that is deeply embedded throughout. Individuals who lack a strong number sense often struggle with foundational math concepts required for complex math thinking (Biddlecomb & Carr, 2011; Dehaene, 2011). Hence, the objectives of the course would be to develop an understanding of numeracy concepts in: quantity relationships, operational sense, and proportional reasoning. Throughout the course, TCs should be immersed in meta-cognition as math learners and reflect on their own math strengths, needs, and learning styles. Additionally, TCs would complete regularly assigned homework and receive support through math tutors and online tutorials. Having completed a MCK course, TCs’ readiness to embrace pedagogical content knowledge in math methods courses would be improved.

Partnerships with University Math Departments

The final recommendation involves building partnerships between faculties of education and departments of math, as well as other faculties involving STEM. Initial partnerships can be supported by matching elementary TCs with math majors who would act as mentors and provide one-on-one or small group math tutoring. By building important relationships between TCs and math students, TCs gain a trusted source to ask questions and gain deeper understandings of math content and curriculum. A potential byproduct of this partnership could realize the attraction of math students to the career of teaching. As STEM occupations continue to expand, enticing potential TCs with STEM backgrounds to the profession would support real-world math connections.
Conclusion

Math teacher education instructors must understand the significance of TCs’ MCK and its relationship to MA. This study demonstrated the strong correlation between the two constructs and how MA decreased and MCK improved. Although additional sessions were offered to build MCK capacities to those TCs who were highly anxious and demonstrated inadequate math skills, some TCs refrained from these supports. As noted in the literature, a possible reason for this avoidance behavior could be attributed to MA. Based on these findings, a compulsory MCK course is recommended by the researchers. This course would provide TCs with necessary and foundational numeracy skills to better prepare them for math methods courses. Stronger MCK will equip TCs to delve deeper into pedagogical content knowledge and successfully teach elementary math for years to come.

References


**Author Details:**
Dr. Mary Reid* is an Assistant Professor of Mathematics Education in the Master of Teaching program at Ontario Institute for Studies in Education of the University of Toronto. Her research interests include the math content knowledge of elementary pre-service teachers, math anxiety in the classroom, the gender gap in STEM, and building efficacy for math teaching. Her research would be of interest to those seeking to enhance pre-service programs through building coherence and implementing strategies to meet the varying backgrounds of student teachers. Email: mary.reid@utoronto.ca

Dr. Steven Reid is a Sessional Lecturer, Mathematics, at Ontario Institute for Studies in Education of the University of Toronto. He has delved deeply into effective leadership development, curriculum implementation, and systems change through positions as Chief Assessment Officer, Director of Field Services, Superintendent of Student Services, and Superintendent of Education. His current research and interests include reconstructing math knowledge and overcoming anxiety, as well as the influence of leaders on evidence-based decision making. Email: steven.reid@utoronto.ca

Dr. Jim Hewitt is an Associate Professor at the Ontario Institute for Studies in Education and Associate Chair for Teacher Education in the Department of Curriculum, Teaching and Learning. His research focuses on the educational applications of computer-based technologies, with a particular emphasis on discursive processes in collaborative learning environments. He is the designer and developer of PeppeR, a second-generation knowledge building technology for online and face-to-face courses. Email: jim.hewitt@utoronto.ca

* Corresponding author