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A Mixed-Methods Investigation of Teacher Developmental Trajectories: Results from a STEM-Focused Program

Margareta Maria Thomson*, Temple Walkowiak, Carrie Lee

Department of Teacher Education and Learning Sciences,

North Carolina State University

2310 Stinson Drive, Raleigh, NC, United States

*Corresponding Author: margareta_thomson@ncsu.edu

ABSTRACT

The current study investigated developmental trajectories of elementary teachers from a STEM-focused program at a large university in the United States. A mixed-methods design was employed; quantitative and qualitative data were collected to measure participants' mathematics specialized knowledge and beliefs (i.e., efficacy and epistemological beliefs), dispositions, and attitudes. Data was collected at different time points during participants' elementary teacher preparation program (ETPP) and into their first two years of teaching. Each time point in data collection represented a critical event for participants: time 1-beginning of ETPP; time 2-beginning of professional coursework; time 3-end of methods courses/beginning of field experiences; time 4- end of ETPP/beginning of 1st year teaching; time 5-end of 1st year teaching; time 6-end of 2nd year teaching. Study results revealed that all participants experienced changes in their mathematical knowledge, beliefs (i.e., efficacy and epistemic), dispositions, and attitudes over time. Participants' developmental trajectory in mathematics knowledge indicated growth from time 2 to time 5 followed by a decline at time 6; efficacy and dispositions followed a similar track, showing increase from time 2 to 4 and a decrease at time 5. Participants' epistemological beliefs and attitudes indicated continued increase at each time point (from time 2 to time 6). Qualitative data augment quantitative findings and provided more depth about participants' experiences in the program, factors that facilitated development, and the context in which changes occurred. Contributions from this study can help teacher preparation programs think about ways to facilitate teachers' professional growth.

Keywords: Beliefs; Knowledge; Teacher Preparation; STEM Program.

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Introduction and Purpose

Educational reforms have been implemented in countries around the world as a response to the need for developing individuals' global competencies, skills, and scientific literacies. Such reforms are calling for improved mathematics and science teaching and emphasize the importance of changes in teachers' thinking and instructional approaches. For instance, reform recommendations in the United States (NRC, 2012; NCTM, 2000, 2014; NGACBP & CCSSO, 2010), Australia (ACARA, 2012)), and the United Kingdom (Royal Society, 2011; Sharp et al., 2009) aim at improving the way mathematics and science is taught and assessed in schools. The current study examined developmental trajectories in elementary teachers' *mathematics knowledge, beliefs* (i.e., efficacy and epistemic), *attitudes*, and *dispositions* as related to mathematics teaching. Data was collected during participants' elementary teacher preparation program and into their first two years of teaching. The current study aimed at capturing the trajectory of development, and the concept of 'when' and 'how' preservice teachers experience changes that mark their teacher professional development.

Literature Review

Reform standards suggest changes to mathematics and science teaching by promoting active learning through the use of constructivist, inquiry-based instruction. Additionally, rather than teaching isolated science and mathematics instructional units focused on mastering content, the new standards formulate the need for students to learn critical thinking skills, such as posing questions, formulating hypotheses, solving problems, and being able to communicate effectively results from mathematical or scientific inquiries. However, these changes in instructional practices do not occur by simply demonstrating inquiry-based instructional strategies and skills in methods courses during preservice teacher education; the process is much more complicated. The work of preservice teacher education must also involve attention to knowledge (Fennema & Franke, 1992), beliefs (Leder, Pehkonen, & Torner, 2002); attitudes (Richardson, 1996), and dispositions (Jong & Hodges, 2013). These teacher attributes have been shown to influence instructional practices and therefore deserve attention not only in the work of teacher preparation, but also in research focused on teacher development.

Knowledge, a cognitive component of teachers' attributes, has been shown in numerous studies to influence mathematics instructional practices (Graeber, 1999; Hill et al., 2008). Our work is grounded in the ideas of Ball, Thames, & Phelps (2008) on "mathematical knowledge for teaching" and focused on their idea of "specialized content knowledge (SCK)." This construct refers to the knowledge teachers need in the work that they do such as interpreting a variety of solution strategies or making decisions about which mathematical representations to use. Little research has been done in understanding the impact of teacher education on the development of SCK over time and into the teaching career; although, one study examined teachers at various points in their career to find that the changes in knowledge seem to take place, as expected, during the teacher preparation program (Kleickmann et al., 2013).

Teachers' beliefs about the nature of mathematics and mathematics teaching have been found to provide an influential base for the methods they choose to utilize in their classrooms (Thompson, 1992; Richardson, 1996). These beliefs tend to be rooted in their own experiences in school mathematics. Those who have been successful in school mathematics often develop beliefs about mathematics and its teaching that are aligned with the ways they were taught. Therefore, if they experienced procedurally focused instruction, they may view the discipline of mathematics as a body of knowledge of skills, procedures, and single approaches/solutions, rather than an open-ended discipline with multiple strategies and solutions. In contrast, research has indicated that sometimes teachers who were not successful in school mathematics were more likely to develop reform-based beliefs as an alternative to their own negative experiences (Anderson, White, & Sullivan, 2005).

Another component of teachers' beliefs that should be developed in preservice teacher education is their confidence or self-efficacy (referred to as efficacy from here onward) in their ability to teach mathematics. Teachers with a higher efficacy are more likely to use inquiry-oriented, student-focused approaches to teaching rather than teacher-directed, procedurally-focused instruction (Czerniak & Schriver, 1994). These findings point to the importance of both developing preservice teachers' sense of efficacy and understanding how it develops longitudinally during the preservice and induction years.

Preservice elementary teachers often have negative attitudes toward mathematics (Rech, Hartzell, & Stephens, 1993; Quinn, 1997); these attitudes are often shaped by their prior experiences in school with mathematics (Jong & Hodges, 2013). Attitudes matter in terms of the instructional practices that they employ during mathematics instruction. Teachers with more negative attitudes more mathematics tend to use practices that are more rule-based and less inquiry-focused (Karp, 1991). However,

there is promise about the impact of preservice teacher education on shaping attitudes toward mathematics to become more positive (Jong & Hodges, 2015).

Dispositions refers to the tendencies to act in certain ways or to adopt particular positions (Bordieu, 1986; Bordieu & Nice, 1984). As described by Jong and Hodges (2013), it seems important to understand how preservice teachers' position themselves in relation to reform recommendations in mathematics education, considering their own formal schooling experiences with mathematics. Currently, there is a lack of research focused on elementary teachers' development of dispositions.

Methods

Participants and Context

Participants ($N=236$) were undergraduate students (and eventually graduates) of a STEM-focused elementary teacher preparation program (ETPP) at a large research university in the United States. The participants were from four different graduating cohorts of the program, as follows, F cohort ($n=66$), J cohort ($n=56$), P cohort ($n=54$), and S cohort ($n=60$). The vast majority of participants were females (92%), white (83%), and with an age range between 18-22 years (when they were preservice teachers) and 22-24 years (during their first two years of teaching). The demographics of study participants are typical of a population enrolled in the Elementary Education teacher programs in the US.

This current study is situated within a large grant-funded research project called *Accomplished Teachers of Mathematics and Science* (ATOMS). The project's aim is to examine the outcomes and impact of a STEM-focused elementary teacher preparation program related to knowledge, beliefs, and instructional practices. In the STEM-focused Elementary Education teacher preparation program, preservice teachers complete nine courses of STEM content. During their junior and senior years, preservice teachers complete three full-time semesters of elementary education coursework accompanied with field experiences and one semester of student teaching. The STEM methods coursework includes one engineering design, three science, and three mathematics courses. Specifically, mathematics instruction includes two methods courses and a two-course sequence of calculus designed specifically for preservice elementary teachers. Further, the two mathematics methods courses (K-2 and 3-5) are aligned with field-based placements and assignments in their K-5 classes under the supervision of mentor teachers and the course instructor. In addition to intense STEM coursework, field experiences are a strong component of the program and equal approximately 833 hours in elementary classrooms.

Data Sources

A mixed-methods design was employed; quantitative (surveys) and qualitative data (interviews) were collected to measure participants' specialized content knowledge, beliefs (i.e., efficacy and epistemological beliefs), dispositions, and attitudes. Data were collected using online surveys and structured interviews during participants' ETPP and into their first two years of teaching at six time points, critical for their professional development (i.e., beginning of ETPP; beginning of their professional studies, end of their professional studies, end of their teacher preparation program, at the end of their 1st and 2nd year of teaching). Appendix A presents the data collection timeline.

Quantitative Measures. Participants ($N=236$) completed an online survey administered at the six time points (see Appendix A); each survey session lasted for about 90 minutes total. The survey instrument were comprised of the following measures:

Demographic data. Participants' demographic data included age, gender, race, and year in teacher education program/or teaching. Pre-teacher education program data were collected related to their SAT scores, number of mathematics courses pre-college and college, and high school and college GPAs.

Learning Mathematics for Teaching-Mathematical Knowledge for Teaching Assessment (LMT-MKT, Hill, Schilling, & Ball, 2004). The LMT-MKT measures elementary preservice-and teachers' mathematics specialized content knowledge using multiple choice items. For this study, participants completed the LMT-MKT in Number and Operations, K-6.

Mathematics Experiences and Conceptions Surveys (MECS, Hodges & Jong, 2012). MECS measures elementary preservice-and teachers' mathematics efficacy, epistemic beliefs, dispositions, and attitudes on a scale 1-5.

Appendix B includes sample items from quantitative measures.

Qualitative Measures. In-depth structured interviews were conducted with selected participants several times a year (see Appendix A). In the larger ATOMS research project, 16 participants were followed during their ETPP and into their first two years of teaching and were interviewed up to seven times per year. The interview participants were from the same cohort (J cohort), due to cohort structures and sequence in the program. Interview participants were selected from a pool of survey participants based on several criteria (i.e., demographics, quantitative scores).

The interviews were conducted either face-to-face or via Skype based on participants' availability and convenience. Interview duration was between 45-60 minutes. The interviews included questions about participants' academic background, mathematics K-12 experiences, college courses and opportunities to learn

mathematics, learning experiences in the ETPP, mathematics teaching efficacy, beliefs about mathematics and mathematics learning, views about mathematics instruction and planned instruction. Interviews were transcribed verbatim.

For the current study we analyzed qualitative data from a subsample of interview participants ($n=4$). A total of twenty interviews (five per participant) related to mathematics teaching are the primary qualitative data for the current study. Interview data (five interviews for each participant, see Appendix A) from participants' junior year was analyzed. Researchers from the ATOMS project individually and in teams read all the interviews and created developmental summaries for these participants in which the major interview categories were summarized.

Results

Overall quantitative results indicated that all study participants experienced changes in their knowledge, efficacy and epistemic beliefs, attitudes, and dispositions over time. Table 1 summarizes the mean scores for all variables at the five (out of six) time points. In the current study none of the variables discussed have data collected at time point 1, thus all results are based on scores from time 2 to time 6.

Table 1

MKT and MECS Mean Scores

Variable/Time	T2 Mean (SD)	T3 Mean (SD)	T4 Mean (SD)	T5 Mean (SD)	T6 Mean (SD)
LMT-MKT Knowledge	0.22 (.74)	0.51 (.72)	0.59 (.73)	0.72 (.85)	0.54 (.92)
MECS-Efficacy	53.46 (7.61)	55.59(6.99)	60.53(6.57)	58.51(4.53)	58.07(5.06)
MECS-Epistemic	44.94 (4.59)	46.23(4.66)	46.89(4.31)	47.48(3.35)	48.34(4.22)
MECS-Dispositions	50.03 (3.83)	52.13(4.92)	52.41(4.28)	48.36(5.25)	49.16(5.82)
MECS-Attitudes	24.56 (7.08)	25.78 (5.83)	27.51(5.49)	29.69(3.87)	29.97(4.46)

Mathematics Knowledge

Mean analysis showed that participants' developmental trajectory in mathematics knowledge indicated growth from time 2 to time 5, followed by a slow decline at time 6. Participants' developmental trajectory indicated that they experienced continued growth in mathematics knowledge during their ETPP (time 2-4) and into their first year of teaching (time 5). The slow decline from time 5 to time 6 coincides with participants' second year of teaching (time 6 being the end of their second year of teaching). Appendix C illustrates participant's trajectory for the knowledge dimension (measured by LMT-MKT).

Mathematics Efficacy, Epistemic Beliefs, Dispositions and Attitudes

Teaching Efficacy Beliefs. Mean analysis for participants' efficacy scores indicated an increase at each time point during their ETPP (from time 2 to time 3 and to time 4), followed by a slow decrease in efficacy during their first and second year of teaching (time 5 and 6). The highest score in efficacy recorded for participants at time 4, coincides with the end of senior year, which is the end of their teacher preparation program.

Epistemic Beliefs. Participants' epistemic beliefs scores indicated that their developmental trajectories followed a pattern of continued increase from time 2 to time 6. Epistemological beliefs scores showed increase at each time point during participants' ETPP (time 2, 3 and 4) and into their first two years of teaching (time 5 and 6), with their highest score at time 6 (end of second year of teaching).

Dispositions. Participants' mathematics dispositions scores indicated an increase at each time point during their ETPP (from time 2 to time 4), followed by a decrease during their first and second year of teaching (at time 5 and time 6).

Attitudes. Participants' developmental trajectories for mathematics attitudes indicated a pattern of continued growth during participants' ETPP (time 2 to time 4) and into their first and second year of teaching (time 5 and time 6). Appendix D presents the developmental trajectories for efficacy beliefs, epistemic beliefs, dispositions, and attitudes.

Interview Developmental Summaries

Data from a subsample of interview participants ($n=4$) were used in the current manuscript to provide a general frame of participants' mathematics development. The twenty interviews (five per participant) from their junior year into the ETPP were the primary data for the creation of developmental summaries for these participants. Twelve major categories were described in each participant's developmental summary and were related generally to participants' background, previous academic experiences, college mathematics coursework, instructional beliefs, efficacy beliefs, visions of mathematics teaching, and future goals. We describe each category briefly below.

Background. Interview data described how a participant's background influenced feelings and thinking about mathematics. For instance, they responded to questions about the ways they learned mathematics at K-12 level, their feelings toward mathematics, and their perceived level of success in mathematics in K-12.

Academic experiences. Participants' experiences at the college level (specifically in the ETPP) were described in relationship with mathematics learning.

Specifically, interviews included data on how the general courses and methods courses influenced participants' feelings about learning mathematics.

Efficacy teaching. Participants described their state of confidence in mathematics teaching, factors that influenced their mathematics efficacy, and how their confidence changed over the course of their junior year.

Role of mathematics. Interview data revealed participants' epistemological beliefs and how they understood the role and value of mathematics in society, as well as the importance of teaching mathematics at the elementary level.

Vision of effective instruction. Participants' expressed their beliefs about what constitutes effective mathematics instruction and learning.

Anticipation of student response. Participants articulated how they would address student misconceptions and their view of the role of prior knowledge in learning mathematics.

Adapting resources. Participants described if and how they would adapt various resources (i.e., lesson plans, sample projects) given to them by school administration, district, or peers to make their teaching effective.

Task implementation. Participants' discussed their task selection and implementation in their respective lesson taught in the spring semester during grades 3-5 methods course.

Representations. Participants discussed the role of representations in teaching and how they used representations in their implemented lesson (Spring semester).

Discourse. Participants discussed how they used discourse in their implemented lesson (Spring semester).

Assessment. Participants addressed the role and nature of assessment in learning and described ways they can assess and monitor student learning.

Conclusion

The aim of the current study was to investigate developmental trajectories for elementary teachers' mathematics knowledge, beliefs (i.e., efficacy and epistemic), attitudes, and dispositions as related to mathematics teaching. Overall, study results revealed that all study participants experienced changes in their mathematical knowledge, beliefs (i.e., efficacy and epistemic), dispositions, and attitudes over time. Quantitative results showed that participants' developmental trajectory in specialized content knowledge showed increase from time 2 to 5 (during ETPP and first year of teaching), and a decrease at time 6 (end of second year of teaching). Participants' efficacy beliefs and dispositions indicated growth from time 2 to time 3 and a sharp increase at time 4 (end of ETPP), followed by a decline at time 5 (first year of teaching). This finding is supported by literature in the field stating that teacher

knowledge and efficacy beliefs are declining as teachers begin to experience the reality of teaching (Charalambous & Philippou, 2010; Putman, 2012).

Study results related to participants' mathematics epistemological beliefs indicated a continued increase at each time point, from time 2 to 6 during their ETPP to the end of second year teaching. Study results related to participants' mathematics attitudes showed similar patterns for participants, indicating a continued increase at each time point, from time 2 to time 5 (during ETPP and end of first year of teaching) and a flat trajectory to time 6 (end of second year of teaching). These findings may suggest that participants' epistemic beliefs and attitudes develop constantly as they progressed during their ETPP and into their first two years of teaching, as they gain more knowledge and experience with mathematics teaching.

Qualitative data provided more depth and revealed how participants' background, mathematics experiences at K-12 level, academic experiences at the university, and experiences in the teacher preparation program influenced their views about mathematics learning, mathematics teaching, and confidence. Participants highlighted factors that facilitated development, such as field experiences, mentor teachers, the coursework, or the instructional approach in college courses. The context in which changes occurred was important as well as individuals that interacted with them in that particular context (i.e., former teachers, current instructors, mentor teachers in the field).

Contributions from this study can help teacher preparation programs think about ways to facilitate teachers' professional growth and provide experiences that will mark a positive development in their knowledge, beliefs, attitudes, and dispositions. In preparing teachers to effectively meet the challenges posed by reform initiatives to prioritize quality science and mathematics teaching in the elementary classrooms, it is important to acknowledge the crucial role of teachers' specialized knowledge and beliefs (i.e., efficacy, epistemic beliefs) in facilitating the implementation of the necessary reform-based strategies (Ball & Forzani, 2009). One way to accomplish this goal is to create and promote adequate training of elementary teachers in mathematics and science areas, given the fact that elementary teachers are trained as generalists and oftentimes lack strong STEM preparation.

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APPENDICES

Appendix A

Data collection timeline

Survey data time points (TP) N=236	Event in professional preparation
TP1	Beginning of Freshman Year
TP2	Beginning Junior Year/ Pre-Methods
TP3	Beginning Senior Year / Post Methods
TP4	End of Senior Year/ End of Teacher Preparation
TP5	End of First Year of Teaching
TP6	End of Second Year of Teaching
Interview data (from J cohort) N=4	Event in professional preparation
-3 general interviews (beginning of academic year, mid-year, and end of academic year) - 2 mathematics cognitive interviews	Junior Year

Appendix B

Sample survey items

Measure/Construct	Description	Sample items
MECS-Confidence (12 items)	Confidence to teach mathematics (self-efficacy beliefs)	I am confident in my ability to be a good mathematics teacher. I am knowledgeable in mathematics. My knowledge of mathematics is sufficient to teach.
MECS-Epistemic Beliefs (10 items)	Beliefs about the nature of mathematics and learning of mathematics	There is typically one way to solve a mathematics problem. Mathematics is an attempt to know more about the world around us. Mathematics is rarely used in society
MECS-Attitudes (6 items)	Attitudes toward mathematics (positive/negative)	I like mathematics. I think mathematics is boring. I enjoy solving mathematics problems.
MECS-Dispositions (10 items)	Dispositions toward the teaching and learning of mathematics	I will lecture as my primary method of mathematics instruction. I will encourage students to explain their thinking.
LMT-Mathematics knowledge (13 items)		Ms. Jamison's attention was caught by an item on the state test about decimals: Which decimal is the largest? .240 .30 1.08 1.1 She thought that this question might be confusing for her students, who would be easily misled by these particular decimals. Which is the correct answer? a) .240 b) .30 c) 1.08 d) 1.1 e) I'm not sure.

Appendix C

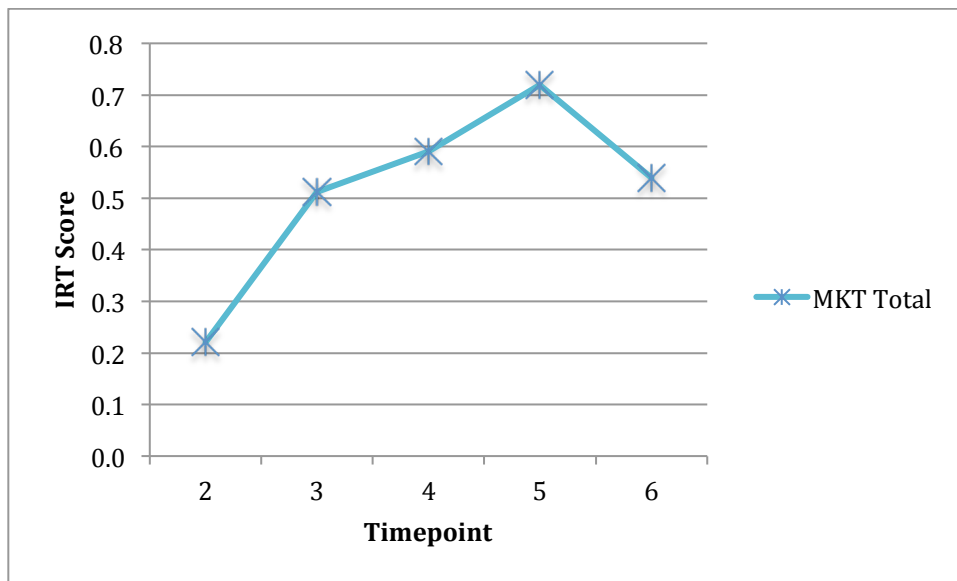


Figure 1. Participants' (N=236) mathematics knowledge trajectory

Appendix D

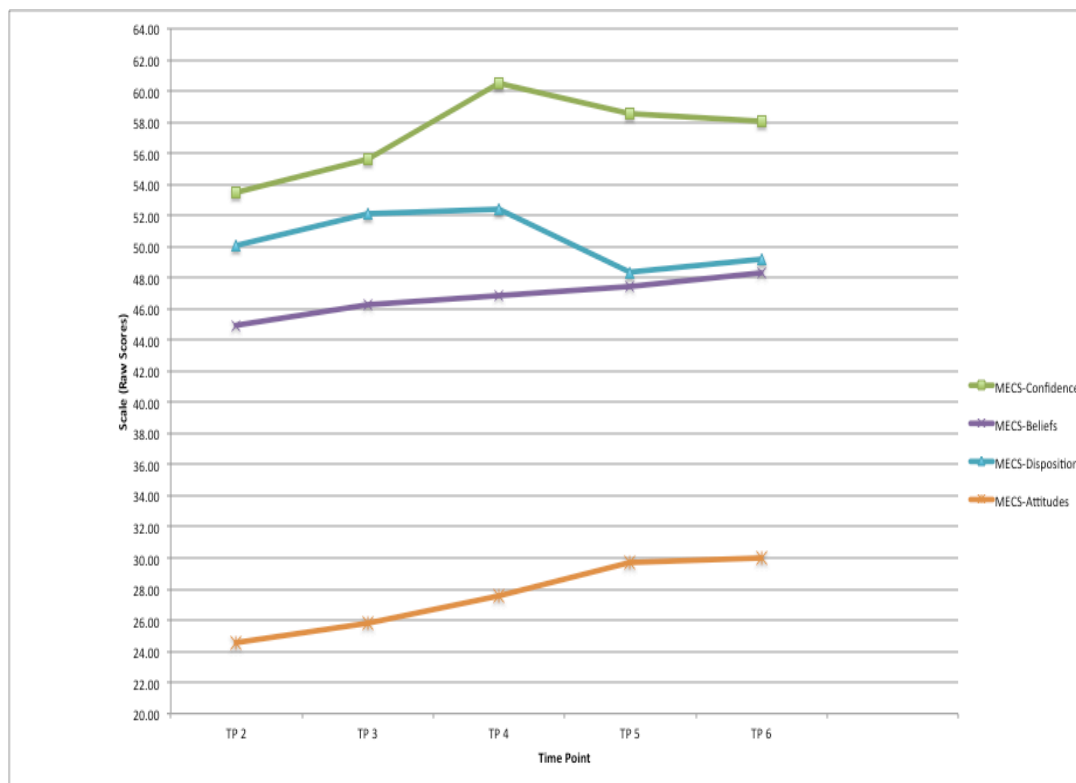


Figure 2. Participants' ($N=236$) developmental trajectories for mathematics efficacy, epistemic beliefs, dispositions and attitudes