Catalyzing the Courage to Lead: A Two-Pronged Approach to Empower Mathematics Teachers as Leaders

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ABSTRACT

All students deserve access to high-quality, effective, and impactful mathematics learning experiences. Yet, embodying a collective commitment to high-quality mathematics instruction necessitates a brave willingness of some members to orchestrate the process and provide a vision, working to get everyone on board, shifting away from teaching as a highly individualized activity, and shifting towards teaching as a shared responsibility. In this paper, we broadly ask, how might we facilitate the advancement of K-8 mathematics teachers as leaders? This study, which is part of a larger 5-year project, is focused on analyzing the development of a community of K-8 mathematics teacher leaders, later mentioned as Fellows, involved in an intentional partnership between a large metropolitan research university, one of the largest school districts in the U.S., and an education-focused non-profit. After describing our project's unique two-pronged approach, we share our longitudinal mixed methods approach and broad results from our first two years, which indicated a trend of consistent growth in Fellows' knowledge as well as their ability as leaders to initiate and sustain improvements in mathematics education. We conclude by engaging in a transparent discussion around implications for practice (importance of two-pronged approach, idea that feeling

valued matters, and intentionality in developing partnerships), implications for research (importance of multi-year district-wide programs for impactful change, the value of longitudinal mixed methods data collection, initial mindsets matter, and the need for further research on classroom teachers as mathematics leaders), and project next steps.

Introduction

All students deserve access to high-quality, effective, and impactful mathematics learning experiences (National Council of Teachers of Mathematics [NCTM], 2020a; NCTM, 2020b). Embodying a collective commitment to high-quality mathematics instruction does not happen by chance. Instead, it necessitates a brave willingness of some members to orchestrate the process and provide a vision, working to get everyone on board, shifting away from teaching as a highly individualized activity, and shifting towards teaching as a shared responsibility (Bush et al., 2022; Karp et al., 2021; NCTM, 2014). However, mathematics teacher leaders are often left in a seemingly impossible position. Mathematics teacher leaders are equipped with the knowledge, resources, and tools essential for transformative change, yet they are not positioned in their setting, or may not feel comfortable, leading beyond their own classrooms or grade-level teams (Bush et al., 2022). Furthermore, conceptualizations and roles which define teacher leadership vary greatly in the literature (Berg & Zoellick, 2019) and in practice. The project discussed in this paper specifically focuses on mathematics teacher leaders who are still in full-time classroom teaching positions (Rutledge, 2023).

Purpose and Research Questions

The purpose of this paper is to explore how K-8 mathematics teacher leaders are empowered to initiate and sustain improvements in their respective settings. This study explores the following research questions: *How does the launch and implementation of an Ed.D. specialization in K-8 Mathematics Education, together with a Teacher Leader Academy, facilitate the advancement of mathematics teachers as leaders?*

We use data from the first two years of a five-year National Science Foundation (NSF) Noyce program for master teachers involving an intentional partnership between a large metropolitan research university, one of the largest school districts in the U.S., and an education-focused non-profit.

Background Literature

Mathematics leadership structures in school districts differ greatly, with some districts implementing numerous layers of support for mathematics instruction and learning at both the school (e.g. principals, assistant principals, instructional coaches) and district (e.g. curriculum and professional development departments) levels, while others primarily depend on classroom teachers to enhance mathematics instruction and learning within individual schools (e.g. department chair, lead teacher). Regardless of the structure, the flow of information and support for mathematics teachers is often fragmented and disjointed. We contend that classroom teachers, as a universal resource across schools, present a practical solution to this challenge. Leveraging their position and expertise offers a promising avenue to address this need. In fact, NCSM articulates the role of a mathematics teacher leader (a classroom teacher) in their NCSM Essential Actions: Framework for Leadership in Mathematics Education (NCSM, 2020).

As mentioned in the introduction, this study specifically focuses on a program model for teacher leaders who are in full-time classroom teaching positions. Prior research has examined various models of mathematics teacher leadership programs including those delivered through graduate teacher education programs, collaborations between universities and school districts, and those not affiliated with a university. University-based programs are frequently delivered through graduate teacher education programs (Criswell et al., 2018b; Ross et al., 2011; Taylor et al., 2011). Research-to-practice partnerships foster collaborative relationships between research institutions (e.g., universities as the research component) and school districts (e.g., practitioners as the practice component) to develop teacher leaders (Auslander et al., 2022; Borko et al., 2021; Sinha & Hanuscin, 2017; Yow et al., 2021). Numerous professional development-focused models that are not affiliated with universities emphasize both cultivating and supporting teachers in their roles as leaders (Alemdar et al., 2018; Criswell et al., 2018; Green & Kent, 2016; Gul et al., 2019; Gul et al., 2022; Meyer & Slater-Brown, 2020; Rebello, Hanuscin & Sinha, 2011; Reid et al., 2022; Yow & Lotter, 2016).

Prior studies focused on developing teacher leaders suggest program models incorporate both professional learning and mentorship components (Green & Kent, 2016; Gul et.al, 2019). Existing research emphasizes the development of teacher leaders but often overlooks creating opportunities for teachers to simultaneously implement or practice leadership with active support and mentorship. There remains an opportunity to make a meaningful contribution by focusing on both content-specific teacher leadership development and mentorship as teachers enact teacher leadership while fulfilling full-time classroom teacher roles. This current study's design centers on a two-pronged approach that combines the content knowledge development of mathematics teachers with organized opportunities to apply their learning in practice with active guidance and mentorship through a research-to-practice partnership.

Inclusion of professional learning and mentorship components in a teacher leadership development program is supported by the Teacher Leadership Exploratory Consortium's (TLEC) Teacher Leader Model (TLM) Standards (2011) and NCSM's Framework for Mathematics Leadership Guiding Principles (2020). The TLM standards include (a) fostering a collaborative culture to support educator development and student learning, (b) accessing and using research to improve practice and student learning, (c) promoting professional learning for continuous improvement, (d) facilitating improvements in instruction and student learning, (e) promoting the use of assessments and data for school and district improvement, (f) improving outreach and collaboration with families and community, and (g) advocating for student learning and the profession (TLEC, 2011). NCSM's (2020) Framework for Leadership in Mathematics Education provides four guidelines to establish the "bold" work of the mathematics teacher leader focused on empowering teachers as professionals, incorporating structures that support teacher professional development, fostering teacher agency to improve student learning, and positioning teachers to advocate for high-quality mathematics instruction. These components and connected research also informed our project design. In a case study examining the development of master teachers as classroom-based mathematics teacher leaders, Rutledge (2023) found that master teachers positioned in this way were empowered to catalyze change in school systems from a unique *within-the-classroom* perspective. This positioning of mathematics teacher leaders offers viable pathways to sustained organizational improvement as these teacher leaders are uniquely positioned to lead, model, and coach their peers in the area of mathematics content knowledge and pedagogy and high-quality teaching practices from within the classroom (Rutledge, 2023).

Hence, this study emphasizes both strengthening classroom-based mathematics teachers' content knowledge and positioning the developing teacher leaders to engage in mathematics education leadership activities as essential components for effective and impactful mathematics teacher leadership development. This study further leans on the existing research of incorporating both professional learning and mentorship (Green & Kent, 2016; Gul et.al, 2019) into programs focused

on harnessing the growth of mathematics teacher leaders. By prioritizing these areas, the study aims to empower classroom-based teachers as on-the-ground leaders to enhance mathematics teaching and learning in their classrooms and at their schools, to advocate for high-quality mathematics instruction from a classroom-based lens, to lead professional development efforts from appropriate and applicable perspectives, and to use their experience to take on broader leadership roles in the education community at large. These goals for classroom-based teachers ensure that they are well-prepared to drive sustainable, meaningful, and lasting improvements in mathematics education.

The broader rationale for this study is grounded in the national literature. NCTM (2014), in their landmark publication *Principles to Actions: Ensuring Mathematical Success for All*, identified Professionalism as one of the six guiding principles for school mathematics. However, in too many schools, professional isolation exists between colleagues within the school, as well as others including teachers from other schools, mathematics educators, and mathematicians (Scholastic and the Bill & Melinda Gates Foundation, 2012). Such professional isolation can hinder continued professional growth, such as the importance of teachers of mathematics at all levels continuing to deepen their mathematics knowledge for teaching (as described in Conference Board of Mathematical Sciences, 2012). Further, such isolation can lead to inconsistencies in practices and negatively impact student learning (NCTM 2020a, 2020b).

Our overall five-year project focuses broadly on the advancement of mathematics teacher leaders including their ability to meet the needs of all learners, mathematical content knowledge for teaching mathematics, mathematical pedagogical knowledge, and leadership capacity. We aim to develop a community of K-8 teachers of mathematics (which we refer to as Fellows) who are mathematics teacher leaders intentionally positioned as classroom-based school and district mathematics education experts. Through our collaborative partnership, we seek to abolish professional isolation, and develop a safe and welcoming space for needed and challenging conversations to happen.

Our Two-Pronged Approach

From the outset of our project, we created and adopted a two-pronged approach. Literature on professional learning effectiveness has long supported an iterative process that oscillates between professional learning and job-embedded components, situated in context (Borko, 2004; Heibert et al., 2005; Lave & Wenger, 1991; Philippou et al., 2015), which led us to this two-pronged approach.

The first prong is to develop mathematics teacher leaders through a new Curriculum and Instruction Ed.D. specialization in K-8 Mathematics Education. The second prong is the launch and implementation of a Teacher Leader Academy (TLA), providing a platform for our Fellows to establish themselves as leaders in their district and enact what they have learned in the Ed.D. program. It is our intent that through our partnership with the district and non-profit, our Fellows, who are K-8 mathematics teacher leaders in classrooms and alongside students and their colleagues every day, once they earn their doctoral degrees will be well-positioned to navigate and contend with the many time, fiscal, policy, and resource barriers that currently exist in K-8 schools. See Figure 1.

Figure 1

Mathematics Teacher Leadership Program Two-Pronged Approach
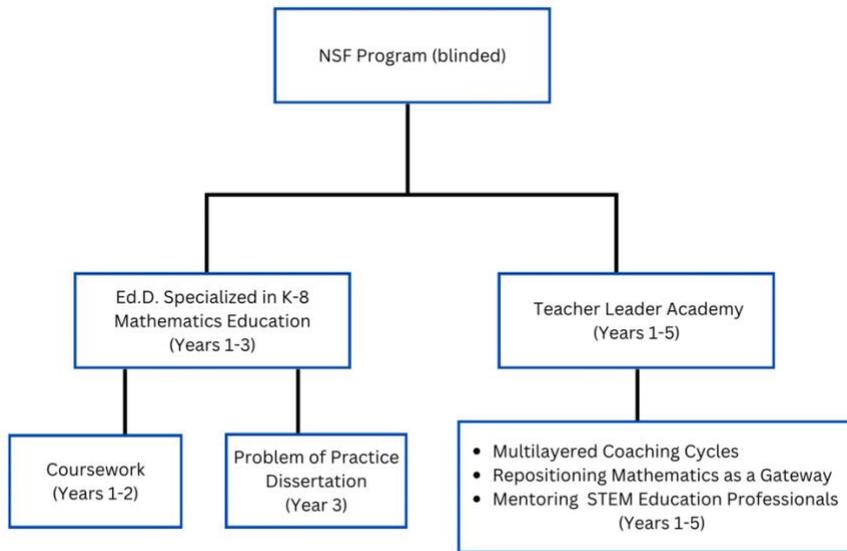
Ed.D. Specialized in K-8 Mathematics Education (Prong 1)

The Ed.D., specialized in K-8 Mathematics Education, was envisioned as a terminal professional degree program designed for educators working full-time who plan to serve as expert practitioners in their settings following degree completion. This new degree program, launched with our cohort of Fellows, encapsulates direct impact to K-12 schools and districts while elevating the teaching profession. With an Ed.D. program in Curriculum and Instruction already in place at the university, this new program builds from a strong foundation of an existing program but fulfills a needed focus on leadership in K-8 mathematics education. Importantly, a key component of our project is that each Fellow's dissertation targets a current problem of practice (Ma et al., 2018) related to K-8 mathematics in their setting with clear alignment to at least one of the four key recommendations in NCTM's Catalyzing Change framework.

The specialization is designed to be completed in three years and includes 57 credit hours of coursework and dissertation. Fellows were positioned to make a long-term impact in their school and district while supporting administrators, instructional coaches, and teachers in research-informed and effective mathematics teaching which will ultimately lead to improved student learning. This program is dedicated to providing all Fellows with content and pedagogical knowledge for teaching mathematics; tools for guiding, planning, and reflecting on instruction; and skills for conducting research and using data to inform decision-making related to the purposes, structures, and teaching and learning of K-8 mathematics.

Figure 2

Program of Studies: Ed.D. Specialized in K-8 Mathematics Education

Semester	Courses
Fall	**Policies, Practices, and Structures in K-8 Mathematics Education** **Content Knowledge for Teaching K-8 Mathematics I**
Spring	Facilitating Learning, Development & Motivation Data, Assessment & Accountability **Seminar in K-8 Mathematics Education (2 credits)**
Summer	Organizational Theory in Education Identifying Complex Problems of Practice
Semester	Courses
Fall	**Content Knowledge for Teaching K-8 Mathematics II** **Instructional Coaching in K-8 Mathematics**
Spring	Analysis of Complex Problems of Practice Analysis and Synthesis of Educational Literature **Seminar in K-8 Mathematics Education (1 credit)** *Milestone 1: Gap Analysis Paper*
Summer	Research Seminar Advanced Writing Workshop *Milestone 2: Dissertation Prospectus, Annotated Bibliography, Initial Committee* *Milestone 3: Dissertation Proposal*
Semester	Courses
Fall, Spring, and Summer	Dissertation in Practice (18 credit hours)

Note: Mathematics Education courses are designated in bold text and program specific milestones not connected to specific courses are designated in italics.

Becoming an expert practitioner is a complex, multi-layered, ongoing endeavor that involves a unique combination of content knowledge for teaching, pedagogical knowledge, leadership development, advocacy, professionalism, understanding of policy, and a deep understanding of research (NCTM, 2014). The goal is for Fellows to be prepared, positioned, and working to be agents of change in their settings.

Teacher Leader Academy (Prong 2)

The Teacher Leader Academy is designed to engage Fellows as mathematics classroom teachers positioned as leaders through the use of a cognitive apprenticeship system of modeling, coaching, and fading (Collins et al., 1987). This coherent system includes job-embedded support and mentoring (Cobb & Jackson, 2011) using an iterative process so the focus on improving student mathematics learning and achievement is maintained (Boston et al., 2017).

"Teacher leaders must be given opportunities to practice and apply what they learn about leadership" (Katzenmeyer & Moller, 2009, p. 37). This quote encapsulated the purpose of the Teacher Leader Academy we developed with our partner district and non-profit so the Fellows could enact what they learned in the Ed.D. program into practice. The Teacher Leader Academy invests in developing Fellows' agency to implement meaningful change. As a result, these mathematics teacher leaders are the ones thinking critically about the greatest needs in K-8 mathematics education, and they are equipped to approach problems methodologically from their job-embedded perspectives.

The Teacher Leader Academy consists of three interconnected synergistic components: Engaging in Multilayered Coaching Cycles; Repositioning Mathematics as a Gateway; and Mentoring STEM Education Professionals. Engaging in Multilayered Coaching Cycles was intentionally developed as a vehicle through which to build leadership capacity and for Fellows to enact what they have learned in the Ed.D. program beyond their own classroom or grade level team. Repositioning Mathematics as a Gateway leveraged the expertise of the mathematician Co-PI of the project to place an intentional focus on the long-term mathematics journey of Fellows' students. Mentoring STEM professionals specifically recognized the need for multiple layers of mentoring in recruiting, retaining, and elevating the leadership of a high-quality mathematics teaching workforce. We provide details on each component.

Engaging in Multilayered Coaching Cycles

Fellows engage in coaching cycles throughout their experience in the Teacher Leader Academy. The multilayering within the coaching cycles include the Fellows evolving as: Researchers developing expertise and conducting research related to their practice; Catalysts for coherence working with administrators and instructional coaches in guiding their messages regarding best practices for teaching and learning mathematics; and Peer coaches providing mentoring for colleagues and the non-profit partner volunteers. Specifically, this project employs the Affirming Learning Walks approach which is described by Ross, Lamb, and Johnson (2023) as providing "asset-based orientation toward teachers, and teaching, and have [has] the potential to develop trust and collegiality among teachers and teacher leaders" (p. 48). During an Affirming Learning Walk, a 10-15-minute classroom visit occurs and then debriefs between the teacher(s) and visitors takes place which only focuses on productive practices (Ross, Lamb, & Johnson, 2023). This helps to build a space of trust and respect that fosters growth over time. Through the partnership with the non-profit, Fellows have the opportunity to apply their learning and leadership skills with volunteers who work to support K-8 students in Title 1 schools. These volunteers are most often young adults who do not have experience in education, and our Fellows coach them on providing individual and small group mathematics instructional supports to students in the district. There are opportunities for Fellows to interact with five rotations of volunteers (volunteers complete a 1-year commitment) during this five-year project. This allows for modeling, coaching, and fading of support as Fellows learn about, develop, and disseminate information related to best practices for mathematics instruction in a supportive and low-risk environment.

Repositioning Mathematics as a Gateway

Historically, mathematics has been identified as a gatekeeper holding students back from the possibilities of pursuing STEM-related careers (NCTM, 2020b) but should be repositioned as a gateway as advocated for in *Charting a Course for Success: America's Strategy for STEM Education* (National Science and Technology Council, 2018). Teacher leaders have real potential to reposition mathematics as a gateway to those very same career opportunities, as well as, importantly, to develop STEM literacy in all students regardless of whether they ultimately pursue a STEM-related career. Because success in secondary and postsecondary mathematics begins with actualizing K-8 mathematics as a dynamic and creative subject, beyond the memorization and rote application of algorithms, teachers must foster in students the ability to think critically about the information they receive (Bressoud, 2015). This component focuses on:

- Cultivating broad and deep understanding of mathematics, so that students know how and why various approaches work in particular mathematical contexts (Dean & Brookhart, 2013).
- Strengthening problem solving skills, so that students can build solutions to a variety of problems without foreknowledge of the relevant mathematics (Giganti, 2007).
- Developing productive persistence in K-8 students, so they are able to learn from mistakes, without becoming discouraged by minor setbacks (Silva & White, 2013).
- Improving communication skills, so that mathematical ideas may be explored appropriately.

The overall goals of this component are to better understand ways in which mathematics is viewed, develop ways to combat the views that are harmful or counterproductive and promote the views that are beneficial or constructive, and develop practical ways to weave the constructive views into K-8 instruction. With these ends in mind, we aimed to develop in Fellows the tools and techniques necessary to catalyze change and to empower Fellows to serve as agents of change with potential to impact K-12 students' future performance (Barber & Mourshed, 2007).

Programmatic elements towards these goals included the project mathematician engaging Fellows in workshops and activities around this component and the Fellows putting into action new ideas. For example, Fellows engaged in readings and discussions around Francis Su's work (e.g. Su, 2013) and the project mathematician engaged Fellows in topics including sense of belonging in mathematics and joy in mathematics. Further, our project mathematician contributed "Mathematics as Gateway" columns across multiple issues of a Fellow-created newsletter.

Mentoring STEM Education Professionals

Research shows early, consistent, and persistent exposure to role models in STEM fields (particularly ones that students feel they can relate to) is elemental in shaping a sense of belonging and interest (Ong et al., 2011; Weber, 2011). Project Fellows receive intentional support through targeted mentoring. They, in turn, mentor their colleagues, as well as the non-profit volunteers, who are volunteering in our district schools to provide individual and small group mathematics instructional supports to students. Mentoring develops within coaching cycles, with support fading over time, aligned to the cognitive apprenticeship system of modeling (Collins et al., 1987).

Setting and Recruitment of Fellows

Our setting is a large metropolitan area in the southeastern United States. The university is one of the largest universities in the country and designated as a Research I. The partner school district is one of the largest school districts in the United States with more than 200,000 students. At the start of the project, the district's student population was 25% white, 24% Black, 43% Hispanic, 5% Asian, and 2% multi-cultural (as identified by the district). The district has a high population of students on

free or reduced-priced meals. The non-profit partner was initially identified as a potential for this project because they had a long-standing partnership with the district. The non-profit partner had provided support for more than 7,200 students during the past nine years in the district (at the time the project started). The non-profit volunteers partner with classroom teachers across the district to help students cultivate many emotional, social, and academic skills. Our partnership with them specifically focuses on Fellows providing support for the mathematics academic aspects.

Fellows were recruited, selected, and inducted following the university and Ed.D. program admission requirements in addition to the selection criteria identified for our project. Recruitment drew heavily from an existing relationship with the school district. Instrumental to this project was the notion of expanding our existing close collaboration as it relates to our K-8 Mathematics and Science Education Master's program, a program that is centered on improving the quality of mathematics and science teaching and developing teacher leaders, which has been offered for approximately three decades. Since the inception of the Master's program, our partner district has had the greatest enrollment of teachers. Thus, this pre-existing partnership between the university and school district provided a natural pipeline of potential applicants.

Minimum requirements for the Fellows included a Master's degree in their teaching field and a position in the school district as a full-time elementary school teacher and a teacher of mathematics or as a middle school mathematics teacher. Potential applicants were informed of the opportunity through district communications via newsletter, email, information sessions, on-going communications, and through introduction interviews. In addition to a $10,000 per year salary supplement Fellows receive for five years provided by the grant, a strong incentive for applying to the program was that the district provides a permanent pay increase for those in teaching positions with an earned doctorate in specific fields. Fellows had to agree to the five-year teaching service commitment required by NSF. Application materials included transcripts, a goals statement, a resume, three letters of reference, teacher evaluations and an applicant analysis of student data, and an interview with project leaders. An incredibly competitive pool of nearly 40 applicants was reviewed, and 15 applicants were ultimately selected as Fellows (we only had funding for 15).

After the first year of the project, one Fellow decided for personal reasons to leave the field of education (to pursue another career helping children outside of education that was of great passion to them). We have had no other attrition to date. Thirteen are graduates from our K-8 or another one of our Mathematics or Science Education Master's programs, and 11 currently work in Title 1 schools. Of the 14, four are currently middle school mathematics teachers, 10 are elementary teachers with some teaching mathematics or mathematics and science all day, and some working as generalists teaching mathematics and science as well as other subjects. Fellows' years of teaching experience ranged from approximately six to more than 25 years at the start of the program.

Methodology

A longitudinal mixed methods approach was selected for this study, which drew on the strengths and minimized the weaknesses of both quantitative and qualitative approaches (Creswell, 2003; Creswell & Plano Clark, 2007). The research question for this study was as follows: *How does the launch and implementation of an Ed.D. specialization in K-8 Mathematics Education, together with a Teacher Leader Academy, facilitate the advancement of mathematics teachers as leaders?*

Data Sources

Specifically, we grounded our data collection plan in alignment to the two prongs. Figure 3 provides an overview of our data collection timeline for Year 1 and Year 2, with the data sources utilized in this report highlighted in bold text. Although there is overlap, data most closely related to

the Ed.D. program (first prong) consists of: a survey to measure Fellows' use of effective instructional practices (Boston, 2013); the Learning Mathematics for Teaching (LMT) content-knowledge assessments (Hill et al., 2008) which was chosen because of its topic-specific modules and alignment to the two mathematics content courses in the EdD program; and videos of Fellows teaching mathematics lessons in their own classrooms, analyzed with the Instructional Quality Assessment (IQA) in Mathematics Toolkit, which is a set of classroom observation rubrics that specifically targets ambitious mathematics teaching practices (Boston, 2012). The quantitative measures assess Fellows' development in content and pedagogy throughout the program, which are important outcomes and also enable us to examine the relationship between content, pedagogy, and the development of teacher leadership practices. Data related to the Teacher Leader Academy (second prong) consists of focus group interviews with project leaders, Fellows, non-profit volunteers mentored by our mathematics teacher leaders, and school administrators (including instructional coaches); a survey for administrators (including instructional coaches), a task sort and video analysis for instructional leaders (Boston et al., 2017); Fellows self-reporting of leadership engagement; and student deidentified achievement data (with matched control). All Fellows and project leaders completed all data collection activities. Non-profit volunteers and school administrators and instructional leaders at Fellows' schools were encouraged to complete data collection activities but were not required (participation rates for these groups varied but were generally high).

Figure 3
Data Collection Timeline For Year 1 and 2

Year	Target Group	Instruments and Data Sources
Year 1	Fellows	• **Pre Instructional Practices Survey (Prong 1)** • **Pre Pedagogical Content Knowledge LMT (Prong 1)** • **Pre/Post Mathematical Content Knowledge LMT (Prong 1)** • **Interviews/Focus Groups (Prong 2)** • Student Achievement data (Prong 2)
Year 2	Fellows	• **Post Instructional Practices Survey (Prong 1)** • **Post Pedagogical Content Knowledge LMT (Prong 1)** • **Post Mathematical Content Knowledge LMT (middle level only) (Prong 1)** • **Interviews/Focus Groups (Prong 2)** • Student Achievement data (Prong 2) • **Classroom Practice: Pre IQA video (Prong 1)** • Coaching and Mentoring: Pre task sort and video analysis (Prong 2)
	Administrators (including instructional coaches)	• Pre task sort and video analysis (Prong 2) • Survey (Prong 2) • Focus Groups (Prong 2)
	Non-Profit Volunteers	• Focus Groups (Prong 2)

Note: Data sources used in this report are bolded.

Data Analysis

In this section, we share how data have been analyzed for this study (see Figure 3 for data sources). Importantly, our focus is to examine Fellows' growth in the advancement areas in a multi-faceted way with examination both within and across data sources.

For Prong 1, the instructional practices surveys were analyzed quantitatively by our external evaluator, using descriptive statistics and statistical tests such as the Wilcoxon Signed Rank tests (non-parametric t-tests for repeated measures and paired data) to examine Fellows' growth across pre-, post-, and (eventually) post-post administrations. Second, the LMT assessments are a national standardized assessment. Fellows complete a pre, post, and post-post assessment for a set of elementary LMT modules and a set of middle grades LMT modules. After Fellows complete the assessment, the system generates results including a number-of-items-correct score, an item response theory (IRT) score comparing the Fellow's performance to a national database, and an analysis of change over time in IRT scores. Classroom video observations, in which Fellows recorded their own teaching, were analyzed with the IQA Mathematics Toolkit (Boston, 2012). IQA data are analyzed using descriptive statistics, *t*-tests (changes over time in overall IQA lesson scores), and *t*-tests for non-parametric data (changes over time for specific rubrics).

Prong 2 data, the focus group interviews, were analyzed systematically through data reduction and connection, allowing for the identification of common themes across participants, as well as divergent cases (LeCompte et al., 1993). Specifically, the external evaluator and a graduate research associate ([GRA]; doctoral student, not a Noyce participant) analyzed transcripts of the focus group audio-recordings line by line (transcribed by Zoom) to identify Fellow's comments related to each goal of the project (e.g., mathematics content knowledge for teaching, teaching practices, teacher leadership) and/or project activities (e.g., Mathematics as a Gateway, Teacher Leadership Academy). The evaluator and GRA categorized Fellows' comments within each of the project goals and identified two additional main themes, Feeling Valued and Personal Growth. Through consensus and discussion, we then (1) refined the selection of comments and (2) identified subthemes to describe groups comments within each broader goal/theme. In this report, qualitative data are used to provide examples of how Fellows perceive the connections between and support provided by the various project components. While the external evaluator conducted most of the data analysis, she worked closely with the project investigators to help make sense of specifically the qualitative data, and to connect the quantitative and qualitative results.

Our data analysis also includes intentionally examining across data sources. For example, the results of the LMT assessments (which examine Fellows' growth in mathematics content knowledge for teaching and pedagogical content knowledge) are correlated with their instructional practices survey results to explore the relationship between Fellows' beliefs and knowledge. Focus group interview data provide evidence of the extent of Fellows' growth in their confidence to serve as mathematics teacher leaders and agents of high-quality mathematics programmatic structures. We have the ability to compare trends over time to Fellows' instructional practices survey results, as well as to surveys completed by each Fellow's administrator and instructional coach. Additionally, we track leadership engagement of the Fellows throughout the project. This provides an opportunity to document their positive influence within their schools and within the broader mathematics education community. We note changes over time as the Fellows expand their reach from their classroom setting to broader impacts.

Results

Ed.D. Program (Prong 1)

LMT Instrument

Fellows increased or maintained positive outcomes across mathematics content knowledge for teaching, beliefs, and instructional practices. Post-tests for LMT Elementary modules were collected after Fellows' engagement in the first content knowledge for teaching course (Year 1) and post-tests for LMT Middle School modules were collected after Fellows' engagement in the second content knowledge for teaching course (Year 2). Table 1 provides results from the individual LMT modules and overall results in Years 1 and 2 for the group of 14 Fellows who participated in the project throughout Year 2 (one of the original 15 Fellows left the project in Year 2). In Year 1, the individual modules exhibited non-significant positive growth trends, and the overall combined score reflected statistically significant positive growth [t(13) =2.15; p(one-tailed) = .026]. In Year 2, 3 of 4 modules and the overall results all indicated statistically significant positive growth.

Table 1

LMT Results by Change in Score (Number Correct), Years 1 and 2

	n	Mean Pre-Test	Mean Post-Test	Change	t	*df*	*p* (one-tailed)
LMT Elementary Tests, Year 1 Pre/Post Comparison							
Number Concepts and Operations	14	18.43	19.07	0.64	0.63	13	0.271
Patterns, Functions, and Algebra	14	19.79	21.00	1.21	1.60	13	0.067
Geometry	14	15.07	16.14	1.07	0.98	13	0.172
Combined results overall	14	53.29	56.22	2.93	2.15	13	**0.026***
LMT Middle Level Tests, Year 2 Pre/Post Comparison							
Number Concepts and Operations	13	13.31	18.54	5.23	4.23	12	**<0.001***
Patterns, Functions, and Algebra	13	14.15	16.15	2.00	1.25	12	0.12
Geometry 4-8	14	16.28	20.28	4.00	4.04	13	**<0.001***
Probability, Data, and Statistics	13	16.08	19.00	2.92	2.15	12	**0.026***
Combined results overall	13	60.23	73.92	13.69	5.05	12	**<0.001***

* Statistically significant at p(one-tailed) < .05

Table 2 provides results for changes in IRT scores for Year 1 and 2 LMT data, by module. Year 1 modules did not exhibit significant change. In Year 2, after the second content knowledge course, Fellows' scores on three of the four middle-level LMT modules indicated significant positive growth, with effect sizes ranging from .39 to 1.06, and significantly higher gain scores than those exhibited in the national LMT database.

Table 2

LMT Results by Change in IRT Scores, Years 1 and 2

	Mean IRT Change Score (SD)	t	*df*	*p* (two-tailed)	Effect Size *(Cohen's d)*
LMT Elementary Tests, Year 1 Pre/Post Comparison					
Number Concepts and Operations	0.13 (0.60)	0.80	12	0.44	0.17
Patterns, Functions, and Algebra	0.24 (0.56)	1.55	12	0.15	0.29
Geometry	-0.09 (0.57)	-0.56	12	0.58	-0.10
LMT Middle Level Tests, Year 2 Pre/Post Comparison					
Number Concepts and Operations	0.66 (0.78)	2.95	11	**.01***	0.66
Patterns, Functions, and Algebra	0.39 (0.57)	2.37	11	**.04***	0.39
Geometry 4-8	0.68 (0.55)	4.45	12	**<.001***	1.07
Probability, Data, and Statistics	0.38 (0.62)	2.09	11	**.06***	0.60

*Statistically significant at $p < .10$

Increased content knowledge and pedagogical content knowledge contributes to Fellows' effectiveness as mathematics teacher leaders by enhancing how they are able to identify and support the instructional practices of their colleagues (Cobb & Jackson, 2011; Stein & Nelson, 2003). In order to identify and support high-quality instructional practices, instructional leaders should have expertise in their content area and be knowledgeable about how that content is best taught and learned (Boston et al., 2017; Steele et al., 2015; Stein & Nelson, 2003).

Instructional Strategies Survey

On the instructional strategies survey, Fellows overall tended to agree/strongly agree (mean ≥ 3.0) with items expressing a reform-oriented view of mathematics teaching (e.g., multiple representations [pictures, words, symbols, charts, graphs, etc.] should be used in teaching a mathematics topic; mathematical concepts are best retained when learned through investigation and application) and tended to disagree/strongly disagree (mean ≤ 2.0) or be neutral toward (mean between 2.0 and 3.0) items expressing a traditional view of mathematics teaching (e.g., students learn mathematical procedures [algorithms] best through repeated practice, rather than by solving problems; tests and quizzes are the best means of assessing student progress in mathematics class). Results were very consistent from Year 1 to 2, with no items having statistically significant changes in means, no

changes in the consensus of agree/strongly agree items (mean > 3.0), and three items changing in consensus of disagree/strongly disagree (mean ≤ 2.0). Across the two years, Fellows self-report moderate, frequent or always/daily use of 32 out of 36 teaching practices (mean > 3.0). The four exceptions with means < 3.0 (infrequently used or never used) are all reflective of traditional mathematics teaching practices: (a) Designate time for students to begin homework in class; (b) Begin class by answering questions about homework; (c) Allow students to use calculators to solve exercises or problems; and (d) Introduce content by lecture or demonstration.

Year 1 Video Observations

In Year 1 lesson videos, a majority of lessons featured tasks ($\frac{10}{14}$; 71%) and implementations ($\frac{12}{14}$; 86%) primarily focused on procedures and computations, without connection to deep mathematical understanding. Discussions consisted of presentations of procedural steps, with few explanations provided by students. Though teachers asked questions (How did you get that? How do you know?), the questions more often pertained to mathematical procedures rather than concepts ("how" rather than "why") or resulted in explanations being provided by the teacher. In contrast, half of Year 2 tasks ($\frac{7}{14}$, **50%**) and implementations ($\frac{6}{14}$; 43%) featured students engaged in reasoning and sense-making, with students providing mathematical explanations and overall increased use of manipulatives, visual representations, good questions, and student-voice. Wilcoxon tests (paired-value t-test for ordinal data) for small samples indicated significance growth on the IQA rubrics of Teacher's Questioning (W=29; p(one-tailed) < .05) and Teacher Linking (W=29; p(one-tailed) < .05), indicating Fellows were asking more high-order questions and providing more opportunities for students to connect ideas to one another.

Focus Groups

From the focus group data, which addressed both Prongs 1 and 2, Fellows attributed instructional changes (specific topics and ways of teaching) to their experiences in the project through the mathematics education coursework they had completed and the activities in the Teacher Leader Academy, and specifically mentioned the Mathematics as a Gateway component (led by project co-PI who is a mathematician) of the Teacher Leader Academy. Fellows also noted the consistency in messages from the mathematician and the mathematics education faculty, especially around tasks and questioning. Fellows described how making a task more exploration-based, supportive of play and creativity, and asking questions to support exploration (from the Mathematics as a Gateway component) also increases the task's cognitive demand and aligned with the questioning types and ideas about high-level implementation (from the content courses and Teacher Leadership Academy). These connections and attribution speak to the seamless overlap between the two-pronged approach. Fellows describe specific changes in their instructional practices that they attribute to the project: being more student-centered; changes in how they teach specific content; changes in their instructional practices aligned with tools and ideas shared during the project (e.g., 13 Rules that Expire by Karp et al., 2014), the value of exploration and play, asking "why" and asking rich questions, applying constructs from a classroom observation tool explored in the Teacher Leader Academy).

Themes in Fellows' focus group responses are provided in Table 3, as well as a comment or comments illustrative of the type of responses coded within the theme or subtheme. Subthemes within the project goals of Leadership, Mathematical Content Knowledge, and Mathematics Pedagogy included Fellows' reflections on their own growth and changes in their perspectives or practices. From Year 1 to Year 2, Fellows described their leadership roles as evolving from offering their services and

support to colleagues in Year 1 (primarily informal leadership activities) to becoming the "math go-to person" at their school in Year 2, with teachers seeking them out and generating more organic opportunities to provide support and with more formal requests for serving in leadership roles. Comments within the theme of Feeling Valued (Support and Collaboration) often arose in response to the prompt, "What has been the best part of the project so far?"

The themes and sample comments in Table 3 tie seamlessly to the various key components of our project. For example, in the Mathematical Content Knowledge theme, there was a strong focus on conceptual understanding and the "whys," which align to the focus of the mathematical content knowledge for teaching courses that were part of Fellows' Ed.D. coursework. Several Fellows mentioned the mathematics as a gateway component and that everyone was capable of learning mathematics, which were ideas they worked on with our project mathematician during the Mathematics as Gateway component of the project. The Mathematics Pedagogy theme showcased changes in Fellows' teaching practices, such as through the use of manipulatives, higher-quality tasks, and effective questioning. This growth was also evident in the video observations. The themes of Leadership, Feeling Valued, and Personal Growth all personified Fellows' continued growth as teachers leaders, instructional advocates, as well as their increased confidence. These responses aligned to Fellows finding their voice, giving feedback, leading professional development as well as the value they placed on our project community, and their own surprise at their own personal growth.

Table 3

Themes in Year 1 to Year 2 Focus Groups

Theme	Descriptions or Subthemes	Sample Comments
Mathematical Content Knowledge (CK)*	Own Math Processes/ Conceptual Understanding	• "We are conceptually understanding every aspect within the mathematics, which I did not have full background of." • "I now understand when kids solve it with a different strategy. I can make connections and make sense of their math." • "I'm reflecting back on how I was teaching before the …program, and how we never truly went over the "why" because again, I didn't understand why things worked one hundred percent."
	Changes to Perspectives on Math	• "Being …the Gateway and not the Gatekeeper." • "Everybody is capable of learning math."
Mathematics Pedagogy*	Changes to Teaching Practices	• "A new thing for me is using research to find the activities I'm going to do." • "My teaching was completely revolutionized by her class." • "Struggle productively as they continue to explore and explore and use those manipulative and collaborate with each other." • "To be able to address any misconceptions, asking those higher thinking questions." • "I have literally taken segments of what she's done with us in class and brought it into my classes. There was one lesson where we modeled equations using algebra tiles, and I immediately did that with my class that same week."

		• "I have been intentional about pulling out manipulatives and drawing pictures to help students conceptually understand. And in the past I've always gone straight to the algorithm." • "I've started actually evaluating the tasks that I present to my students. So I look at the potential of the task …and then my implementation of the task." • "Now, when I'm looking at a lesson, I start rethinking what I need to start asking kids because I'm not asking the right questions."
Leadership*	Formal Leadership Activities	• "I'm being asked to deliver more professional development." • "I am supporting the team lead; she comes to me a lot so, and the other team member, if we have new teachers and they still come to me."
	Informal Leadership Activities	• "Teachers are starting to recognize we're in that leadership role, even without being officially in that leadership role." • "I do give them feedback, in the area of mathematics." • "I use as an opportunity to share some of the things that we have learned in the class here with them."
	General Collaboration Within School	• "Trying to collaborate with not just the principal, but other stakeholders in the building." • "Enjoyed the collaboration with other teachers"
Feeling Valued	Collaboration (within the cohort)	• "I love the collaboration that we have as a family of Fellows." • "We have a tight knit support system here."
	Support (by project leaders)	• "I think that the support that we've gotten has definitely helped us grow in that role." • "We feel special to be here." • "Anytime we do voice a concern, we feel heard, and we feel respected in the way that they will do what they can to help us." • "Because we feel trusted, and we feel like we can trust them. Because we have that connection and that bond."
Personal Growth	General Comments on Personal Growth	• "I can't believe how much I did not know." • "I'm still growing, and this program itself has allowed me to reevaluate myself." • "The attributes of a true leader. I am learning that in class." • "My ability to read literature is little bit more refined, and I think that the course work has really helped me develop that side of myself as a student and as a learner, which I think I've seen the most exponential growth."

*Themes that align with Focus Group Prompts and Project Goals

Across Data Sources

Looking across data sources, teachers with high content knowledge for teaching (on the LMT) tended to have higher classroom observation scores (on the IQA). The alignment between Fellows' perceptions of different instructional strategies (as expressed in the survey) and the strategies observed in their own classrooms (from classroom videos) will be interesting to continue to monitor.

From the first two years of data collection related to Prong 1, we have found that Fellows began the project with strong beliefs aligned with high-quality mathematics teaching (which have remained). Regarding their mathematical content knowledge for teaching and pedagogical content knowledge as well as their instructional practices, we have a trend of evidence of growth after the first two years.

Teacher Leader Academy (Prong 2)

Results from interviews with project leadership, Fellows, and school administrators identified the impact of the Teacher Leader Academy (TLA). In particular, TLA assignments and Ed.D. course activities were reported to have intentional positioning, scaffolding, and support of Fellows' development as mathematics teacher leaders. For example, Fellows conducted a Catalyzing Change Needs Assessment assignment and Affirming Learning Walks in their schools. Both of these were incorporated (or engaged in) to position Fellows to build rapport with administration, which provided a platform for Fellows to be recognized and acknowledged as mathematics teacher leaders. While engaging in the Catalyzing Change Needs Assessment and in other activities (particularly, in serving as mentors to interns from the non-profit agency), Fellows initially expressed apprehension in their emerging role as mathematics teacher leaders in Year 1. They described how project leaders developed trust and provided support, particularly around navigating the landscape to promote high-quality mathematics instruction. Project leaders describe how they intentionally planned the Catalyzing Change Needs Assessment and mentoring activities so that Fellows would be recognized by and interact with school administrators as teacher leaders. In Year 1, Fellows describe the following components of their emerging role as teacher leaders: (a) being recognized by their principals as teacher leaders; (b) increased role in mentoring; (c) requests to lead professional learning activities; and 4) developing expertise and confidence.

In Year 2, all 14 Fellows noted the value of the Affirming Learning Walks in being seen as teacher leaders at their school, providing an opportunity to share a new walk-through structure with their principal, and providing an opportunity to lift up their colleagues. Fellows also explored a classroom observation instrument (Boston, 2012) through their TLA engagement, and this instrument was identified as impacting their practice (during focus groups) in ways such as how they analyzed curriculum and instructional tasks and how they provided support to colleagues in their schools. Other tools specific to the project noted by Fellows as impacting their thinking and practice include *Catalyzing Change* (NCTM, 2020), *The Math Pact* (Bush et al., 2021), the Catalyzing Change Needs Assessment assignment and the Milestone 1 Gap Analysis assignment (see Table 1).

Year 2 included new opportunities for leadership activities: attending and presenting at professional conferences and increased opportunities to serve as teacher leaders in their schools. In Year 2, Fellows expressed increased confidence and provided evidence of actions as mathematics teacher leaders including through engaging in the Affirming Learning Walks. Increases in Fellows' self-perceptions as mathematics teacher leaders were identified (e.g., no longer feeling imposter syndrome), recognition by others, and number of leadership activities (self-initiated or requested by administration or teacher colleagues). For example, seven of the 14 Fellows engaged in 32 school-based leadership engagements, such as leading Professional Learning Communities (PLCs), supervising college teacher candidates, mentoring peers, or hosting a community math night. None of

them reported engaging in initiatives at the district level or in the broader mathematics education community. By Year 2, 12 Fellows engaged in a combined 62 school-based initiatives; two of the Fellows engaged in district-level initiatives; and nine of the Fellows engaged in the broader mathematics education community. Collectively, they delivered 21 presentations at both state and national conferences focused on mathematics education and leadership in mathematics education.

In Year 2, Fellows made explicit connections between specific components of the project and their mathematical learning, teaching practice, and role as mathematics teacher leaders. Several Fellows made connections between tools explored in the TLA and instruction modeled during the content classes and Mathematics as a Gateway experiences: (1) the construct of "cognitively challenging tasks" from a classroom observation tool explored in the TLA and the suggestions offered (and modeled) during the Mathematics as a Gateway for making tasks more exploration and play-based; and (b) the questioning types in the classroom observation rubrics and how the professor of the mathematics content courses asked questions of them. In Year 2 focus groups, they connected ideas from Catalyzing Change (shared in Year 1) to the Affirming Learning Walks and gap analysis project. They acknowledged (as did project leaders) how their increased knowledge of content, pedagogy, and research served to enhance their confidence, willingness to act, and actions as instructional leaders.

Some of the most interesting data we collected was the Year 2 focus group interviews (aligning to both Prongs 1 and 2), which provided us with a deeper look at Fellows' perceptions of their own growth since beginning the program, as well as how they are connecting the different components of the project. We share several quotes from Fellows that capture their reflections regarding their growth:

- *"At my school, a lot of teachers are trying to skip out on the exploration piece because of timing…[and I say], 'Let me tell you this experience we had with (blinded – the mathematician investigator on the project), and how I learned more by exploration than just for us to go straight to the tasks,' … experiencing that with him helped me to talk to teachers more about how exploration is key, because if we take that opportunity away from our students, they might not be able to in-depth conceptualize everything we want them to."*

- *"For me, one of the biggest [changes] I do now is, I now understand when kids solve it with a different strategy. I can make connections and make sense of their math. Because … a lot of it has been previewed with (blinded – one of the mathematics education investigators on the project), and because I can now make the connections, I see my own students making connections and solving in ways that are not necessarily always common."*

- *"I've started actually evaluating the tasks that I present to my students. So I look at the potential of the task…and then my implementation of the task. I look at the students' evidence and teachers' questions to make sure that the quality of the tasks that I'm doing is more level four tasks where there's that justification state."*

- *That's definitely the kind of leader that I would want to be, is helping teachers understand what they do well, because sometimes we just focus on the negative…or the criticism too much, and that can really bring down a teacher's confidence and morale. So I think that's been really beneficial to me, being a leader that's helping others."*

In summary, the results for Prongs 1 and 2 indicate a trend of consistent growth toward the overall goal of empowering K-8 mathematics teachers as leaders to initiate and sustain improvements in our education system. Fellows have been supported as they seek to have positive impacts on their colleagues and the broader community, and they are developing the skills and confidence necessary to enact and disseminate what they have learned in their doctoral program.

Results also support the importance of the longitudinal mixed methods approach. For example, Fellows' exhibited growth in content knowledge for teaching and pedagogical content knowledge on the LMT, and in the focus groups, they describe feeling stronger and more confident in content knowledge based on their coursework experiences and how this new-found confidence has encouraged and empowered them to take more actions as mathematics teacher leaders. Similarly, as Fellows are (a) engaging in ambitious instructional practices as learners in the Mathematics as a Gateway and other courses, and (b) using tools to identify and promote high-quality instructional practices in the Teacher Leader Academy, they are increasing their use of these practices in their own classrooms (as indicated by IQA results), encouraging their peers to implement such practices (e.g., see the quote above about exploration), and using the language from the tools provided in the Teacher Leader Academy to discuss high-quality instruction with their administrators (as reported during focus groups with administrators).

Discussion

Implications for Practice

With the goal to empower K-8 mathematics teachers as leaders to initiate and sustain improvements in our education system consistent with the frameworks that guided this study (NCSM, 2020; TLEC, 2011), we needed to determine both the space for these improvements to occur and the opportunities for Fellows to develop the knowledge and skills necessary to thrive. Our first implication for practice is the importance of a two-pronged approach. We created the space and simultaneously equipped Fellows with the knowledge and skills they needed as they eased into that space (i.e. the Teacher Leader Academy). The knowledge was gained and the skills were developed within coursework and experiences in the Ed.D. program. The link between the two was guided by the cognitive apprenticeship system of modeling, coaching, and fading (Collins et al., 1987). There was an intentional focus on developing Fellows' content knowledge for teaching mathematics and as their voices were elevated, they used their voices to promote mathematics reasoning and sense making in all teachers and students. This promotion of mathematics reasoning and sense making was modeled in their coursework. Fellows were coached through Affirming Learning Walks (Ross et al., 2023) and other activities within the Teacher Leader Academy. Through their work formally in the Teacher Leader Academy, and informally through their school-based leadership experiences, they found their voice with regards to advocating for high-quality mathematics instruction at a more impactful level. The support provided by faculty is now starting to fade as Fellows are positioned as leaders in their schools and districts.

Second, feeling valued matters. As shared in the findings from focus groups (Table 3), Fellows consistently identified support from project leaders and from within their cohort as the best aspect of the project. As Fellows felt valued, their excitement related to the project and their confidence seemed to flourish—and subsequently, their roles as leaders began to flourish as well. This was evident in the focus groups (e.g., multiple quotes aligned with the sample shared herein) and in the number and type of new leadership activities undertaken and initiated by Fellows in Year 2. We propose that the confidence that the feeling of being valued brings, and also because others began to see them as leaders, served as a catalyst for their new role as teacher leaders. This finding is an important implication of our work for administrators in schools and districts, and aligns to one of Berg and Zoellick's (2019) four dimensions of teacher leadership, legitimacy. They share that one way teacher leadership legitimacy has been described is as "something that might emerge as teachers are recognized as leaders by colleagues" (p. 7) even though they might not hold a formal leadership position. Findings by Barth and colleagues (2023) also point to the strong impact the role of recognition plays on teacher leader identity. We ensured Fellows were celebrated in press releases, news articles, and school board

announcements; they were featured on panels, on websites, and through awards; and they were and continue to be sought out by colleagues, coaches, and administrators. Although these efforts take time and mentoring, we have found they are some of the most essential components for numerous reasons including that they critically work to counteract negative stereotypes about teaching and professionalize (to the public) the STEM teaching profession. As Fellows feel more valued, their impact broadens. For example, in Year 2, two Fellows attended a state conference and learned about a fact fluency program that focused on building conceptual understanding to foster fluency (Dixon, 2023), where they saw that senior administrators in their district were also attending the same presentation. They had the courage and confidence to approach the administrators and ask to lead an initiative to implement the program across the district. They worked with one of the project leaders to make a plan for implementation. The project leader gave the first workshop to launch the program with the district (modeling); the project leader helped the Fellows to plan the follow-up workshops (coaching); and moving forward, the Fellows took on leadership in the full implementation of the program, with access to the project leader for support as needed (fading). This level of leadership was new to the Fellows and likely grew from experiences in the program. Efforts to center the Fellows and honor their expertise takes time, energy, and knowledge.

Third, our partnership also took effort and intentionality to develop. Trust needed to be established between the university, the district, and the nonprofit partner. The investment of time and energy in nurturing the partnership should not go unnoticed. It was built by being flexible, open, and transparent. We (the partners) planned well-organized meetings and prioritized attendance and participation in those meetings. The meetings were and continue to be important touch points where information is shared, work is completed, and tasks are assigned. While there were some changes in leadership within the organizations, the clear lines of communication and norms for these interactions have been passed along and upheld. This may have worked so seamlessly because each partner could see value in their involvement.

Related to practice, we want to be forthcoming about obstacles we faced along the way. For example, as Fellows grew in their leadership roles in their school and the district, they were occasionally met with resistance from their colleagues and/or a building administrator. We worked closely with the Fellows to help them navigate these situations. Our project was also situated in one of the largest school districts in the country with more than 100 elementary schools and approximately 40 middle schools. It was challenging to reach district-wide implementation even on initiatives our Fellows were helping to lead at the district level. We imagine this would be less challenging in smaller districts.

Implications for Research

Our work also holds several implications for research and project design. In Year 2, we are beginning to see significant growth in content knowledge (e.g., higher LMT results), positive shifts in instructional practices (e.g., increases in IQA results for half of Fellows), evidence of Fellows' development as teacher leaders (e.g., self-reports of their confidence, increases in the number of leadership activities, and activities self-initiated versus requested by others) and recognition as teacher leaders by colleagues and school administration (e.g., from interviews and requests for teacher leadership activities). Our findings have two implications for project design. First, multi-year, district-wide projects may be necessary to initiate organizational change, particularly those focused on shifting towards more effective structures. Change in individuals and institutions takes time, and based on our work at the end of Year 2, we posit that a minimum of 2–3 years are needed to see the growth necessary for individuals to begin to initiate change in their institutions. As suggested in previous research, single-year projects may not have the time and sustained intentionality necessary to affect universal change in schools (Boston et al., 2017; Cobb & Jackson, 2011).

Second, the longitudinal, mixed methods data collection has been critical in providing a complete picture of Fellows' growth and journey throughout the project. Quantitative measures have identified specific aspects of Fellows' growth, but it is the coordination of quantitative and qualitative data that have truly captured the synergistic aspects of the project. For example, increases in content knowledge in Year 2 (as seen on LMT results) are a factor self-identified by Fellows (during focus groups) as supporting their confidence to act proactively as teacher leaders and as minimizing their feelings of imposter syndrome. While quantitative methods provide evidence of change, we cannot underscore the importance of qualitative methods in describing and understanding how and why that change occurred. Projects need to consider the importance of identifying different evidence markers: statistical significance, practical significance, or both.

Third, we also attribute the capacity for growth of our Fellows to their initial mindsets and motivation to enact change in their school settings, which speaks to the value and importance of the recruitment process. We were incredibly intentional during the interview portion to explore applicants' mindset and beliefs towards teaching. Fellows began the project with the mindset and motivation to be teacher leaders, but needed the platform and confidence. Hence, Fellows were eager to receive the tools and support provided by the Teacher Leader Academy (e.g., Catalyzing Change Needs Assessment, Affirming Learning Walks) to enact change in their schools.

Finally, we suggest the need for additional research on classroom-based mathematics teacher leaders and the role they have in catalyzing change and improving teaching and learning in their schools and districts. Research often focuses on principals as instructional leaders (e.g., Boston et al., 2017) or teacher leadership in content areas other than mathematics (Criswell et al., 2018; Gul et al., 2019). Similarly, additional research is needed on the roles and impacts of stakeholder groups (research institutions, district level administrators, school-based administrators, teachers, and partner organizations) on the success of research-to-practice partnerships in a variety of settings and contexts.

Next Steps for Our Project

As we reflect on this journey so far, we briefly share some of our priorities as we consider next steps. First, in addition to the planned Teacher Leader Academy activities, we will keep our eyes open to individualized avenues to support our Fellows in their mathematics teacher leader growth. Along the same lines as the example we described regarding two Fellows leading a conceptually-based fact fluency initiative in the district, we believe more grassroots organic opportunities will present themselves, and we will be here to encourage and support our Fellows through the modeling, coaching, and fading cycle. By the end of Year 2, Fellows have become quite insightful in thinking broadly beyond the walls of their own school and are starting to identify needs at the district level. Fellows' colleagues, administrators, and district leaders now seek out their advice and expertise as they are becoming the "go-to" experts. The district also started committing funds for Fellows to attend and/or present at state and national conferences. Second, at the time of this writing, our Fellows are in the midst of conducting their dissertation-in-practice research, in which they align to one or more of the recommendations in Catalyzing Change. We simultaneously worked to protect their time so they can stay focused on completing their dissertation while also helping them position themselves for future teacher leader opportunities in their district and through our national and state professional organizations. Third, we have seen a shift from Fellows' spheres of influence being more at their school to becoming more district-level (or multi-school). As we continue to consider how Fellows' impacts can have a more integrated and influential role across their district as well as consider their impacts on a state and national level. Finally, we recognize much of the progress made in Years 1 and 2 had been on improving mathematics learning within existing structures, and we are still working to navigate how some structures might be reimagined and built to ensure all students have access to the mathematics they deserve.

Concluding Thoughts

We believe the two-pronged approach can be adopted and adapted across a wide range of projects and scopes. Simply put, no matter your project, building a strong and caring community focused on learning and doing something meaningful and then providing teachers a space and place to enact it, grow, and flourish with support and encouragement can go a really long way!

To conclude, it is challenging to capture all we have learned about the Fellows, as well as our own immeasurable personal growth as mathematics teacher educators and mathematics education researchers through this journey. We have learned at least as much from our Fellows' strength and resilience; passion for advocating, leading, and teaching; and care for their students as they have learned from us. While the data and results from this project are critical and serve to inform the field in ways we hope are important and impactful, we are most proud of the heart of this work - the Fellows who pour their heart and soul into this work every day and the unwavering dedication of all partners. Mathematics teacher leadership, and STEM teacher leadership more broadly, is not for the faint of heart. It's hard, complicated, complex, exhausting, but absolutely essential work. We join our colleagues in sharing in our project's overall goal and call to action: How do we move beyond improving mathematics learning within existing structures to reimagining and rebuilding to ensure all students have the mathematics learning experiences they deserve?

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References

Alemdar, M., Cappelli, C. J., Criswell, B. A., & Rushton, G. T. (2018). Evaluation of a Noyce program: Development of teacher leaders in STEM education. *Evaluation and Program Planning, 71*, 1-11. https://doi.org/10.1016/j.evalprogplan.2018.06.005

Auslander, S.S., Tanguay, C. L., Myers, K. D., Phillips, K. L., & Sanders, T. (2022). Preparing and supporting elementary mathematics specialists through school-university-community partnerships. *PDS Partners: 2022 Themed Issue*. 155-169.

Barber, M. & Mourshed, M. (2007). *How the world's best-performing school systems come out on top*. McKinsey & Company. https://www.mckinsey.com/industries/education/our-insights/how-the-worlds-best-performing-school-systems-come-out-on-top.

Barth, S. G., Lotter, C., Yow, J. A., Irdam, G., & Ratliff, B. (2023). Understanding the process of teacher leader identity development. *International Journal of Leadership in Education*. https://doi.org/10.1080/13603124.2023.2258083

Berg, J. H., & Zoellick, B. (2019). Teacher leadership: Toward a new conceptual framework. *Journal of Professional Capital and Community*, *4*(1), 2-14. https://doi.org/10.1108/JPCC-06-2018-0017

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*, 3-15. https://doi.org/10.3102/0013189X033008003

Borko, H., Carlson, J., Deutscher, R., Boles, K. L., Delaney, V., Fong, A., Jarry-Shore, M., Malamut, J., Million, S., Mozenter, S., & Villa, A. M. (2021). Learning to lead: An approach to mathematics teacher leader development. *International Journal of Science and Mathematics Education, 19*, 121-143. https://doi.org/10.1007/s10763-021-10157-2

Boston, M. D. (2012). Assessing the quality of mathematics instruction. *Elementary School Journal, 113*(1), 76-104. https://doi.org/10.1086/666387

Boston, M. D. (2013). Connecting changes in secondary mathematics teachers' knowledge to their experiences in a professional development workshop. *Journal of Mathematics Teacher Education, 16*, 7-31. https://doi.org/10.1007/s10857-012-9211-6

Boston, M. D., Henrick, E. C., Gibbons, L. K., Berebitsky, D., & Colby, G. T. (2017). Investigating how to support principals as instructional leaders in mathematics. *Journal of Research on Leadership Education, 12*(3), 183-214. https://doi.org/10.1177/1942775116640254

Bressoud, D. (2015). Insights from the MAA National Study of College Calculus. The *Mathematics Teacher, 109*(3), 179-185. https://doi.org/10.5951/mathteacher.109.3.0178

Bush, S. B., Brooks, L. A., Dixon, J. K., Rutledge, T., Butler, M. B., & Moore, B. (2022, May 26). *Elevating voices, catalyzing change: A partnership approach to supporting K-8 mathematics teacher leaders.* American Association for the Advancement of Science (AAAS) Advancing Research & Innovation in the STEM Education of Preservice Teachers in High-Need School Districts (ARISE). https://aaas-arise.org/2022/05/26/elevating-voices-catalyzing-change-a-partnership-approach-to-supporting-k-8-mathematics-teacher-leaders/

Bush, S. B., Karp, K. S., & Dougherty, B. J. (2021). *The math pact, middle school: Achieving instructional coherence within and across grades.* Thousand Oaks, CA: Corwin and Reston, VA: National Council of Teachers of Mathematics.

Cobb, P. & Jackson, K. (2011). Towards an empirically grounded theory of action for improving the quality of mathematics teaching at scale. *Mathematics Teacher Education and Development, 13*(1), 6-33.

Collins, A., Brown, J. S., & Newman, S. E. (1987). *Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics.* Technical Report No. 403. Urbana, IL: Center for the Study of Reading.

Conference Board of the Mathematical Sciences (CBMS). (2012). *The mathematical education of teachers II.* Providence, RI: American Mathematical Society and Washington DC: Mathematical Association of America.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches.* Sage.

Creswell, J., & Plano Clark, V. (2007). Designing and conducting mixed methods research. Sage.

Criswell, B., Rushton, G., McDonald, S., & Gul, T. (2018). A clearer vision: Creating and evolving a model to support the development of science teacher leaders. *Research in Science Education, 48*, 1-27. https://doi.org/10.1007/s11165-016-9588-9

Curriculum Associates (2023). I-Ready Assessments. Retrieved at Assessment Suite - Intuitive Reports and Insights | i-Ready (curriculumassociates.com).

Dean, C. & Brookhart, S.M. (2013). Mathematical Practices for deep understanding. *Educational Leadership: Getting Students to Mastery*, *71*(4). https://www.ascd.org/el/articles/mathematical-practices-for-deep-understanding

Dixon, J. K. (2023). *The fact tacticsTM fluency program: Building reasoning skills for multiplication in grades 3-6.* Bloomington, IN: Solution Tree Press.

Giganti, P. (2007). *Why teach problem solving, part I: The world needs good problem solvers! CMC ComMuniCator*, *31*(4), 15-16. https://camc.memberclicks.net/assets/docs/WhyTeachProblemSolvingPart1.pdf

Green, A.M., & Kent, A.M. (2016). Developing science and mathematics teacher leaders through a math, science & technology initiative. *The Professional Educator, 40*(1).

Gul, T., Criswell, B., Demir, K. (2022). Impacts of teacher-driven professional development on teacher leadership identity. *International Journal of Leadership in Education, 28(4), 875–902.* https://doi.org/10.1080/13603124.2022.2052754

Gul, T., Demir, K., & Criswell, B. (2019). Constructing teacher leadership through mentoring: Functionality of mentoring practices evolving teacher leadership. *Journal of Science Teacher Education, 30*(3), 209-228. https://doi.org/10.1080/1046560X.2018.1558655

Hiebert, J., Stigler, J. W., Jacobs, J. K., Givvin, K. B., Garnier, H., Smith, M., & Gallimore, R. (2005). Mathematics teaching in the United States today (and tomorrow): Results from the TIMSS 1999 Video Study. Educational Evaluation and Policy Analysis, 27, 111-132.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education, 39*(4), 372-400. https://doi.org/10.5951/jresematheduc.39.4.0372

Karp, K., Bush, S. B., & Dougherty, B. (2014) 13 rules that expire. *Teaching Children Mathematics, 21*(1), 18-25. https://doi.org/10.5951/teacchilmath.21.1.0018

Karp, K. S., Dougherty, B. J., & Bush, S. B. (2021). *The math pact, elementary: Achieving instructional coherence within and across grades.* Thousand Oaks, CA: Corwin and Reston, VA: National Council of Teachers of Mathematics.

Katzenmeyer, M., & Moller, G. (2009). *Awakening the sleeping giant: Helping teachers develop as leaders.* Corwin.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge, England: Cambridge University Press.

LeCompte, M., Preissle, J., & Tesch, R. (1993). *Ethnography and qualitative design in educational research.* Academic Press.

Ma, V., Dana, N., Adams, A., & Kennedy, B. (2018). Understanding the problem of practice: An analysis of professional practice EdD dissertations. *Impacting Education: Journal on Transforming Professional Practice, 3*(1), 13-22. https://doi.org/10.5195/ie.2018.50

Meyer, F., & Slater-Brown, K. (2020. Educational change doesn't come easy: Lead teachers' work as change agents. *Mathematics Education Research Journal, 34*(1), 139–163. https://doi.org/10.1007/s13394-020-00333-y

Munter, C., & Wilhelm, A. G. (2021). Mathematics Teachers' Knowledge, Networks, Practice, and Change in Instructional Visions. *Journal of Teacher Education, 72*(3), 342-354. https://doi.org/10.1177/0022487120949836

National Center for Science and Engineering Statistics. (2023). Diversity and STEM: Women, minorities, and persons with disabilities. NCSES. https://ncses.nsf.gov/pubs/nsf23315/

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.* Reston, VA: Author.

National Council of Teachers of Mathematics. (2020a). *Catalyzing change in early childhood and elementary mathematics: Initiating critical conversations.* Reston, VA: NCTM.

National Council of Teachers of Mathematics. (2020b). *Catalyzing change in middle school mathematics: Initiating critical conversations.* Reston, VA: NCTM.

National Science and Technology Council. (2018). *Charting a course for success: America's strategy for STEM education.* A report by the Committee on STEM Education at the National Science and Technology Council.

NCSM: Leadership in Mathematics. (2020). *NCSM essential actions series: Framework for leadership in mathematics education.* Englewood, CO: NCSM.

Ong, M., Wright, C., Espinosa, L. L., & Orfield, G. (2011). Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. *Harvard Educational Review, 81*(2), 172-209. https://doi.org/10.17763/haer.81.2.t022245n7x4752v2

Philippou, S., Papademetri-Kachrimani, C., & Louca, L. (2015). 'The exchange of ideas was mutual, I have to say': Negotiating researcher and teacher 'roles' in an early years educators' professional development programme on inquiry-based mathematics and science learning. *Professional Development in Education, 41*, 382-400.

Rebello, C. M., Hanuscin, D., & Sinha, S. (2011). Leadership in freshman physics. *Physics Teacher, 49*, 564-566. https://doi.org/10.1119/1.3661103

Reid, J. W., Hardee, A. B., Criswell, B. A., Elrod, M., Berryhill jr., S., & Rushton, G. T. (2022). Empowering teacher leaders: The role of research in changing teacher leaders' sense of themselves as professionals. *International Journal of Leadership in Education*. https://doi.org/10.1080/13603124.2022.2045629

Riegle-Crumb, C., King, B., Grodsky, E., & Muller, C. (2012). The more things change, the more they stay the same? Prior achievement fails to explain gender inequality in entry into STEM college majors over time. *American Educational Research Journal, 49*(6), 1048-1073. https://doi.org/10.3102/0002831211435229

Ross, D., Adams, A., Bondy, E., Dana, N., Dodman, S., & Swain, C. (2011). Preparing teacher leaders: Perceptions of the impact of a cohort-based job embedded, blended teacher leadership program. *Teaching and Teacher Education, 27*, 1213-1222. https://doi.org/10.1016/j.tate.2011.06.005

Ross, D. L., Lamb, L. L., & Johnson, J. F. (2023). Using affirming learning walks to build capacity. *Journal of School Administration Research and Development*, *8*(1), 47-54. https://doi.org/10.32674/jsard.v8i1.4783

Rutledge, Treshonda, "An Exploration of K-8 Classroom-Based Mathematics Teacher Leader Development" (2023). *Electronic Theses and Dissertations, 2020-*. 1766. https://stars.library.ucf.edu/etd2020/1766

Scholastic and the Bill & Melinda Gates Foundation. (2012). *Primary sources: 2012 – America's teachers on the teaching profession*. https://www.scholastic.com/primarysources/pdfs/Gates2012_full_noapp.pdf

Silva, E. & White, T. (2013). *Pathways to improvement: Using psychological strategies to help college students master developmental math*. Carnegie Foundation for the Advancement of Teaching. https://www.carnegiefoundation.org/wp-content/uploads/2017/03/pathways_to_improvement.pdf

Sinha, S., & Hanuscin, D. (2017). Development of teacher leadership identity: A multiple case study. *Teaching and Teacher Education, 63*, 356-371. https://doi.org/10.1016/j.tate.2017.01.004

Steele, M. D., Johnson, K. R., Otten, S., Herbel-Eisenmann, B. A., & Carver, C. L. (2015). Improving instructional leadership through the development of leadership content knowledge: The case of principal learning in algebra. *Journal of Research on Leadership Education, 10(2)*, 127-150. https://doi.org/10.1177/1942775115569353

Stein, M. K., & Nelson, B. S. (2003). Leadership content knowledge. *Educational Evaluation and Policy Analysis, 25*(4), 423-448. https://doi.org/10.3102/01623737025004423

Su, F. (2013). The lessons of grace in teaching. https://www.francissu.com/post/the-lesson-of-grace-in-teaching

Taylor, M., Goeke, J., Klein, E., Onore, C., & Geist, K. (2011). Changing leadership: Teachers lead the way for schools that learn. *Teaching and Teacher Education, 27*, 920-929. https://doi.org/10.1016/j.tate.2011.03.003

Teacher Leadership Exploratory Consortium. (2011). Teacher leaders model standards. https://www.ets.org/s/education_topics/teaching_quality/pdf/teacher_leader_model_standards.pdf

Thomas-Browne, C. G., Boston, M. D., & Parke, C. S. (2020). Developing a tool to capture productive and unproductive mindsets about teaching mathematics to African American students: An initial review. *Urban Education*. https://doi.org/10.1177/0042085920934859.

Weber, K. (2011). Role models and informal stem-related activities positively impact female interest in stem. *Technology and Engineering Teacher, 71*(3), 18-21.

Yow, J. A., & Lotter, C. (2016). Teacher learning in mathematics and science inquiry professional development program: First steps in emergent teacher leadership. *Professional Development in Education, 42*(2), 325-351. https://doi.org/10.1080/19415257.2014.960593

Yow, J. A., Wilkerson, A., & Gay, C. (2021). Mathematics and science teacher leadership: Understanding through a teacher leadership course. International Journal of Science and *Mathematics Education, 19*, 839-862. https://doi.org/10.1007/s10763-020-10080-y