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Landscape Review: State of Professional Learning for Mathematics Teacher Educators

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Mathematics teacher educators can reasonably be assumed to be a major influence on future teachers' preparation (Goodwin et al., 2014). However, a formal understanding of what MTEs need to know and do to support teachers has not been agreed upon by the field (Castro Superfine et al., 2024). As a result, there have been calls for better understanding of what mathematics teacher educators need to know and how they are prepared (e.g., Beswick & Goos, 2018). And while research on MTE knowledge is growing (Castro Superfine et al., 2024), understandings of MTEs' professional learning of MTEs is still being developed (e.g., Jackson et al., 2020). This literature review seeks to contribute to these understandings by addressing the following research question: What does the research on mathematics education say about how MTEs engage in professional learning across the learning trajectory of their careers? Using a systematic review of the literature, twenty-four studies were identified for review. These were categorized according to their locus and grouping of professional learners and included: individual professional learning, institution-based collaborative professional learning, interest-based collaborative professional learning, and institution-sanctioned professional learning. Conclusions from the literature and implications for the field are discussed.

Keywords: mathematics teacher educators, professional learning, learning trajectories

Mathematics teacher educators (MTEs) can reasonably be assumed to be a major influence on future teachers' preparation (Goodwin et al., 2014). However, a formal understanding of what MTEs need to know and do to support teachers has not been agreed upon by the field (Castro Superfine et al., 2024). As a result, there have been calls for better understanding of what MTEs need to know and how they are prepared (e.g., Beswick & Goos, 2018). And while research in the field of MTE knowledge is growing (Castro Superfine et al., 2024), understandings of MTEs' professional learning of MTEs is still being developed (e.g., Jackson et al., 2020). A major literature review (Castro

Superfine et al., 2024) focused on the knowledge and skills MTEs require and the contexts in which that knowledge has been developed. In this landscape review, we build on that work by addressing the following research question: What does the research on mathematics education say about how MTEs engage in professional learning across the learning trajectory of their careers?

Theoretical Orientations

In 1986, Shulman proposed that teachers need specialized knowledge about their fields that was unique to teaching and separate from disciplinary knowledge. This idea has been taken up in multiple forms by MTEs, including Mathematics Knowledge for Teaching (e.g., Hill & Ball, 2009) and Political *Conocimiento* for Teaching Mathematics (Gutiérrez, 2017). Each of these frameworks seeks to outline the kinds of knowledge and skills that future mathematics teachers need to successfully engage with students. In addition to conceptual frameworks, research has shown that a focus on developing knowledge supports prospective teachers' success in the classroom (Hill et al., 2005).

Because it can be assumed that MTEs are a major influence on the preparation of mathematics teachers (Goodwin et al., 2014), the knowledge and skills required to undertake teacher preparation are equally important. And given that the knowledge and skills needed by prospective mathematics teachers are necessarily complex (Anthony & Walshaw, 2009), MTEs' knowledge must be equally complex. In conceptualizing MTE knowledge, frameworks have developed encompassing mathematics teacher knowledge understandings but also requiring a *meta* version of the teacher knowledge as well as other specialized forms of knowledge unique to MTEs (Castro Superfine et al., 2024). The skills and knowledge that MTEs need to be professionally successful is not just information, include both information and processes required to support the learning of prospective teachers (Shaughnessy et al., 2016).

Based on the literature, the field does not have a definitive view of what skills and knowledge MTEs need; however, this is a growing research concern (Castro Superfine et al., 2024). Even as the field continues to develop these understandings, teacher educators report being underprepared for the work of educating prospective teachers (Goodwin et al., 2014). In 2018, Beswick and Goos edited a special edition of *The Journal of Mathematics Teacher Education* where they asked, "Mathematics teacher educator knowledge: What do we know and where to from here?" Amongst their considerations were what they described as a relatively understudied area of MTEs' professional learning trajectories. In Castro Superfine and colleagues' (2024) major review of MTE knowledge, they described the contexts of professional learning for MTEs, including: a) carrying out research as way to develop professional knowledge; b) professional learning programs and models to develop professional

knowledge; and c) professional learning development through self-study. In this literature review, we build on this work by centering opportunities that MTEs need to develop the professional knowledge and skills across the career span.

Literature Review Objectives and Methods

In this section, first important operational definitions and the review objectives will be described. Next the inclusion criteria and process will be outlined. Finally, the literature search and selection outcomes will be outlined.

Review Objective

The objective of this review is to address the question, "What does the research on mathematics education say about how MTEs engage in professional learning across the learning trajectory of their careers?" But more precisely, it is to catalogue the various approaches MTEs take to grow in their own professions across their professional lives. To address this purpose, operational definitions for the following terms are required: professional learning and learning trajectory.

Operational definitions originated in Early Twentieth Century psychology in Stevens' (1935) seminal paper. There, Stevens described the notion of an operational definition as one that could be used to distinguish between constructs and allow for identifying their measures. The operational definitions here are essential because they will be used to guide article inclusion and study analysis.

Learning Trajectory for Mathematics Teacher Educators

Learning trajectories in the professional world can be counter to the inertia of built into notions like proficiency or aptitude that assume complete knowledge upon entry into the working world (Lahn, 2011). The concept of learning trajectories, then, captures the mathematics teacher educators' need for continued and continual professional growth as they move through their careers. Further, learning trajectories are shaped by MTE's current professional knowledge and skills, professional context, and their orientation to opportunities to learn (Goos, 2009). While the notion of learning trajectories that guides mathematics curriculum design and what it requires (e.g., Clements et al., 2011) is very useful in that arena, in this paper, we are focused on a longer timescale, a less clear progression, and fewer constraints on content competence. Here, learning trajectories are assumed to include the activities and actions that are undertaken by a mathematics teacher educator that will support their professional work in the arenas of teaching or research within their field. Thus, a variety of approaches to professional learning are included and these result in equally broad outcomes. Further, although hypothetical learning trajectories can be used to drive PK-12 mathematics curriculum design (e.g., Baroody et al., 2004), no such approach was identified in the arena of

mathematics teacher educator professional learning, thus no single hypothetical learning trajectory is the focus of this paper.

Professional Learning for Mathematics Teacher Educators

Professional learning is a complex process that requires consideration of the many systems at play, rather than a prescriptive, linear arrangement of activities and outcomes (Opfer & Pedder, 2011). Further, professional learning has been described as requiring active participation, rather than passive reception of new ideas (Easton, 2008). Pedder and colleagues (2007) propose four crucial aspects of professional learning for teachers that encompass both the independent and collaborative activities that contribute to professional learning. These describe professional learning as a) an embedded, reflective practice, b) increased by considering external sources of information (e.g., published articles), c) intensified by completing mutual activity (e.g., in community with other teachers), and d) dependent on discussions of and investments in learning (Pedder et al., 2007). For the purposes of the current literature review, if any aspect of professional learning could be identified, the paper was included.

Literature Inclusion Criteria

Using the identified objectives and appropriate definitions, a series of inclusion criteria were developed to address the research question. There were two rounds of review, first to select abstracts and then to finalize the articles, which is described fully in the Literature Search and Selection Section that follows. In this section, the description of inclusion criteria for abstract review and manuscript selection are provided.

Inclusion Criteria for Abstracts

Inclusion data were based on the existing literature, with an eye to addressing the research question. The five initial criteria for inclusion in this review were: a) published after 2018; b) empirical; c) published in a peer-reviewed journal; d) university-based MTEs; and e) primarily centered MTEs professional learning.

The first criterion, publication after 2018, was identified because that was when Beswick and Goos (2018) called for a better understanding of MTEs' professional learning experiences. In recent years, the focus on MTEs' knowledge and their professional learning experiences has increased (Castro Superfine et al., 2024). As a result, the field has an improved, but fragmented, understanding of how mathematics teacher educators learn professionally. Here, we attempt to update that understanding.

The second and third criteria, research-based and peer-reviewed, were chosen in tandem. For the purposes of this literature review, we have taken an expansive view on research approaches, including multiple research traditions and methods. Creswell (2013) describes the research process as starting with a)

a set of assumptions or theoretical orientation, b) a topic of inquiry, c) a set questions about the objective of study, d) rigorous data collection, and e) analysis of the data. For the purposes of this review, studies were required to include each of these areas as appropriate to their own methodological tradition. Further, we included the third criterion, peer review, to ensure the rigor of methods and conclusions, rather than attempting to assess them as part of this literature review.

The fourth and fifth criteria were at the crux of the purpose of this literature review. First, studies of MTEs were limited to university-based educators with a focus on undergraduate or graduate education. Studies were not excluded if MTEs worked in a context where they served both in-service teachers and university students. This population was the focus of the study because many of the papers focused on mathematics knowledge for teacher educators has centered university-based individuals (e.g., Beswick & Goos, 2018; Castro Superfine et al., 2024; Goodwin et al., 2014). MTEs who supported the development of mathematical knowledge for teaching in classes designed for prospective teachers (PTs) irrespective of faculty departmental affiliation or professional training were included.

The final criterion required that studies emphasize the professional learning of MTEs, rather than providing implications for MTE preparation. Some qualities of professional learning included were close association with the professional work, analysis of data to impact the MTEs' classrooms, and a collaboration of professionals that leverages and respects the expertise of participants (Easton, 2008). If the focus of the study was on prospective or in-service teachers' professional learning, rather than MTEs, the study was excluded.

In the abstract selection stage, these criteria were applied broadly. If it seemed possible the manuscript would meet these requirements, it was included for full manuscript review.

Inclusion Criteria for Full Manuscripts

After the abstracts were reviewed using the initial criteria, full manuscripts were examined using both the initial criteria used for the abstracts and three additional criteria. The additional criteria included: a) an orientation toward professional growth that included a professional learning trajectory, b) an operational definition of professional learning, and c) some evidence that the approach is useful in moving forward on a professional learning trajectory.

Upon abstract review, criteria were broadly applied to ensure the most associated studies were reviewed included in the literature review. During this phase, if upon examination of the full manuscript, the study was found not to meet the full set of initial criteria, it was excluded. This occurred for a variety of reasons. For example, the abstract might not make clear the professional-context of MTEs and upon additional review it became apparent that the research focused on district- or school-based MTEs. In other cases, the abstract

appeared to be about professional learning opportunities, but rather focused on implications for further learning. This step was completed in conjunction with the other full manuscript criteria.

In addition to the initial criteria, manuscripts also were considered for their orientation toward professional learning trajectories. In order to be included, studies necessarily had to consider MTE professional learning a continual and ongoing practice rather than discrete and/or skills focused experiences. This approach to learning as a trajectory was chosen because they account for prior knowledge (e.g., Andersson & Hellberg, 2009) or career stage and the many systems that exist around learners (e.g., Goos, 2009). Papers were included if any of these constructs were included.

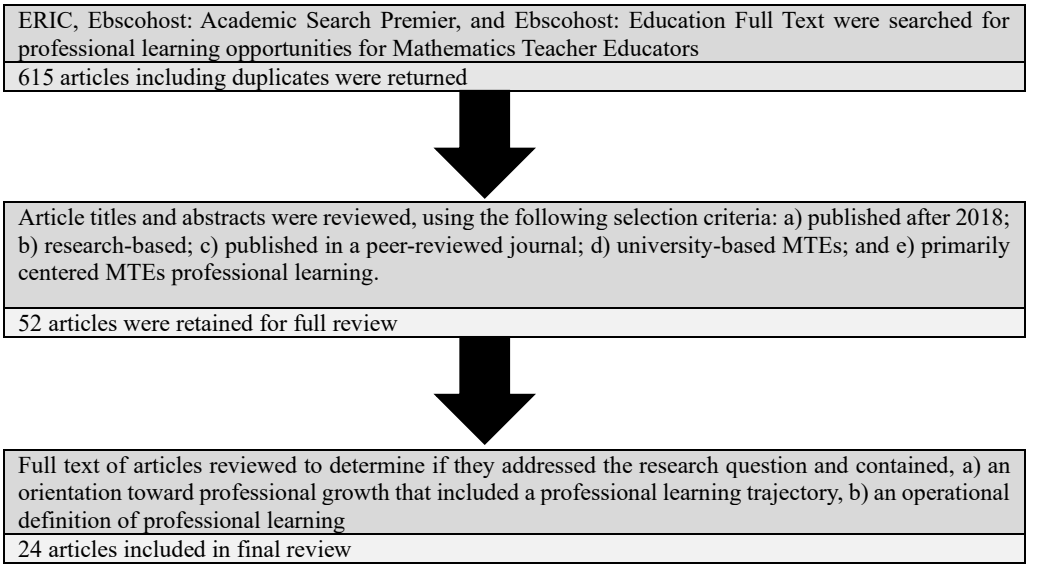
Finally, the professional learning had to exhibit at least one of the attributes identified in the operational definition. Those attributes included: a) professionally embedded and reflective, b) augmented with external sources, c) collaborative or community-focused, and d) centered on the value of learning (Pedder et al., 2007). Just as with the abstract search, an expansive approach to definitions and orientations was taken.

Literature Search and Selection

To identify the appropriate literature for this review, the authors searched ERIC and Ebscohost: Academic Search Premier, and Ebscohost: Education Full Text Databases. Each database was searched for the following terms: a) "mathematics teacher educators" AND “professional development,” b) "mathematics teacher educators" AND “professional learning,” and c) "mathematics teacher educators" in peer reviewed journals.

The search returned a total of 615 abstracts, including duplicates. Duplicates were removed and abstracts were screened for initial inclusion criteria: a) published after 2018; b) research-based; c) published in a peer-reviewed journal; d) university-based MTEs; and e) primarily centered MTEs professional learning. and duplicates were removed. Fifty-two articles were selected for full manuscript review; one article was not included because while the abstract was available, the full paper was not. The full manuscripts were reviewed with attention to the initial criteria and the following foci: a) an orientation toward professional growth that included a professional learning trajectory, and b) an operational definition of professional learning as described. Studies whose scope included features beyond professional learning were included in the corpus and the portions aligned with the research question were considered for further analysis. A total of 24 articles were included in the final analysis.

Figure 1
Outline of Literature Selection Process



Framing the Review

In this section, the analytic framework that was used to guide the review of the literature will be described. Next the categories that emerged from this analysis will be explained. The results section that describes the application of the framework will follow.

Analytic Framework

To make sense of the literature identified through the outlined process an adapted version of the instructional triangle (Cohen et al., 2003) was identified. The instructional triangle describes the complex interactions that occur during classroom instruction (Cohen et al., 2003). In this model, a triangle with teacher, content, and students are at each vertex are surrounded by circles representing the environments in which learning takes place (Cohen et al., 2003). Notably, the sides of the triangles are two-headed arrows to highlight the reciprocal relationships between vertices (Cohen, et al., 2003). This model has been extended to the context of teacher professional learning and teacher educator professional learning (Nipper & Sztajn, 2008). In the version for teachers, the researchers proposed that the content vertex could be math content or an examination of the K-12 classroom model (Nipper & Sztajn, 2008). And in a parallel model for teacher educators, the content could be math content, an examination of the K-12 classroom model, or an examination of the teacher learning context (Nipper & Sztajn, 2008). Relationships between subsystems, like teachers, schools, and learning activities, have been theorized to influence professional learning depending on combination interactions (Opfer & Pedder,

2011) and thus considering these interactions provides an analytic lens for understanding this literature.

Analytic Framework for Review of the Literature

In this framework, the professional learning organizer represents the planner or facilitator of the professional learning activity, however, it does not indicate that the person is necessarily providing or sharing expertise. The learner or learners are participants in the learning activity who is attempting to grow their professional learning. The professional learning activity includes any experience that could credibly be assumed to lead to an increase in professional knowledge. These might include a range of actions like reading, conversing, observing, creating, and practicing in the professional context.

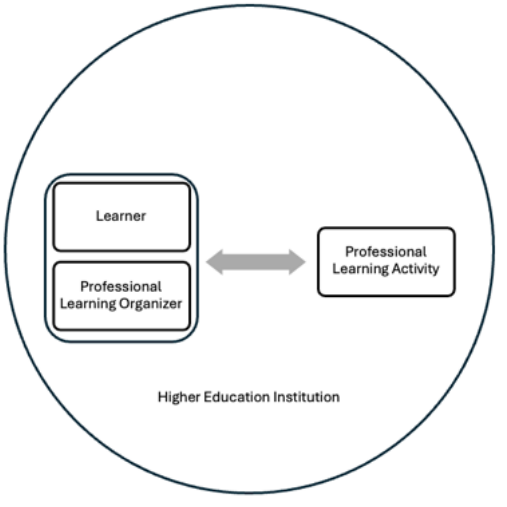
Emergent Categories

To address the research question, the identified literature was categorized according to the analytic framework and arranged to address the research question. Four categories were identified: a) individual professional learning, b) institution-affiliated collaborative professional learning, c) interest-based collaborative professional learning, and d) institution-sanctioned professional learning.

The individual professional learning classification includes studies where MTEs focus on efforts that do not require collaboration, although they might occur as part of the professional learning activity. In this "triangle," the professional learning organizer and the learner are the same participant (see Figure 2). The context for these studies is the home institution of the participant, although it is not always explicitly stated. The professional learning activities primarily focus on self-directed examination of learning materials.

Figure 2

Model of Individual Professional Learning



The second category, collaborative institution-affiliated professional learning, includes collaborative professional learning where the groups were formed via institutional affiliation such as fellowships and institutions of higher education. In these cases, each participant is both a learner and an organizer. In multiple cases, there were more than two participants. Figure 3 depicts a relationship where there are three participants. The collaborative learning models would continue to increase in the number of nodes if more the number of participants increased. Learning activities include approaches to collaborative learning including co-reflection and lesson study. As a note on these studies, some have common authors, indicating that the studies might be part of the same larger research group; however, they are listed individually in this literature review.

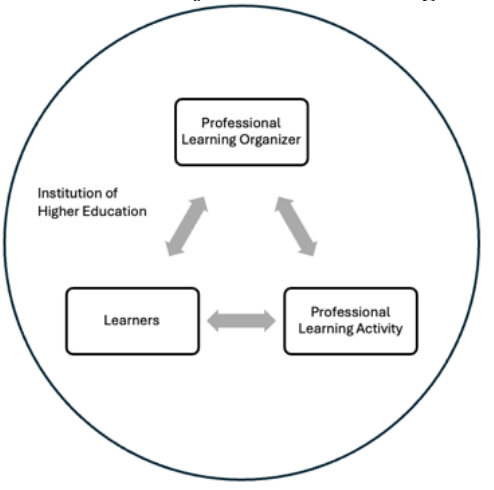
The next group, interest-based collaborative professional learning, including those where the group affiliation was not defined and instead describe instances where MTEs shared an interest in the construct of study. Just as with the Institutional-affiliated projects, MTEs were both organizers and learners. But the context is different in this category and is the construct or topic of study. The professional learning activities in this case also include collaborative exercises as previously described.

Figure 3

Model of Collaborative Institution-Affiliated Professional Learning

The final category includes institution-sanctioned professional learning, where higher education institutions formalized the professional learning effort. As a result, the context for this professional learning experience is the institution of higher education. For this category, each study had a professional learning organizer that was separate from the learner who included both in-serve and preservice MTEs. The professional learning activities in this category included experiences ranging from formal coursework to shared classroom materials (see Figure 4).

Figure 4
Model of Institution-Sanctioned Professional Learning



As a note on categorizing the studies, each study was placed into exactly one category based on the information provided and associated with the analytic framework. For studies that contained multiple constructs around MTE professional knowledge, only those directly to professional learning were considered for categorizing the study.

Results

In this section, results for each category are described. This will include synthesizing details of each study and how it responds to the research question. The categories will be reviewed in the order outlined in the Emergent Categories section.

Individual Professional Learning

This category contains five studies, including: one action research study (Chen et al., 2018;), two individual self-studies (Kortjass, 2019; Simpson, 2019), one qualitative study with 12 participants (Gibbons et al., 2023), and one large-scale mixed methods survey study (Ozmantar & Agac, 2023). Table 1 provides an overview of the studies and their findings.

As previously described, in these studies the professional organizer and the learner were the same participant. These studies included participants from across the career spectrum including pre-service or early-career MTEs (Chen et al., 2018; Kortjass, 2019; Simpson, 2019) as well as in-service MTEs across the career spectrum (Gibbons et al., 2023; Ozmantar & Agac, 2023). This range of participation suggests that this is a common approach to professional learning across the professional learning trajectory. The context for these learning experiences is assumed to be the institution where the learners are; it is not always clarified by the authors. The does not seem to be a prominent feature of

the professional learning as described; however, it must impact learners by providing time and/or space for these learning activities.

Table 1
Individual Professional Learning

Citation	Participants/Context; Methods	Major Finding(s) Related to Professional Learning
Chen et al. (2018)	1 university-based novice MTE supporting school-based professional development; Design-approach to action research	Through the design process, MTE learned to integrate theoretical and practical knowledge and understand in-service teachers' professional learning
Gibbons et al. (2023)	12 university-based MTEs who field tested educative curriculum; Qualitative analysis	Videos embedded in educative curricula offer opportunities to support MTEs' development of noticing in the classroom
Kortjass (2019)	1 university-based MTE and doctoral candidate; Self-study	Self-study supported MTE to understand PTs mathematical thinking and the pedagogical skills PTs needed
Ozmantar & Agac (2023)	281 university-based MTEs across Turkey; Survey with mixed-methods analysis	Professional learning is primarily self-regulated, and sources include literature, educational experience (i.e., coursework), official documents, other professional activities (i.e., teaching experience), classroom observations, professional interaction with other professionals including academics, PTs, in-service teachers, role models, and academic activities (i.e., research)
Simpson (2019)	1 university-based novice MTE with 21 PTs; Self-study	Self-study supported MTEs' understanding of how to create co-learning partnerships through sharing stories and shared research

The professional learning activities for this group fell into two categories: learning about theory and practices within mathematics education (Gibbons et al., 2023; Ozmantar & Agac, 2023) and learning to apply and refine practices within mathematics education (Chen et al., 2018; Gibbons et al., 2023, Kortjass, 2019; Ozmantar & Agac, 2023; Simpson, 2019). The studies focused on learning about theory and practice within mathematics education centered the use of external materials in the form of educative curriculum (Gibbons et al., 2023) or literature and official documents (Ozmantar & Agac, 2023). In the second category, the primary means of professional learning was self-study and iteration of practices with PTs or in-service teachers (Chen et al., 2018; Gibbons et al., 2023, Kortjass, 2019; Simpson, 2019). The final study identified another mode of similar learning that emerges from classroom and other professional interactions focusing on self-regulated professional learning (Ozmantar & Agac, 2023). That is, participants identified interactions with others in the same

field as being educative for their ability to apply and refine applications of practice (Ozmantar & Agac, 2023).

In sum, this category contains studies that identify how individual professionals expand their knowledge using professional learning activities that can be completed individually by leveraging local resources. In each case, the professional learning was self-initiated and self-directed. The focus of the learning outcomes was primarily new knowledge of theory or specific practices.

Collaborative Institution-Affiliated Professional Learning

This is the largest of the four categories in this literature review and includes ten studies. One of these was an action research study (Erbilgin, 2019). Four were collaborative self-studies (Baker & Bitto, 2020; Baker et al., 2023; Borowski & Rupe, 2023; Taylen et al., 2022). One was a collaborative inquiry (Levenson et al., 2023). One was a duoethnography (Lloyd et al., 2021). The final three were lesson studies, including one continuous improvement lesson study (Dick et al., 2019; Huang et al., 2023; Soto et al., 2019). Table 2 provides an overview of the studies included in this group.

In these studies, participants played both the role of learning organizer and learner. The MTEs in these studies were either identified as early career (Baker et al., 2023; Borowski & Rupe, 2023; Dick et al., 2022; Soto et al., 2019) or their professional trajectory was not identified (Baker & Bitto, 2020; Erbilgin, 2019; Huang et al., 2023; Levenson et al., 2023; Lloyd et al., 2021; Taylen et al., 2022). In the mode of collaborative interaction, different MTEs would act as learners or organizers across the professional learning experience. The context for these studies included a shared institution of higher education (Baker & Bitto, 2020; Borowski & Rupe, 2023; Erbilgin, 2019; Huang et al., 2023; Levenson et al., 2023; Lloyd et al., 2021; Taylen et al., 2022) and a fellowship opportunity (Baker et al., 2023; Dick et al., 2022; Soto et al., 2019). For all these professional learning opportunities, membership in the professional learning opportunity required access to a participating institution.

The nature of the professional learning activities varied, but they all required collaborative approaches to growing in the profession. Four of the studies used versions of lesson study or lesson implementation and reflection to identify and improve classroom practices (Dick et al., 2022; Erbilgin, 2019; Huang et al., 2023; Soto et al., 2019). Three studies explicitly identified "critical friendship" (Baker & Bitto, 2020; Baker et al., 2023; Borowski & Rupe, 2023) as their approach to professional learning, while others referred to collaborative feedback or professional learning communities (Levenson et al., 2023; Lloyd et al., 2021; Taylen et al., 2022). Each of these learning activities required that participants to spend time with each other in conversation, enacting shared norms with a common goal.

Table 2
Collaborative Institution-affiliated Professional Learning

Citation	Participants/Context; Methods	Major finding(s) related to professional learning
Baker & Bitto (2020)	2 in-service MTEs teaching graduate courses in math education at same higher education institution; Collaborative self-study	Critical friendship provided a vehicle for MTEs to develop their understanding of anti-racist practice
Baker et al. (2023)	7 in-service early-career MTEs from different institutions connected through fellowship; Collaborative self-study	Critical friendship provided support for MTEs to develop in multiple roles, including equitable practices for prospective teachers
Borowski & Rupe (2023)	2 in-service early-career MTEs from the same higher education institution; Collaborative self-study	Critical friendship provided support for enacting beliefs, especially around humanizing mathematics
Dick et al. (2022)	4 in-service early-career MTEs from different institutions connected through fellowship: Continuous Improvement Lesson Study (CILS)	Through CILS, developed educative lesson for sharing with MTE community and improved their own practice
Erbilgin (2019)	2 in-service MTEs from the same higher education institution; Action research	Through collaborative planning and reflection, MTEs improved their lesson planning and implementation skills to encourage MTEs' consideration of PTs' thinking, and skills in teaching and learning
Huang et al. (2023)	4 in-service MTEs from the same higher education institution; Lesson study	Participation in the lesson study supported MTEs to enhance equitable practices in the classroom, especially addressing student authority, and using student thinking in the lesson
Levenson et al. (2023)	3 in-service MTEs from the same higher education institution; Collaborative inquiry on community of practice	Collaborative inquiry supported MTEs to identify key goals and routines, especially attending to what should shift and what should stay the same
Lloyd et al. (2021)	3 in-service MTEs from the same higher education institution; Duoethnography	Through conversation, MTEs recognized how their own perspectives and identities shaped their classroom observation of students
Soto et al. (2019)	5 in-service early-career MTEs from different institutions connected through fellowship; Lesson Study	MTEs use of technology-facilitated lesson study supported the development of a Community of Practice that supported MTEs to reflect on teaching practice, increased comprehension of PTs' thinking, and professional growth.
Taylen et al. (2022)	4 in-service MTEs from the same higher education institution; Self-study	Through the process of self-study, MTEs were able to reflect on their practices and grow their pedagogical content knowledge

For these studies, the focus of the common goal was generally on classroom practice. The learning activities resulted in considerations of how a) identity, perspectives, and beliefs impact practice (Borowski & Rupe, 2023; Levenson et al., 2023; Lloyd et al., 2021), b) to improve lesson planning (Erbilgin, 2019; Taylen et al., 2022), c) to foster equitable classroom practices (Baker & Bitto, 2020; Baker et al., 2023; Borowski & Rupe, 2023; Huang et al., 2023), and d) to build technology enhanced learning (Huang et al., 2023). Only one study produced a material product: a lesson plan designed to be educative for MTEs (Dick et al., 2022). Notably, the outcomes of these studies were different from the previous category, focusing primarily on refining or better understanding known practices and theories, rather than looking to expertise external to the group. In total, these studies provide insights about professional collaborations where collaborators had the opportunity to meet co-researchers through institutional means.

Interest-Based Collaborative Professional Learning

Six studies make up this category, including one action research study (Helliwell & Ng, 2022) and five collaborative self-studies (Kalinec-Craig et al., 2020; Kastberg et al., 2019; 2020; Keazer & Maher, 2021; Livers & Wiley, 2023). Table 3 provides an overview of the studies included in this group.

In this category, like the previous, the learners and professional learning organizers each played both roles. All participants were identified as in-service MTEs; one study identified participants as early career (Keazer & Maher, 2021). This group shares a lot of similarities with the collaborative Institution-affiliated professional learning category; just as with that group, each participant represents a different node in the model. The major difference between this group and the former is that these studies focused on a common interest and did not describe an institutional route for their collaboration. Two studies described a collaboration that resulted from a conference workshop (Kastberg et al., 2019; 2020), while the remaining studies did not describe the origin of their collaborations (Helliwell & Ng, 2022; Kalinec-Craig et al., 2020; Keazer & Maher, 2021; Livers & Wiley, 2023).

The professional learning activities in this category were also similar to those outlined in the previous category and were collaborative primarily focused on classroom practices. These included a focus on specific practices like MTE questioning (Kastberg et al., 2019), written feedback (Kastberg et al., 2020), and use of video clips (Kalinec-Craig et al., 2020). Additionally, most professional learning activities contained an explicit outcome related to equitable practice including designing mathematics tasks that focused on ecological sustainability (Helliwell & Ng, 2022), designing tasks that were relevant and contextual (Keazer & Maher, 2021), applying a framework for equity (Kalinec-Craig et al., 2020), and moving forward with equitable pedagogy (Livers & Wiley, 2023). Just as with the previous group, the focus of

this work was mostly about refining and clarifying ideas, rather than primarily on learning new theory from experts external to the group.

Table 3
Interest-based Collaborative Professional Learning

Citation	Participants/Context; Methods	Major Finding(s) Related to Professional Learning
Helliwell & Ng (2022)	2 in-service MTEs from UK and Hong Kong focused on courses for undergraduate and graduate PTs; Action research	Participation in the Action Research project allowed MTEs and PTs to understand how to leverage mathematics to teach about ecological sustainability using the local context
Kalinec-Craig et al. (2020)	3 in-service MTEs from 3 different institutions; Playlist process collaborative self-study	Playlist process supported MTEs to gain insight into their practice, including using scaffolds for teacher noticing, the use of a framework for equitable participation, and attending to the sequence and focus of video clips
Kastberg et al. (2019)	3 in-service MTEs from 3 different institutions who met through a conference working group; Collaborative self-study	Self-study provides a structure for MTEs to improve their questioning practice over time
Kastberg et al. (2020)	3 in-service MTEs from 3 different institutions who met through a conference working group; Collaborative self-study	Written feedback practices are mediated by other factors, like MTE identities and college accreditation processes
Keazer & Maher (2021)	2 early-career in-service MTEs at 2 different institutions; Collaborative action research	In the process of supporting PTs, MTEs learned to clarify and refine their understanding of relevant and authentic tasks
Livers & Wiley (2023)	2 in-service MTEs at different institutions; Collaborative self-study	Collaborative self-study supported MTEs to unearth hidden racist structures and move forward with equitable pedagogical practices

Institution-Sanctioned Professional Learning

This is the smallest group, containing three studies: one lesson study (Barlow et al., 2021), one case study (Jankvist, et al., 2019), and one large-scale survey (Masingila & Olanoff, 2021). In this review, general statements will be made about Masingila and Olanoff (2021); however, the survey reached over 400 participants and as a result, the nuance of these results cannot be reported. Table 4 describes the studies in this category.

Table 4
Institution-Based Professional Learning

Citation	Participants/Context; Methods	Major Finding(s) Related to Professional Learning
Barlow et al (2021)	1 in-service MTE & 5 doctoral-student MTEs teaching sections of the same undergraduate course in math education; Lesson study	Lesson study is an appropriate methodology to support MTE professional growth, conditions for learning include teaching at least once per cycle and embedding lessons in a methods course to broaden growth
Jankvist et al. (2019)	2 prospective MTEs participating in a mathematics history mini course; Case study	The history of mathematics course can support MTEs' development of disciplinary knowledge related to an epistemological understanding of mathematics
Masingila & Olanoff (2021)	413 university-based MTEs; Large-scale survey	15-58% of institutions offer training for PT math content courses; Training opportunities included: informal support, attendance at workshops, single training meeting, regularly scheduled training meetings, and shared materials

This group of studies was an outlier when compared to the other categories. This is the only category where the learner and professional learning organizer were separate individuals/institutions. The learners in these studies ranged across the career trajectory and included prospective MTEs (Jankvist et al., 2019), novice MTEs (Barlow et al., 2021), and in-service MTEs (Barlow et al., 2021; Masingila & Olanoff, 2021). The professional learner organizers were both in-service MTEs (Barlow et al., 2021; Jankvist et al., 2019) and formal or informal institutional support (Masingila & Olanoff, 2021). The context for these professional learning triangles included both course-based activities (Barlow et al., 2021; Jankvist et al., 2019) and broadly construed, institutional activities (Masingila & Olanoff, 2021).

The professional learning activities identified in these studies varied and included both formalized collaborations, as with coursework (Barlow et al., 2021; Jankvist et al., 2019) and a combination of individual and collaborative, ongoing or discrete, but primarily informal events (Masingila & Olanoff, 2021). The learning goals for the identified learning activities included both classroom practices (Barlow et al., 2021) and deepening the mathematics content knowledge of MTEs (Jankvist et al., 2019; Masingila & Olanoff, 2021). In the case of Masingila and Olanoff (2021) the purpose of their study was to identify access to this kind of learning, while for Jankvist and colleagues (2019) this was the focus of the associated course. Several items stand out from this category. First, there are very few studies in this group compared to the others; this is notable because these are the professional learning opportunities that are

promoted by the institution. Second, the focus of these studies ranges across the different aspects of a MTEs professional role, but the focus on mathematics content was unique amongst the described studies. Finally, it is notable that these are identified as institution-sanctioned for this paper, but other activities or organizations here might have been sanctioned by the institution in a similar way.

Reliability and Validity

To address issues of reliability and validity of the results section, we used the approach to a systematic literature using steps outlined by Shaheen and colleagues (2023). The first criteria is a well-defined research question (Shaheen et al., 2023). This question is designed to address the emergent nature of the field's understanding and has been clearly designated throughout the literature review process. The second criterion is an adequate and relevant search strategy (Shaheen et al., 2023). The databases identified for this study were included due to the volume of educational research that they house. Further, the databases were chosen because they are specialized enough to ensure a depth of appropriate research studies. The search terms are thoroughly described in the previous section and were identified to provide extensive associated studies. Inclusion and exclusion criteria are fully described as recommended (Shaheen et al., 2023). The fourth criterion, quality assessment of included studies (Shaheen et al., 2023) is addressed by including a range of research traditions, inclusion guided by the definition provided by Cresswell (2013) and peer review process for the included studies. The next criterion is that synthesis of data is appropriately conducted (Shaheen et al., 2023). The use of an established framework to guide analysis provides research guidance. Next, risks of bias and limitations of the study should be addressed (Shaheen et al., 2023), which occurs at the end of the discussion in this literature review. Finally, Shaheen and colleagues (2023) encourage authors to disclose any conflicts of interest; we have no known conflicts of interest.

Discussion

The analytic framework will be used to compare the results of the literature review. The first focus of the model are learners and professional learning organizers. Nine of the 24 studies identified learners as either prospective or early-career MTEs (Baker et al., 2023; Barlow et al., 2021; Borowski & Rupe, 2023; Chen et al., 2018; Dick et al., 2022; Gibbons et al., 2023; Jankvist et al., 2019; Keazer & Maher, 2021; Kortjass, 2019). The remaining studies were not clear about the career stage of participating MTEs. For the studies in the individual and two collaborative categories, participants served both as the professional learning organizer and the professional learner. This dual role approach to professional learning reflects the assumption that MTEs gain knowledge not just from other MTEs, but also through their

interaction and reflection with PTs (Castro Superfine et al., 2024); further it suggests that MTEs can provide each other with appropriate feedback. That is, there is an implicit assumption that professional learning is a reflective piece of the professional trajectory.

The context for these learning activities included both formal and informal networks. However, only three studies that specifically identified institution-sanctioned approaches to professional learning (Barlow et al., 2021; Jankvist et al., 2019; Masingila & Olanoff, 2021). This finding is consistent with what other studies suggest about a dearth of formal professional learning opportunities for MTEs (Castro Superfine et al., 2024). Each of the categories, except the individual professional learning category, required access to one of these networks. In many cases the networks were informal or unsanctioned (as with the two collaborative categories) meaning that group membership requires a particular kind of social capital.

The learning and research activities were primarily self-reflective, either individually or in a group and included 19 of the 24 selected studies (Baker & Bitto, 2024; Baker et al., 2023; Barlow et al., 2021; Borowski & Rupe, 2023; Chen et al., 2018; Dick et al., 2022; Erbilgin, 2019; Helliwell & Ng, 2022; Huang et al., 2023; Kalinec-Craig et al., 2020; Kastberg et al., 2019; 2020; Keazer & Maher, 2021; Kortjass, 2019; Levenson et al., 2023; Livers & Willey, 2023; Lloyd et al., 2021; Simpson, 2019; Soto et al., 2019; Taylen et al., 2022). This is consistent with previous literature (e.g., Castro Superfine et al., 2024) and is connected to the previous statements about assumptions about feedback and learning for MTEs.

In terms of the learning activities, only three identified mathematics content as the focus (Barlow et al., 2021; Jankvist et al., 2019; Masingila & Olanoff, 2021); the remainder centered classroom practices or theory. The focus on learning about practice, in community, as with the self-inquiry methodologies, is a common approach to in-service teacher learning and has been found to sustain professional learning (Widodo, & Allamnakhrah, 2022) as well as improve specific practices like centering social justice (e.g., Ribay, 2024). The other difference in content was how participants learned from each other, in most cases expertise was assumed to come from the collaboration between learners, but in the case of coursework (Barlow et al., 2021; Jankvist et al., 2019) and individual review of materials (Gibbons et al., 2023; Ozmantar & Agac, 2023), it can reasonably be assumed that at least some of the expertise was provided by an external source.

Overall, the literature review points to several key ideas. First, professional learning for MTEs is primarily self-initiated and self-regulated, rather than institutionally identified opportunities. This means that individuals need to either have access to the professional knowledge to support their individual work or professional networks that can support them to do so. Next, the majority of these studies focused on classroom practice rather than mathematics content development. This suggests that MTEs may feel well-

prepared to share content but wish to continue to grow in their classroom practices. Finally, considering the role of the professional learning organizer and learner in MTE professional learning systems provides some insight into knowledge is shared with MTEs.

It should be noted that any conclusions here come with many caveats. First, there are many MTEs in the world, the Association of Mathematics Teacher Educators alone has over 1000 members (*About AMTE*, n.d.); however, only on 24 studies were reviewed as part of this literature review. Certainly, this does not address the breadth of professional learning opportunities for MTE. Further, only a small number of research traditions, including small-scale self-studies and two larger-scale surveys, were reviewed. This narrow array of research has some implications for this literature review, specifically that generalities are hard to draw based on these studies and a significant amount of work on theory around MTE professional learning is necessary. Additionally, reporting bias is a concern for these studies. The institutional support reported in two studies were focused on coursework provided as part of an MTEs' degree programs. Indubitably, there are other similar opportunities offered as part of degree or other training programs that have not yet been reported. Finally, the studies did not represent the range of global locations where MTEs work. Most studies, 17 total, had authors from the United States; the remaining author's institutional affiliation's countries included two from China, one Denmark, one from Israel, one from Kuwait, one from Norway, three from Türkiye, two from South Africa, and two from the UK. Clearly any analysis contained in this paper leans heavily towards the perspective of professional learning in the United States and contains far fewer perspectives from the Global South.

Conclusions and Implications

To address the research question, most studies suggest that much of MTE professional learning requires MTEs to design or identify their own learning structures, often in the form of self-studies and generally are focused on improving aspects of classroom practice. Further, most of these studies focused on pre-service or early career MTEs with fewer focused on later career individuals. Finally, very few of the professional learning opportunities were designed by the MTEs' professional institution.

There are several implications for the field from this review, both for research and practice. Future research directions could include both a focus on more MTE participants and additional research traditions. Given the limited scope of MTE participants' career spans in the published studies, further work on the understanding of professional learning across the learning trajectory would provide insights into the MTEs professional learning trajectory. Second, research that leverages additional research traditions might provide new understandings about reproducible interventions or supports. Some reviews of self-study projects, for example, comparing the professional learning

experiences would provide new information about the kinds of experiences that are supportive and under which conditions. Finally, research into what structural barriers exist and supports are necessary to implementing institutionally focused professional learning opportunities would provide important direction for the field.

In terms of practice, the reporting MTEs seem adept at leading and directing their own professional learning. While more research needs to be done on this topic, it is worth considering if these skills are developed by doctoral or other MTE preparation programs. If they are not, it seems MTEs would benefit from acquiring such skills. The second implication is that for categories outside of the individual learning category, MTEs need to have access to learning partners, either through institutional means or informal networks. This means that some learners may be excluded by such opportunities because they do not have access to these networks. The field should consider creating clear pathways for individuals to connect to these networks, including specific outreach activities to ensure broader participation.

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