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The Teaching of Instructional Technology Implementation in Mathematics Teacher Education Research: A Critical Analysis From a Praxeology-Informed Perspective

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Instructional technology implementation is increasingly being addressed in teacher education, though research literature on its implementation remains limited. This literature analysis draws the Anthropological Theory of the Didactic to map what and how instructional technology is integrated into preservice mathematics teacher education and to identify conditions that facilitate or hinder the adaptation. Drawing from 22 peer-reviewed articles published between 2010 and 2022, the study maps empirical studies of instructional technology integration in mathematics teacher education. Key findings reveal that preservice teachers consistently engaged in lesson planning, practiced teaching peers in 13 cases, and taught actual learners in three instances, while reflection occurred in seven cases. However, the underlying reasoning (logos) behind the didactical practices were not presented to the preservice teachers, remained implicit, or were not clearly linked to the praxis. Furthermore, the decomposition of teaching practices was an underused pedagogical practice. Learning opportunities included rehearsals, the use of exemplary curriculum materials, teamwork, and constructive feedback. A key challenge in adapting the didactical praxeologies was the participants' lack of prior experience with technology. The analysis highlights the need to make the reasons behind teaching practices explicit and calls for more intentional integration of teacher education pedagogies to enhance learning outcomes.

The widespread integration of information and communication technology (ICT) in all aspects of modern life has led to the pressure to bring ICT into education (e.g., Msafiri et al., 2023; Timotheou et al., 2023). According to Howland et al. (2012), "technologies afford students opportunities to engage in meaningful learning when they learn *with the* technologies, not *from it*" (p. 5). The perspective of learning with technology has led to the inclusion of ICT in teacher competency frameworks, such as the European Digital Competence of Educators (Caena & Redecker, 2019). No less so in the field of mathematics education, where ICT can, among other things, facilitate the integration of visual and symbolic representations.

Rather than expect teachers to learn to use ICT meaningfully and critically independently, it is imperative, albeit complex, to include this practice in teacher education in teaching both content and pedagogy (see Tondeur et al., 2019; Voogt & McKenney, 2017). Research has shown that the quality of teacher education preparation significantly impacts preservice teachers' (PSTs') ability to integrate technology into their teaching (Baran et al., 2019; Kafyulilo & Fisser, 2019), including after graduation (Mouza et al., 2017; Tondeur et al., 2016).

Although efforts by teacher education programs have sometimes appeared beneficial, they have also been criticized for failing to adequately provide PSTs with the hands-on experiences integrating ICT into their teaching (Fathi & Ebadi, 2020; Marron & Coulter, 2021). Studies suggest that only a few PSTs creatively and adaptively integrate ICT into their teaching, providing learners with deeper epistemological access to mathematics (Bang & Luft, 2013; Tondeur et al., 2017).

We examined current teacher education practices to gain meaningful insight into ways PSTs are prepared to use ICT in teaching mathematics. Understanding current teacher education practices involves understanding what PSTs are being taught regarding the utilization of ICT in mathematics teaching, how they are being taught, and the conditions and constraints of adapting what was taught in the school setting. One way to understand current teacher education practices is through case studies (e.g., Mensah, 2024) and another through identifying current practices as reflected in the literature. The analysis aims to highlight the current practices reflected in the research literature.

The Association of Mathematics Teacher Educators' (AMTE, 2017) first standard, particularly indicator C.1.6 – "use of mathematics tools and technology" is highly relevant to our analysis. The standard emphasizes the necessity for PSTs to be proficient in utilizing various mathematical tools and technologies to support mathematical reasoning and sense-making, both in their practice and in supporting student learning. The standard indicator validates the relevance of our focus and provides a structured framework for evaluating and improving the integration of technology in mathematics teacher education.

Drawing on the standard indicator C.1.6, we emphasized the critical necessity of preparing PSTs with the skills and knowledge to integrate emerging technologies seamlessly into their instructional practices. By fostering a robust understanding of technological tools and their applications, teacher educators can ensure that PSTs are well-prepared to create engaging, innovative, and effective learning environments.

Several frameworks exist to support mathematics teacher educators (MTEs) in designing instructional materials, communicating with PSTs, and assisting them in integrating digital tools into their instruction. However, these frameworks have been designed for general educational contexts, not mathematics and teacher education.

For instance, the study by McCulloch et al. (2021) serves as a prime example within a general education context. Within mathematics education, the Anthropological Theory of the Didactic (ATD; Chevallard & Bosch, 2020) is a comprehensive framework for analyzing teaching and teacher education in context. Therefore, we used this framework to draw out the contributions of the analyzed papers. We supplemented the ATD with a distinction of different uses of ICT, as described in the section on reference models.

To differentiate between the ATD-specific use of technology and technology's general application, we use the term "instructional technology" in this paper. We use the term instructional technologies to refer to integrating digital tools into the classroom to either increase the efficiency with which teachers and students can accomplish their tasks or the depth with which teachers and students can acquire new knowledge, or both. While ICT is the broadest category, encompassing all communication and information processing technologies, instructional technology focuses specifically on applying these technologies to improve teaching and learning. Digital tools, on the other hand, are specific applications and software that can be used within ICT and instructional technology frameworks to accomplish particular tasks. Although ICT, instructional technology, and digital tools are often intertwined, our approach to instructional technology is defined by its specific focus on teaching and learning, aiming to transform educational practices substantially.

Theoretical Framework and Research Questions

ATD works from the assumption that the practices of human activity cannot be separated from the arguments of why those practices are feasible (Chevallard & Bosch, 2020). The notion of *praxeology* captures this duality. A praxeology has two constituent parts: the praxis and the logos. The type of tasks that need to be solved and the techniques for doing so constitute the praxis. In contrast, logos consist of technology (not to be confused with instructional technology), serving as a discourse for the techniques and theory that justifies the technological discourse.

ATD, as a research program, discusses two types of praxeologies: mathematical praxeologies and didactic praxeologies. A *mathematical praxeology* is when the types of tasks, techniques, technologies, and theories are mathematical (Chevallard & Bosch, 2020). The logos used in mathematical praxeology refers to the discourse used to discuss and justify mathematical task-solving techniques. This discourse includes theorems that prove the accuracy of the techniques. Conversely, when the types of tasks, techniques, technologies, and theories support the teaching or learning of mathematical praxeology, they are referred to as *didactic praxeologies*. Consequently, the two subsets of praxeologies are codetermined (Bosch et al., 2019).

While didactic praxeology refers to the activities of teachers in schools, it is intrinsically linked to the knowledge at stake in teacher education. The connection arises because teacher preparation courses aim to equip PSTs with both practical skills and theoretical understanding necessary for effective teaching. Teachers' activities involve applying their knowledge and skills to facilitate student learning in schools. The school activities encompass planning lessons, delivering instruction, assessing student understanding, and managing classroom dynamics. These school activities are rooted in a deep understanding of educational theory, subject matter expertise, and pedagogical strategies.

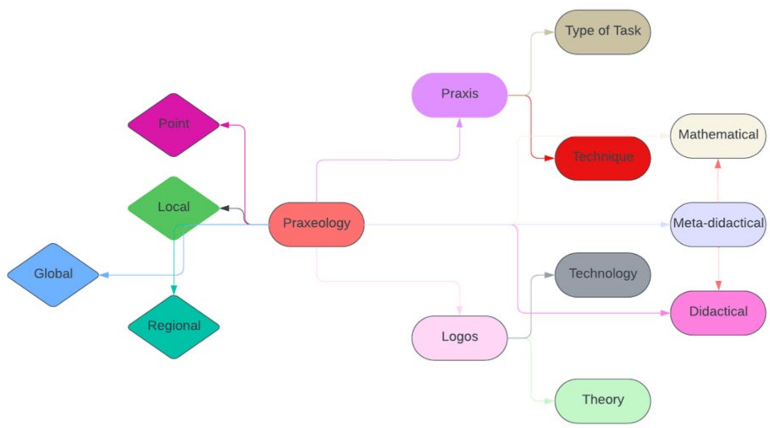
In teacher education, at stake are the critical knowledge and skills that PSTs must acquire to perform school activities competently once they become practicing teachers. Teacher education programs focus on imparting both the practice (the hands-on skills and techniques) and the logos (the underlying principles and theories) of teaching. Therefore, the activities of PSTs in teacher education are designed to simulate real classroom experiences, helping them to bridge the gap between theoretical knowledge and practical application.

From the perspective of the mathematics teacher educator, the knowledge at stake is simply a didactical praxeology in teacher education. Metadidactical praxeologies encompass the tasks, techniques, and justifying discourses that arise during the teacher education process, specifically where the teaching of mathematics is the focal knowledge at stake (Arzarello et al., 2014). For clarity, in this paper we refer to the concept as metadidactical praxeology whenever didactical knowledge is the central concern.

Praxeologies can be point praxeologies, where one technique goes with one type of task; local praxeologies, where one technique can be applied to several types of tasks; regional praxeologies, where one technology spans several types of techniques and types of tasks; and global praxeologies, where only the theory is common. We used these distinctions to develop our analytical tool (see reference model). Figure 1 presents a visual representation of the various types of praxeologies.

Praxeologies are dependent on the specific context (Chevallard & Bosch, 2020). They are situated in a *para-didactical infrastructure,* defined as the set of conditions (constraints and opportunities) outside the classroom related to a given mathematical or didactical praxeology (Miyakawa & Winsløw, 2019). In the case of teacher education, PSTs may develop one or more praxiologies of instructional technology integration in mathematics teaching during their teacher education. However, the constraints and opportunities associated with integrating instructional technology influence how extensively PSTs apply these praxeologies in their teaching, both during their teacher preparation and after graduation.

Figure 1
Diagram of the Types of Praxeologies



Drawing on ATD, the following research questions guided the study:

1. What types of didactical praxeologies of instructional technology integration into mathematics teaching are PSTs taught?

2. What metadidactical praxeologies do MTEs employ in teaching the didactical praxeologies to PSTs in the context of teacher education?

3. What conditions favor or hinder the adaptation of didactical praxeologies of instructional technology integration into teaching practice?

In the next sections, we expand on the theoretical constructs and their operationalization in the context of the current study through two reference models. Next, we describe the methods used in searching for, selecting, and coding the included articles. The results address each research question separately, showing the relatively limited range of didactical praxeologies of instructional technology integration addressed in mathematics teacher education research, particularly the absence of reasons (logos) and minimal utilization of analysis (decomposition) of didactical praxeologies. We then discuss the relevance of the results to the research community and mathematics teacher education. We conclude the paper with some recommendations and limitations of the study.

Due to our focus and research questions, this article does not review the learning outcomes of preparing PSTs to teach with instructional technology. Instead, this article reports our critical analysis of how and what PSTs are taught about teaching mathematics using instructional technology and the reasons (logos) behind these teaching methods in the context of mathematics teacher education research.

Reference Models

A reference model (RM) describes the knowledge at stake in a study or a context by explicitly defining the praxeological elements of praxis and logos in what is taught (Wijayanti & Winslow, 2017). It is called an RM because it is subsequently used as a reference for understanding and interpreting activities. Since a shared understanding of what counts as knowledge in a domain often does not exist, an RM could be considered a "working hypothesis" (Ruiz-Munzón et al., 2013) and must be developed based on an analysis of data across different institutions.

We drew on existing literature for this study to develop broad typologies of both didactical and metadidactical praxeologies, constituting our RMs. However, the descriptions in teacher education research often lacked the detail needed to distinguish between didactical and metadidactical tasks, techniques, technology, and theory. Hence, we limited our RMs to the regional and global praxeological levels.

To answer Research Question 1, we developed a didactical RM by first differentiating between three types of praxis (see Table 1): predidactical, postdidactical, and didactical praxis. Predidactical praxis concerns the activities preceding the teaching, such as planning or developing tasks. Postdidactical praxis concerns activities following a teaching activity, such as reflecting on the lesson. Didactical praxis concerns activities taking place in a teaching-learning situation. We then drew on categorizations of the use of instructional technology provided by Angeli and Valanides (2009) and Clark-Wilson et al. (2020) to develop a robust RM. Drawing on the types of technology used by Angeli and Valanides, we distinguished between transformative and amplifying use (see Table 1).

Transformative use refers to scenarios where technology fundamentally changes the knowledge at stake in the teaching situation or significantly enhances learners' engagement with mathematical ideas and relationships. It can involve altering the types of tasks learners engage with, their methods, or their reasoning. Transformative use might include using technology for exploration, creating cognitive conflicts, and making mathematical relationships more accessible. An example Angeli and Valanides (2009) gave includes using dynamic geometry software to explore geometric properties. Students use the software to manipulate shapes and observe properties and relationships dynamically, facilitating an understanding that would not have been possible with static images.

On the other hand, *amplifying use* refers to applying technology that does not significantly alter the teaching or learning process. It helps increase efficiency and convenience but does not alter the nature of the tasks, the methods of engagement, or the depth of understanding. For example, using a calculator to perform arithmetic operations more quickly falls under amplifying use. It makes the process faster but does not change the underlying mathematics or learning approach.

Table 1
RM for the Global and Regional Praxis Components of the Didactical Knowledge at Stake in Teacher Education for the Use of Instructional Technology, With Examples

Use of Instructional Technology	Explanation	Example
Predidactical transformative use	Involves PSTs using technological tools and resources to explore mathematical content before formal teaching begins.	PSTs use dynamic geometry software to explore relationships, such as the Pythagorean theorem and congruent triangle properties, as part of preparing a lesson for learners.
Predidactical amplifying use	Involves PSTs using technological tools and resources to prepare and enhance the learning environment before formal teaching begins.	PSTs use a learning management system like Google Classroom or Moodle to organize and distribute course materials such as syllabi, lesson plans, reading assignments, and teaching notes.
Didactical transformative teacher use	Involves PSTs strategically integrating technology to fundamentally change teaching and learning, leading to improved outcomes and innovative ways of engaging with mathematical content.	PSTs use dynamic geometry software to facilitate their students' exploration of trigonometric concepts.
Didactical amplifying teacher use	Involves PSTs strategically integrating technology to enhance existing teaching practices.	PSTs use interactive whiteboards, like SMART Boards, to visually demonstrate solving equations, plotting graphs, and constructing geometric shapes.
Didactical transformative learner use	Involves how PSTs engage learners to actively engage with technology in a way that fundamentally changes how they learn mathematical concepts, develop problem-solving skills, and demonstrate their knowledge.	PSTs engage learners to use dynamic geometry software like GeoGebra to explore and manipulate geometric shapes, algebraic equations, and functions.
Didactical amplifying learner use	Involves PSTs engaging learners to use technological tools and resources to enhance the learning environment during formal teaching.	PSTs engage learners to use a calculator to perform arithmetic operations more quickly.
Postdidactical transformative use	Involves PSTs strategic application of technological tools and resources after formal teaching activities to reinforce learning, assess understanding, provide feedback, and support ongoing education.	PSTs reflect on micro-teaching, where they used GeoGebra to demonstrate and explore trigonometric concepts.

Use of Instructional Technology	Explanation	Example
Postdidactical amplifying use	Involves PSTs application of technology after the main teaching activities have been completed.	PSTs keep track of assessment results from their micro-teaching in a spreadsheet.

Our rationale for drawing on Angeli and Valanides (2009) to distinguish technology uses in education is based on their emphasis on the extent to which these uses significantly enhance learning opportunities. Other distinctions, such as Dick and Hollebrands (2011), who differentiated between conveyance and mathematical action technologies, and Cullen et al. (2020), who identified four roles for effective technology use (promoting cycles of proof, presenting and connecting multiple representations, supporting case-based reasoning, and serving as a tutee), offer valuable insights. However, they fall short in determining whether the learning opportunities are substantially enhanced.

The distinction of transformative versus amplifying use provides an understanding of how technology can impact teaching and learning processes, allowing researchers to identify and promote the most meaningful uses of digital tools in educational settings. Since instructional technology's transformative and amplifying uses contain different types of didactical tasks, different didactical techniques, and probably different (praxeological) technologies but not necessarily different theories, we view these uses of instructional technologies as two regional praxeologies.

Clark-Wilson et al. (2020) classified instructional technology into four different uses: two are about pre- and postdidactical praxeologies (planning or keeping track of assessment results, collaboration with other teachers), and two are didactical, namely representation and learners' independent work. The categorization by Clark-Wilson et al. indicated the use of instructional technology either by the teacher or the learner.

The distinction between whether the main agents are teachers or learners is reflected in other suggested categorizations of the use of instructional technology (see Angeli & Valanides, 2009; McCulloch et al., 2021) and the AMTE (2017) standard indicator C.1.6. It also mirrors distinctions within mathematics education more generally between, for instance, rituals and explorations (e.g., Heyd-Metzuyanim & Graven, 2019; Lavie et al., 2019). In praxeological terms, these concepts could be studied using different didactic theories or paradigms, which is why we examined them as global praxeologies.

Drawing on the distinctions of pre- and postdidactical and didactical, the distinction of transformative versus amplifying uses, and the distinction of who is the main agent in using the instructional technology, we developed a two-dimensional RM to answer Research Question 1 (see Table 1). In what we attempted as a praxeological analysis, we could not distinguish clearly between the type of task and the technique for carrying out the task in the data. Hence, we combined the type of task and technique for completing the task as the praxis in the RM for the didactical knowledge at stake.

We also developed a RM (see Table 2) as an analytical tool for exploring the praxis component of the teacher educators' teaching (specifically the metadidactical techniques). Studies across contexts revealed a variety of teacher educators' didactical techniques for preparing PSTs to integrate instructional technology into their teaching (e.g., Admiraal et al., 2017; Austin & Kosko, 2022; Niess, 2008; Tondeur et al., 2012; Yildiz Durak, 2021).

To answer Research Question 2, we drew on the broad types of pedagogies suggested for practice-based teacher education (Grossman et al., 2009). Hence, MTE didactical techniques used to facilitate PST learning to integrate instructional technology in their future mathematics teaching are categorized as instances of (a) representation, (b) decomposition, and (c) approximation (see Table 2).

Table 2
RM for the Praxis Components of the Teacher Education Techniques for Teaching the Didactical Knowledge at Stake, With Examples

Type of Metadidactical Technique	Explanation	Example
Representation	Representation of practice refers to the ways in which teaching with instructional technology is made visible and explicit to PSTs.	Observe practising teachers or MTEs using instructional technology didactically.
Decomposition	Decomposition of practice is where PSTs analyse what works or does not work using different instructional technologies in different task situations. The decomposition can be both of the practice of others (teachers, teacher educators) and of the PSTs themselves.	Analyse existing lessons, lesson plans, or learner activities involving instructional technology, breaking them into components.
Approximation	Approximation is when PSTs try to enact instructional technology integration into their teaching as they practice teaching mathematics with learners or peers	Practice making lesson plans or systematically reflecting on taught lessons; practice constructing explorative learner activities involving instructional technology.

The categories of Table 2 identify the operationalization of the teacher educators' metadidactical techniques. The operationalization of metadidactical techniques in Table 2 is supported by literature on effective teaching practices and teacher education. These descriptions are based on the framework by Grossman et al. (2009), which identified core practices essential for teaching and learning. Additionally, they draw on the work of Shulman (1987) and Loewenberg Ball and Forzani (2009), who emphasized the integration of content knowledge and pedagogy, as well as practice-based teacher education. These sources collectively underpinned the techniques described and ensured their grounding in established educational research.

The didactical and metadidactical logos were determined inductively by examining the substantiations of the identified praxis. The process involved looking for evidence rationalization within the articles to understand how praxis was justified, explained, and linked to theoretical constructs. Our approach to Research Question 3 was inductive, not relying on any RM.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 protocol (Page et al., 2021) was adapted for the critical analysis, requiring specific research questions and well-defined procedures for locating, selecting, evaluating, collecting, and analyzing study data. The utilised procedures are presented in the following sections.

Eligibility Criteria

We report on the documentary features: document type, language, search period, level of education, subject area, methodology, and focus (see Table 3). To balance between comprehensiveness, practicality, and the adaptation of instructional technologies, we opted to limit the critical analysis to papers from January 2010 to December 2022 (the time of searching). We limited the literature to peer-reviewed articles from indexed journals to ensure the included studies met commonly accepted high-quality research standards.

Despite the apparent limitations language provides, we had no option but to restrict ourselves to articles written in English, the only language all authors can read. Given the research questions' focus, this critical analysis was limited to mathematics teacher education and papers containing descriptions of what was taught and how. Additionally, we included only empirical studies, because the research questions address current practice. As we focused on the metadidactical praxeologies, we included all papers concerning PSTs' learning relating to praxis (know-how) and logos (know-why) of teaching mathematics using instructional technologies. Table 3 shows the inclusion and exclusion criteria.

Information Sources

Applying keywords and with the help of a librarian, we conducted an electronic search and selection of journal articles from the different databases, all of which were last searched on December 22, 2022, and supplemented on June 22, 2024. For the critical analysis, leading databases with full-text publishing mechanisms for bibliographic papers across various fields were considered, especially for transdisciplinary research in education. We searched through the Education Resource Information Centre (ERIC) via ProQuest, Scopus, and Web of Science (WoS).

Table 3
Criteria for Inclusion and Exclusion: Documentary Features

Category	Observation	
	Inclusion	**Exclusion**
Document Type	Only peer-reviewed articles from indexed, non-predatory journals	Doctoral theses, book chapters, conference proceedings
Language	Full paper in English	Any language other than English
Period	Published from January 2010 to December 2022	Any published article before January 2010 or after December 2022
Level of Education	Teacher Education	Secondary, primary, and early childhood education. Higher education other than teacher education
Subject Area	Mathematics	All subjects other than mathematics
Methodology	Empirical studies	Theoretical or methodological studies, position papers
Focus	Teaching to teach mathematics with instructional technology	Any mathematics teacher education research without a focus on teaching how to teach mathematics with instructional technology

Search Strategies

A search strategy was created for the analysis to find relevant research literature. Three groups of keywords were defined as the search keywords used for the critical analysis:

- Technology-related buzzwords such as “technologies,” “technological,” “technology,” “digitalisation,” “digitalization,” “digital tools,” and “ICT.”
- Educational-related terms such as “mathematics teacher education,” “mathematics teacher training,” “mathematics teacher preparation,” and “teacher preparation in mathematics.”
- Participant-related terms such as “pre-service teachers,” “preservice teachers,” “prospective teachers,” “teacher candidates,” “novice teacher,” “teacher student,” or “student teachers.”

Boolean operators and filters were employed in the advanced search option in each database (see Appendix B).

Selection Process

A three-stage approach was used in the selection process. We independently assessed the identified articles and the studies for inclusion. Two authors completed the first two stages, while we all the completed the last stage. Using the PRISMA protocol, Figure 1 tracks the selection process for the articles included in the critical analysis. A total of 2,358 files were registered and uploaded to an online platform for proper management. The initial stage involved checking for duplication using the platform automation. A total of 177 files were duplicates, leaving 2,181 files.

The second stage involved evaluating the titles of the articles; if the title contained any words related to technology and mathematics teacher education or preservice teachers, it was considered for further review. By filtering titles for specific keywords, the review ensured that only articles directly pertinent to technology and mathematics teacher education or PSTs were included. The focus helped maintain the literature's relevance, which was crucial for drawing meaningful and specific conclusions. Also, given the vast number of articles available, a keyword-based title screening provided an efficient method to manage and narrow down the initial pool of literature. One hundred thirty files passed the title screening and were considered in the next stage. Metadata for all 130 files was exported.

In the final step, we each independently read the abstracts of all 130 papers that passed the second stage screening, and any disagreements were settled through discussion. One hundred eight of the 130 articles did not include elements of didactical and metadidactical praxeologies. Hence, applying the criteria in Table 3 resulted in a final sample of 22 articles (see Figure 2).

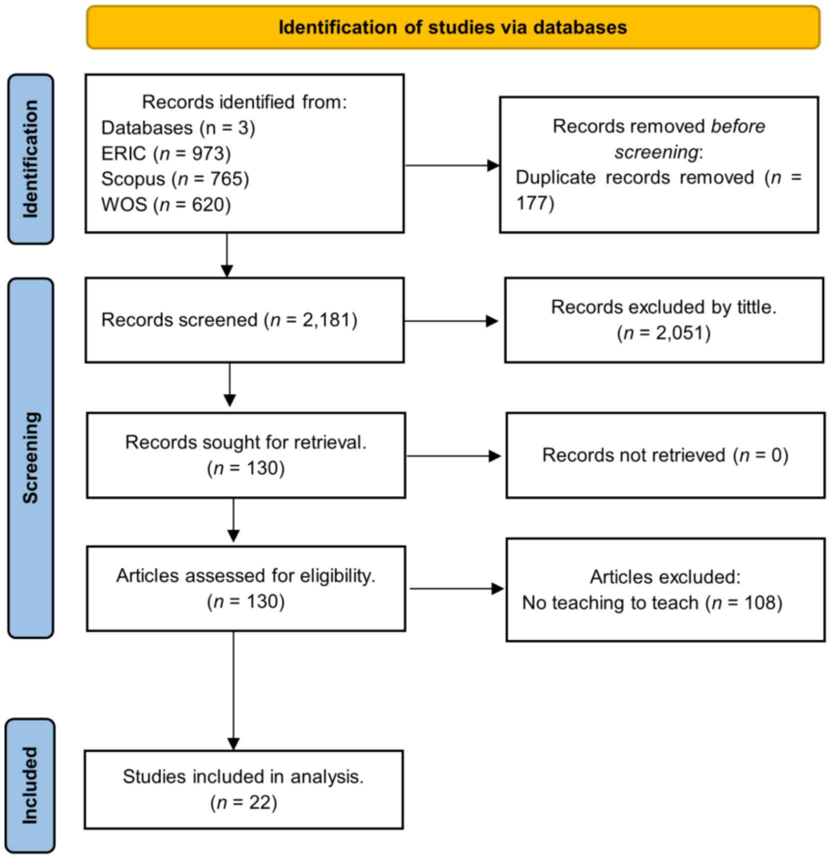
Data Items

Documentary features, the didactical knowledge at stake, types of metadidactical techniques, and opportunities and constraints of learning to teach mathematics with instructional technologies were extracted from the articles.

Data Extraction Process

The routine for data extraction was as follows. MaxQDA software for qualitative analysis was used to code each article according to the RM shown in Table 1 for any praxis PSTs were expected to learn or practice. The text was scrutinized for each praxis to determine the reasons (logos) for using these practices. Further, any pedagogy used to teach how to teach mathematics integrating instructional technology was coded according to the RM shown in Table 2. Any reasons (logos) for the choice of approach were marked as MTE didactical logos. Finally, information was extracted regarding the success or failure of adapting the praxis taught to the school context and the reasons for these outcomes.

Figure 2
Diagram of the Selection Process



To ensure consistency of coding and coherence with the developed RMs, each author independently extracted data from three articles, which were then compared. The data extraction resulted in adjustments and reformulations of the elements of praxis and logos to create clearer, more distinct categories, enhancing their comprehensibility and practical application to the form presented here (see Tables 1 and 2).

Next, data from one paper were extracted collaboratively and classified according to the RMs. Explicit routines were drawn up and discussed in the data items section. Using these routines, two authors independently extracted data from nine articles. To avoid bias, if any of the reviewed articles had an author known to one of us, the data were extracted by a different team member who had no prior connection to the author. The results were compared, and as the agreement was almost complete in all cases, the first author extracted data from the remaining articles alone. These were then shared, and any queries by the two other authors were resolved.

Risk of Bias Assessment

Unlike medical intervention studies, educational interventions often do not allow for randomized trials or for unbiased assignment of participants to control or intervention groups. To assess the risk of bias in the included studies, it was not feasible to use either the Cochrane RoB tool for randomized trials (Higgins et al., 2011) or the ROBINS-I tool for nonrandomized trials (Sterne et al., 2016). Instead, for each paper, we noted to what extent (a) the study was conducted by MTEs on their students, (b) the studies involved a control group, and (c) the study included a method for adjusting for the nonrandomized selection of participants.

Only four studies were not conducted by the MTEs teaching the intervention. Only one study included a control group. No studies included a method for adjusting for the nonrandomized selection process. The exception to the norm for categories (a) and (b) was when the researcher was an observer of the intervention (see Appendix C).

Synthesis Methods

Since the focus of the critical analysis was on the didactical knowledge at stake and the types of metadidactical techniques, not on the effect size of interventions, we noted in our qualitative software the presence or absence of didactical praxeology to be learned and the pedagogy used for facilitating this teaching. We also included the conditions and constraints that the studies claimed to favor or hinder teaching how to teach mathematics with instructional technology. The textual data for all other categories informed the synthesis.

Results

The critical analysis results align with the research questions. As a starting point, we offer an overview of the research characteristics, considering the participants, preparation or teaching context, methodology, and data collection instruments (see Appendix C). Further, we comment on the date of publication, countries of data collection, types of instructional technology used, and duration of the studied teacher education activity. Following the research questions, the findings are presented under the headings “taught didactical praxeologies,” “metadidactical praxeologies,” and “conditions.”

Research Characteristics

The number of publications varied between zero and three per year, and the sample size was too small to identify any trends. Only five countries were represented in the included studies. Out of the 22 articles included in the study, eight were conducted each in Türkiye and the USA, three in Ghana, and one each in Tanzania, Portugal, and Australia. The studies primarily (n = *17*) took place in the context of method courses but also in separate workshops (n = *4*), practicum courses (n = *3*), mathematics content courses (n = *2*), modelling courses (n = *1*) or a pedagogy course (n = *1*). Despite the varied contexts, the courses and activities studied were all designed to focus on using instructional technology in teaching and learning mathematics.

The duration of the course or intervention could contribute to the ways PSTs are prepared to integrate instructional technology into their teaching. The analysis revealed that most (*n* = *19*) of the studied teacher education activities were contained within a semester. One of the studies was less than a semester (3 weeks). However, in two other publications the preparation/teaching program was two or three semesters. A semester usually lasts 4-5 months, leaving little time to measure the impact of the mathematics teacher preparation activity. The papers included in the analysis did not specify whether the interventions were confined to a single course or implemented throughout the entire teacher education program. However, the interventions were derived from one or a combination of three specific courses.

Three main groupings of research approaches were identified. Qualitative research (*n* = *11*) was most prevalent. Eight studies used a mixed-methods research approach, utilizing various designs. A quantitative research approach (*n* = 3) was less frequently used.

We identified a large number of data collection instruments, including achievement tests, lesson plans, participation reports, TPACK scale, interviews (e.g., semistructured interviews, video-stimulated recall interviews), questionnaires, researcher's logbook, observations, reflections, students' teaching philosophy statements, perception scale, self-assessment survey, self-efficacy scale, microteaching videos, video lessons, peer feedback, screencast video lessons, attitude survey, and course artefacts. Appendix C shows an overview of the primary research characteristics.

Different types of instructional technology were used in the preparation and teaching of PSTs. Most common were web-based applications (*n* = 14) for tutorials, drills and practice, problem-solving, instructional games, simulations, or exploration tools. GeoGebra (*n* = *10*) is a dynamic open-source software for teaching and learning mathematics that incorporates geometry, algebra, and calculus. GeoGebra was used as a demonstration and visualization tool, a tool for exploring mathematics, and a tool for creating teaching and learning resources.

Calculators (*n* = *9*) were also present, most commonly scientific and graphing calculators. Students in some studies engaged with a spreadsheet application (*n* = *6*) designed to assist higher order thinking in mathematics. Geometer's Sketchpad (*n* = *6*) was used to explore geometry, algebra, calculus, and other areas of mathematics to help increase student accomplishment, understanding, and engagement. Interactive Whiteboards (*n* = *3*) were used to enhance the kinaesthetic, drawing, marking, and highlighting of any computer-based output to aid the teaching and learning process in whole-class interactions. Cabri Software (*n* = *2*) was used for teaching and learning geometry and trigonometry.

Taught Didactical Praxeologies

To address Research Question 1, we systematically categorized all instances of tasks and techniques demonstrated to, taught to, or rehearsed by PSTs, according to the studies, using the RM outlined in Table 1. For the praxis component, the critical analysis demonstrated that PSTs were taught to use instructional technology in transformative ways in 21 studies. Four studies taught PSTs to use instructional technology to teach mathematics in amplifying ways. Three studies taught PSTs to use instructional technology in both amplifying and transformative ways. Most studies were not explicit about what mathematics should be taught with instructional technology.

The few studies that explicitly identified the mathematics that should be taught suggested the use of dynamic geometry software such as GeoGebra to teach geometry (Bonafini & Lee, 2021a, 2021b; Kartal & Çınar, 2022) or calculus (Zengin, 2018). All the studies engaged PSTs in the predidactical praxis of instructional technology use (planning), with 16 of the studies involving the didactical praxis (teaching) and seven involving the postdidactical praxis of instructional technology use (reflecting).

Although all the studies involved a predidactical praxis, 18 of the predidactical praxis involved planning and designing mathematics lessons that integrated instructional technologies individually or in small groups. Other predidactical activities had different orientations. For example, in Rocha (2020), the predidactical practice involved PSTs working in groups to select a set of six tasks suitable for 10th-grade students studying functions, where the use of digital technologies was important. We also included predidactical situations where PSTs engaged with the instructional technology as learners ($n = 6$). This approach not only models practices (the metadidactical praxis of representation) but also equips PSTs with firsthand knowledge and experiences of how the technology operates and how learners interact with it and, therefore, was considered a predidactical activity.

The didactical praxis involved PSTs practicing to teach mathematics with instructional technologies in microteaching ($n = 11$) or field placement settings ($n = 5$). The didactical praxis focused more on PSTs' use of instructional technology in their role as teachers ($n = 14$) at the expense of learner use ($n = 6$) in teaching and learning mathematics. Thus, while PSTs were taught to use instructional technologies to enhance students' conceptual understanding of mathematics, they were less frequently taught how to guide their students in using these technologies during the instructional process.

The postdidactical praxis involved postlesson debriefing, watching personal videos of lesson enactment, and reflecting on the lesson enactment implementation. The seven papers that included postdidactical praxis also included predidactical and didactical praxis.

The logos component of the taught predidactical, didactical, and postdidactical praxis was either not present ($n = 13$), not linked to the praxis ($n = 3$), or implied ($n = 6$). A didactical logos implied for some didactical praxis was the TPACK and activity-based learning (ABL) concept, which were taught, but how they were linked to the taught praxis was not evident from the articles. For example, the logos for the spreadsheet-supported lessons in Agyei and Voogt (2016) implied ABL. We also inferred from the study by Bozkurt and Yiğit Koyunkaya (2022) that the didactical logos linking the praxis were the dynamic geometry task analysis and instrumental orchestration frameworks.

Metadidactical Praxeologies

Drawing on Grossman et al.'s (2009) three pedagogies of practice as an RM (see Table 2), Research Question 2 was answered. The praxis component specifically concentrated on the didactical techniques (pedagogies) used by MTEs. The critical analysis demonstrated that MTEs engaged in at least one of the three didactical techniques of Grossman et al.'s pedagogies of practice, depending on the purpose of the study. The most frequent metadidactical technique was representation of practice ($n = 17$), closely followed by approximation of practice ($n = 16$) and deconstruction of practice ($n = 10$). Seven interventions used only one MTE didactical technique, while another eight used all three. Like the didactical logos, the metadidactical logos were either absent ($n = 15$) or implied ($n = 7$).

The metadidactical technique of representation of the practice of instructional technology integration is demonstrated in teacher education research through direct observation of MTEs or watching videos of specific didactical situations (e.g., Agyei & Voogt, 2015; Akapame et al., 2019), written exemplary curriculum materials (e.g., Açıkgül & Aslaner, 2020; Agyei & Voogt, 2012) and other teaching and learning activities (e.g., Akkaya, 2016; Zambak & Tyminski, 2020). This metadidactical technique of representation of the practice of instructional technology could be interpreted as a way PSTs can broaden their perspectives on and understanding of professional practice.

The thoroughness of this metadidactical technique of representation varies (Austin & Kosko, 2022). While some of the documented interventions entailed the integration of metadidactical techniques of representation of the practice of instructional technology over an entire semester, others were only a few days of workshops designed to develop the didactics of instructional technology. Certain aspects were more visible depending on the characteristics of the metadidactical representation techniques. For example, in direct observation of MTEs/researchers or videos of specific didactical situations, the interactive features of technology integration were visible. However, the metadidactical logos underlying the actions were hidden.

We, however, inferred some metadidactical logos relating to the metadidactical technique of representation of practice. For example, in Akapame et al. (2019), the implied metadidactical logos states that teachers teach the way they are taught; wherefore, they need to experience the desired teaching approach.

Mathematics education interventions not only use the metadidactical technique of representing the practice of instructional technology but also actively engage PSTs in a series of approximations of practice. MTEs engaged PSTs in an approximation of practice, where PSTs were given the opportunity to teach mathematics using instructional technology through microteaching settings (n = 11; e.g., Bozkurt & Yiğit Koyunkaya, 2022; Kartal & Çınar, 2022) or field placement (n = 5) (e.g., Akapame et al., 2019; Bozkurt & Yiğit Koyunkaya, 2022). In small groups of peers, PSTs planned, designed, and enacted mathematics lessons that integrated instructional technology.

The PSTs then received feedback from their peers and MTE/researcher, which served as the basis for reflecting on their practice. The metadidactical logos were often general and implied, though there were references to previous research at times. For example, Yenmez et al. (2017) stated that they employed microteaching because it enabled PSTs to experience an instructional process and the challenges that come with it. Through the field placement, PSTs could observe, teach, and assess the impact of instructional technology on student learning.

From the critical analysis, the didactical technique of decomposition of the practice was used by MTEs to engage PSTs through coding aspects of teaching (e.g., Agyei & Voogt, 2012), analyzing teaching episodes (e.g., Bozkurt & Yiğit Koyunkaya, 2022; Yenmez et al., 2017), discussing observed teaching practice (e.g., Bozkurt & Yiğit Koyunkaya, 2022; Kartal & Çınar, 2022) and reflections on their own teaching practice (e.g., Kafyulilo et al., 2015; McDonald, 2012). While the interventions using decomposition all included at least one other metadidactical technique, these metadidactical techniques were not always clearly connected. For example, in Agyei and Voogt (2012), PSTs coded TPACK components in the exemplary lesson materials. The PSTs also evaluated the exemplary lesson materials but were not provided the opportunity to translate the decomposed TPACK components into an approximation of practice.

We did not find or infer any metadidactical logos for the metadidactical technique of decomposition of practice. Only three studies reported on PSTs decomposing the represented practices, which suggests limitations of the extent to which PSTs get access to the professional judgement (logos) that informs the choices made in teaching.

Conditions

Research Question 3 was analyzed inductively. The key supportive conditions included practical experiences, teamwork, feedback, and framework engagement, while constraints involved time management challenges and a lack of prior experience with instructional technology.

The conditions that supported learning to teach mathematics with instructional technology in the interventions included the representations, decomposition, and approximations mentioned previously, but also learning from exemplary curriculum materials (e.g., Agyei & Voogt, 2012, 2016; Meagher et al., 2011), working in teams and learning from each other (e.g., Agyei & Voogt, 2016; Kafyulilo et al., 2015; Zengin, 2018), receiving constructive feedback from peers and MTE (e.g., Akkaya, 2016; Rocha, 2020) and learning from or engaging with frameworks (e.g., Bozkurt & Yiğit Koyunkaya, 2022; Zengin, 2018).

Time was considered as an opportunity and a constraint. The opportunities to use instructional technology to make the most of the time available become apparent in the lesson delivery, as different lesson activities were carried out within the shortest possible time (e.g., Agyei & Voogt, 2015, 2016; Yenmez, 2017).

Agyei and Voogt (2016) identified time management as a constraint in PSTs' didactic practices as they struggled to complete their lesson within the given time frame. This constraint was due to difficulties balancing instructional technology with other aspects of lesson delivery. The constraints also included PSTs' lack of experience with instructional technology integration before the course (e.g., Agyei & Voogt, 2012; Zambak & Tyminski, 2020) and limitations of the pedagogy of the course or limitations of what the PSTs knew before the intervention (e.g., Agyei & Voogt, 2016; Akapame et al., 2019).

Discussion

The critical analysis maps the taught didactic praxeologies, metadidactical praxeologies, and conditions that favor or hinder the adaptation of the taught didactical praxeologies of instructional technology integration into teaching practice. The critical analysis is first in its approach to research on teacher education, examining how and what PSTs are taught to teach mathematics using instructional technology and for what reasons (logos), grounded in an analysis informed by the ATD.

The study included 22 articles from six countries. The result suggests limited literature focused specifically on mathematics teacher education research that addresses teaching to teach mathematics by integrating instructional technology. The articles primarily focused on method courses, workshops, field placement, mathematics content, modelling, and pedagogy courses. The duration of the courses or activities was mainly a semester. Studies on instructional technology have suggested sustaining preparation programs over time (e.g., DeSantis, 2012), with durations extending to one academic year and contact hours spread over time (Gerard et al., 2011). However, a more extended preparation program may not necessarily equate to increased effectiveness. Instead, effectiveness could be achieved through a well-structured, organized, and purposefully directed program.

Well-organized and purposefully directed programs are more effective because they provide clear goals, coherent content, and practical experiences aligned with real classroom needs. For instance, Darling-Hammond et al. (2005) found that teacher preparation programs with strong, well-integrated coursework and extensive clinical practice better prepared teachers for effective instruction. Furthermore, the effectiveness of teacher education is often linked to the quality of experiences rather than the length of the program. Most studies used web-based applications, GeoGebra, calculators, and spreadsheet applications, suggesting the technologies' ability to enhance learning quality, particularly in exploring, visualizing, and constructing mathematical concepts.

As evidenced by most of the studies analyzed, PSTs were predominantly taught to use instructional technology in transformative ways. In contrast, fewer studies focused on using instructional technology in amplifying ways or combining both. The result suggests a preference for transformative uses of instructional technology across various contexts. The preference for transformative uses of instructional technology aligns with the recommendations of Drijvers (2015) and Hillmayr et al. (2020), suggesting that transformative approaches are favored for their potential to enhance educational outcomes significantly.

All the studies involved PSTs in predidactical praxis, which involved planning and designing lessons that integrated instructional technologies. By integrating instructional technology, PSTs were taught how to integrate technology into a lesson from a specific curriculum and turn it into engaging and meaningful student learning activities. Planning and designing lessons are integral to teachers' everyday practice, so learning about planning and designing in teacher education was expected.

The didactical praxis focused on PSTs' (teacher) use of instructional technology at the expense of learner use. Thus, while MTEs are teaching PSTs how to use instructional technology in their future classrooms, they are not adequately teaching these PSTs how to engage their own learners with instructional technology to deepen their conceptual understanding of mathematics. The findings align with Pepin et al. (2017), who observed that teachers use instructional technology primarily to transform the presentation space, while transformations in the problem, work, and navigation spaces remain minimal. However, the findings fall short of the AMTE (2017) standard, emphasizing the need for PSTs to be proficient in using instructional technology for their own practice and in supporting student learning. Also, the finding does not support earlier recommendations, such as those by Graham et al. (2009), which stressed the importance of actively involving students in using instructional technology to enhance their learning and comprehension of mathematical concepts.

Postdidactical praxis involved postlesson debriefing, watching personal videos, and reflecting on lesson implementation but were infrequent across the studies. As mentioned, when some didactic logos were addressed in the interventions, they were not always clearly linked to praxis. This fact could be concerning; if PSTs are not taught to make informed choices of instructional technology and of didactical praxeologies in relation to learners, institutional frames, and content, they may not be able to teach for the transformative use that the literature recommends.

Linking praxis to logos ensures teaching practices are grounded in theory, making teaching practices effective and adaptable to diverse student needs (Chevallard, 1992). The alignment of praxis to logos fosters deeper professional development for mathematics teachers, promoting critical reflection, innovation, and contributions to educational discourse (Barbé et al., 2005). The alignment of praxis to logos also equips teachers to address educational challenges with practical solutions, which is essential for dynamic classroom environments (Chevallard, 2006). Conversely, a lack of theoretical understanding (logos) can lead to rigid, ineffective teaching methods, stifling innovation and weakening teachers' professional identity and confidence.

Representation of practice was the most used metadidactical technique in the reported interventions. However, opportunities to learn the practice of integrating instructional technology into teaching cannot be sustained if PSTs miss the opportunity to see how this representation of practice could function, for example, in a dynamic high school mathematics classroom.

According to Grossman et al. (2009), in practice-based teacher education, learning the practice of teaching involves not just observing (representation of practice) but also actively participating through decomposition and approximations of practice in real classroom situations. Combining the pedagogies of practice ensures that PSTs gain a holistic understanding of integrating instructional technology into their future teaching practices.

Further, the representations would benefit from making the professional judgement (logos) informing the practice more visible. Making professional judgment visible helps PSTs grasp the rationale behind teaching decisions and instructional strategies, which is crucial for their development. Loewenberg Ball and Forzani (2009) highlighted that exposing the reasoning behind pedagogical choices allows PSTs to internalize and apply these judgments in their teaching contexts. Similarly, Shulman (1987) stressed that a teacher's knowledge base includes content knowledge, pedagogical content knowledge, and the decision-making processes behind effective teaching. By making these elements explicit, PSTs can bridge theory and practice more effectively, enhancing their ability to integrate instructional technology in a pedagogically sound and contextually appropriate manner (Grossman et al., 2009).

The MTEs also used approximation of practice to engage PSTs in planning, designing, and enacting lessons using instructional technology in microteaching settings or field placements. The MTEs' use of approximation of practice aligns with the recommendations of the AMTE (2017), which proposed that teacher education programs should involve PSTs in practical instructional activities to improve their development of pedagogical practices when teaching mathematics.

Microteaching, in particular, was a restricted version of practice, which can sometimes be problematic if PSTs are provided with a one-dimensional portrait of what it takes to be a professional teacher because their approximations of practice were on primary components or exploring the potency of instructional technologies. However, it also has advantages because — as some educators argue (e.g., Grossman et al., 2009; Lampert et al., 2013) — the primary focus of approximations should be to provide PSTs with a supportive environment in which to rehearse aspects of practice rather than exposing them to complexities. The approximations of practice cap the complexities of the task, allowing PSTs to focus on specific aspects of instructional technology integration that could otherwise get lost (Grossman et al.).

One of the most exciting possibilities afforded by these approximations of practice was the way PSTs got exposure to and experienced how to integrate instructional technology into their teaching, promoting meaningful learning. Studies by Howell and Mikeska (2021) and Grossman et al. (2009) highlighted the significance of approximations of practice. These approximations are particularly exciting because they allow PSTs to rehearse teaching in a supportive environment, helping them gain the confidence and competence crucial for fostering meaningful and impactful learning experiences in their future classrooms.

PSTs also had experiences differentiating instructional technology components (e.g., the component of technology, pedagogy, and content knowledge) and integrating them into their teaching. Experiences that help PSTs differentiate between what works and what does not, as well as the many different components of instructional technology, are essential if PSTs are to learn to integrate these instructional technologies deliberately into their teaching.

The MTE didactical technique of decompositions of practice engaged PSTs through coding, analysis, and reflection. Decomposition of practice is often combined with representations and approximations in practice. Therefore, it was unsurprising that some MTEs employed decomposition practices to teach PSTs how to use instructional technology to teach mathematics. However, it is noticeable that decomposition was mainly of PSTs' lessons, not of the representations of practice, which again limits PSTs' access to the decision-making behind teaching choices.

Further, the three metadidactic techniques did not appear coherently linked in teaching the PSTs. Based on the study, we conjecture that developing a core practice of using instructional technology in teaching mathematics for understanding and exploration would benefit from a synergetic effect by more clearly linking what is represented, decomposed, and approximated. This conjecture aligns with the recommendations from practice-based teacher education (Grossman et al., 2009).

One challenge PSTs face during their preparation for using instructional technology in teaching mathematics is their lack of experience with the technology. This inexperience makes it essential to provide PSTs with opportunities to familiarize themselves with and use the technology before delving into the didactical aspects of teaching. Such hands-on experiences are crucial, even if they initially serve as mere representations of actual teaching scenarios.

Integrating technology into mathematics teacher education requires careful consideration of various contextual factors that can significantly influence preservice teachers' experiences and effectiveness. Key factors include access to technology, school infrastructure, and teachers' and students' digital literacy levels (e.g., Quaicoe & Pata, 2020). By addressing these contextual factors, teacher education programs can better prepare PSTs to integrate instructional technology meaningfully into their mathematics teaching, ensuring they can meet the diverse needs of their future students.

The studies reported here do not explicitly address these examples of contextual factors, wherefore comparisons of this component of teacher education across contexts would be welcome. Results from such studies might enable mathematics teacher education programs to leverage the constraints and turn them into opportunities to learn to teach mathematics by integrating instructional technology.

Recommendations

Based on our findings, we strongly recommend that MTEs engage the reasons (logos) for using specific didactical praxis when teaching their PSTs. Linking the praxis explicitly to logos will help PSTs learn to make informed instructional decisions. The clarity can lead to more thoughtful and meaningful integration of instructional technology, providing PSTs with a solid theoretical foundation to guide their practice. In many of the studies in our analysis, the didactical logos taught were vague, implicit, or absent. Enhancing the transparency of these logos can significantly strengthen teacher education practices and contribute to a more cohesive discourse within mathematics teacher education.

Similarly, the metadidactical logos were rarely clear in the analyzed articles. It is important to clarify that this does not critique MTEs' awareness of their pedagogical choices. Rather, it is a call for improved reporting practices within the field. While MTEs may have been conscious or explicit about their instructional strategies, the studies analyzed often did not adequately document these details.

Furthermore, we advocate for conducting research in a wider range of geographic locations beyond the few countries currently represented in our analysis. A broader scope will help researchers understand how different contexts impact the teaching to teach mathematics with instructional technology. The existing research has been concentrated in specific regions and may not reflect the diverse educational environments worldwide. Studies in varied geographic and cultural settings can reveal unique challenges and opportunities, leading to more inclusive and universally applicable findings.

We also recommend shifting the focus from merely the ways PSTs (teachers) use instructional technology to the ways learners can use these instructional technologies for conceptual understanding. While PSTs must thoughtfully select and integrate instructional technology to enhance learning and understanding, rather than using it for novelty or convenience, the goal remains to enhance learner understanding and knowledge (Mishra & Koehler, 2006). Consequently, MTEs are expected to balance the focus on teacher use and learner use of instructional technology between transformative and amplifying use, which can significantly enhance the teaching and learning experience. Balancing the uses of instructional technology can promote active engagement, foster critical thinking, and support deeper understanding, helping learners master complex mathematical concepts more meaningfully (Kirkwood & Price, 2014).

Activities such as debriefing sessions, reviewing personal lesson videos, and reflecting on lesson implementation are crucial for PSTs to consolidate their learning and enhance their teaching practices. Reflection and feedback are key to professional growth (e.g., Daniel et al., 2013). By engaging in debriefing and video analysis, PSTs can critically assess their teaching, pinpoint areas for improvement, and reinforce effective practices. However, MTEs should integrate more decomposition of expert representations into their courses so that PSTs get access to the aspects of expert practice that are not as easily visible. By decomposition of expert representations, we mean breaking down the sophisticated, often tacit ways of thinking expert teachers use into observable and learnable parts.

For example, an expert teacher solving a calculus problem might verbalize their thought process, explaining why they chose a particular integration technique and how they check their work for accuracy. This think-aloud protocol gives PSTs insight into the decision-making and problem-solving strategies experienced educators use.

Another example is real-time demonstrations of expert practices, such as conducting a lesson on geometric transformations with interactive technology accompanied by detailed explanations, allowing PSTs to see and understand the methods in action. This demonstration helps PSTs grasp how experts engage students, manage the classroom, and adapt instructions based on student responses.

Limitations

While the study provides valuable insights into how MTEs teach PSTs to teach mathematics by integrating instructional technology, some limitations must be acknowledged to contextualize the findings more accurately. First, the analysis was based on 22 peer-reviewed journal articles. The limited number of articles included in the analysis highlights the scarcity of research in mathematics teacher education that describes teaching PSTs to teach mathematics by integrating instructional technology. The limited number of articles not only underscores the need for more studies in this area but also restricts the generalizability of the findings, making it difficult to draw broad conclusions. Although peer-reviewed journal articles are typically considered the gold standard in academic research due to their rigorous review process, they represent only one segment of the scholarly communication ecosystem. By excluding conference proceedings, doctoral dissertations, and book chapters, the scope of the analysis was narrowed, potentially omitting relevant descriptions of practice. Including these sources could have enriched the analysis with diverse contributions and perspectives.

The process of filtering titles for specific keywords comes with some acknowledged limitations. Articles that are relevant but do not explicitly mention the chosen keywords in their titles may be excluded. Filtering titles for specific keywords could lead to a loss of potentially valuable information pertinent to the research but described using different terminology. Additionally, some articles may have titles that are not fully indicative of their content. Therefore, important studies might be overlooked if they do not explicitly include the specified keywords despite being highly relevant to the topic. Complementary strategies, such as abstract or full-text screening, could capture relevant studies that may have been overlooked during the title screening stage.

The analysis was conducted using reference models informed by the ATD. It is possible that a different theoretical framing would have yielded other insights. Nonetheless, this framing highlights a need to pay more attention to the inclusion of reasons (logos) in teacher education and to bring teacher education pedagogies into play with each other. Suppose the inclusion of reasons (logos) can inspire teacher educators teaching PSTs to use instructional technology to make more explicit professional judgments informing didactical choices. In that case, this paper has made a worthwhile contribution.

Conducting a critical review using only ERIC, Scopus, and WoS has limitations. For instance, Scopus and WoS may not comprehensively cover niche education journals, particularly those from smaller or non-Western publishers, potentially excluding important studies. These databases primarily index English-language journals, which means valuable research published in other languages might be missed. While robust for educational literature, ERIC may not promptly include the latest publications. Additionally, Scopus and WoS have proprietary indexing criteria, which can result in missing relevant but less-cited studies. The unique search functionalities of each database can also restrict the search strategy's flexibility. More extensive reviews could use additional databases like Google Scholar, Education Full Text (EBSCOhost), and Emerald. The broader approach could ensure a more comprehensive and balanced review, reducing the risk of missing pertinent studies.

Focusing exclusively on how and what PSTs are taught about teaching mathematics using instructional technology, explicitly excluding PSTs' learning and knowledge, presents some limitations. Teaching and learning are interconnected processes, and omitting the learning and knowledge of PSTs leads to an incomplete understanding of the educational ecosystem, particularly in how instructional technology integration evolves from teacher preparation to practice. Including PSTs' learning and knowledge in the research could have offered a more comprehensive and holistic view of how PSTs are prepared to use instructional technology in teaching mathematics.

Author Notes

The authors state that they have no competing interests that may have influenced the work reported in this paper. Additionally, the authors confirm that ethical approval was not required for this article, as the data collection consisted of already published articles.

The data used in this study are already published and are freely available for access (Appendix A).

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References

Admiraal, W., van Vugt, F., Kranenburg, F., Koster, B., Smit, B., Weijers, S., & Lockhorst, D. (2017). Preparing pre-service teachers to integrate technology into K–12 instruction: Evaluation of a technology-infused approach. *Technology, Pedagogy and Education*, *26*(1), 105–120. https://doi.org/10.1080/1475939X.2016.1163283

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualisation, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, *52*(1), 154–168. https://doi.org/10.1016/j.compedu.2008.07.006

Arzarello, F., Robutti, O., Sabena, C., Cusi, A., Garuti, R., Malara, N., & Martignone, F. (2014). Meta-didactical transposition: A theoretical model for teacher education programmes. In A. Clark-Wilson, O. Robutti, & N. Sinclair (Eds.), *The mathematics teacher in the digital era: An international perspective on technology focused professional development* (pp. 347–372). Springer. https://doi.org/10.1007/978-94-007-4638-1_15

Association of Mathematics Teacher Educators. (2017). *Standards for preparing teachers of mathematics*. https://amte.net/standards

Austin, C. K., & Kosko, K. W. (2022). Representations of practice used in mathematics methods courses. *Contemporary Issues in Technology and Teacher Education*, *22*(1), 60–76. https://citejournal.org/volume-22/issue-1-22/mathematics/representations-of-practice-used-in-mathematics-methods-courses

Bang, E., & Luft, J. A. (2013). Secondary science teachers' use of technology in the classroom during their first 5 years. *Journal of Digital Learning in Teacher Education*, *29*(4), 118–126. https://doi.org/10.1080/21532974.2013.10784715

Barbé, J., Bosch, M., Espinoza, L., & Gascón, J. (2005). Didactic restrictions on the teacher's practice: The case of limits of functions in Spanish high schools. *Education Studies in Mathematics, 59,* 235-268. https://doi.org/10.1007/s10649-005-5889-z

Baran, E., Canbazoglu Bilici, S., Albayrak Sari, A., & Tondeur, J. (2019). Investigating the impact of teacher education strategies on preservice teachers' TPACK: The impact of teacher education strategies on TPACK. *British Journal of Educational Technology*, *50*(1), 357–370. https://doi.org/10.1111/bjet.12565

Bosch, M., Chevallard, Y., García, F. J., & Monaghan, J. (Eds.). (2019). *Working with the anthropological theory of the didactic in mathematics education: A comprehensive casebook*. Routledge.

Caena, F., & Redecker, C. (2019). Aligning teacher competence frameworks to 21st-century challenges: The case for the European Digital Competence Framework for Educators. *European Journal of Education, Research, Development and Policy*, *54*(3), 356–369. https://doi.org/10.1111/ejed.12345

Chevallard, Y. (1992). Fundamental concepts in didactics: Perspectives provided by an anthropological approach. In R. Douady & A. Mercier (Eds.), *Research in "didactique" of mathematics. Selected papers* (pp.131-168). La Pensée Sauvage.

Chevallard, Y. (2006). Steps towards a new epistemology in mathematics education. In M. Bosch (Ed.) *Proceedings of the 4th conference of the European Society for Research in Mathematics Education (CERME 4)*. http://ermeweb.free.fr/CERME4

Chevallard, Y., & Bosch, M. (2020). Anthropological theory of the didactic (ATD). In S. Lerman (Red.). In S. Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 53–61). Springer International Publishing. https://doi.org/10.1007/978-3-030-15789-0

Clark-Wilson, A., Robutti, O., & Thomas, M. (2020). Teaching with digital technology. *ZDM*, *52*(7), 1223–1242. https://doi.org/10.1007/s11858-020-01196-0

Cullen, C., Hertel, J., & Nickels, M. (2020). The roles of technology in mathematics education. *The Educational Forum, 84*(2), 166–78. doi:10.1080/00131725.2020.1698683

Daniel, G. R., Auhl, G., & Hastings, W. (2013). Collaborative feedback and reflection for professional growth: Preparing first-year pre-service teachers for participation in the community of practice. *Asia-Pacific Journal of Teacher Education, 41*(2), 159–172. https://doi.org/10.1080/1359866X.2013.777025

Darling-Hammond, L., Hammerness, K., Grossman, P., Rust, F., & Shulman, L. (2005). The design of teacher education programs. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing teachers for a changing world: What teachers should learn and be able to do, (*390-441). Jossey-Bass

DeSantis, J. (2012). Getting the most from your interactive whiteboard investment: Three guiding principles for designing effective professional development. *The Clearing House*, *85*(2), 51–55. https://doi.org/10.1080/00098655.2011.607867

Dick, T. P., & Hollebrands, K. F. (2011). *Focus in high school mathematics: Technology to support reasoning and sense making*. National Council of Teachers of Mathematics.

Drijvers, P. (2015). Digital technology in mathematics education: Why it works (or doesn't). In S. J. Cho (Ed.), *Selected regular lectures from the 12th International Congress on Mathematical Education* (pp. 135–151). Springer International Publishing. https://doi.org/10.1007/978-3-319-17187-6_8

Fathi, J., & Ebadi, S. (2020). Exploring EFL pre-service teachers' adoption of technology in a CALL program: Obstacles, motivators, and maintenance. *Education and Information Technologies*, *25*(5), 3897–3917. https://doi.org/10.1007/s10639-020-10146-y

Gerard, L. F., Varma, K., Corliss, S. B., & Linn, M. C. (2011). Professional development for technology-enhanced inquiry science. *Review of Educational Research*, *81*(3), 408–448. https://doi.org/10.3102/0034654311415121

Graham, C. R., Tripp, T., & Wentworth, N. (2009). Assessing and improving technology integration skills for preservice teachers using the teacher work sample. *Journal of Educational Computing Research*, *41*(1), 39–62. https://doi.org/10.2190/EC.41.1.b

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching*, *15*(2), 273–289. https://doi.org/10.1080/13540600902875340

Heyd-Metzuyanim, E., & Graven, M. (2019). Rituals and explorations in mathematical teaching and learning: introduction to the special issue. *Educational Studies in Mathematics*, *101*(2), 141–151. https://doi.org/10.1007/s10649-019-09890-x

Higgins, J. P. T., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savović, J., Schulz, K. F., Weeks, L., & Sterne, J. A. C. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*, *343*, d5928. https://doi.org/10.1136/bmj.d5928

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers & Education*, *153*, 103897. https://doi.org/10.1016/j.compedu.2020.103897

Howell, H., & Mikeska, J. N. (2021). Approximations of practice as a framework for understanding authenticity in simulations of teaching. *Journal of Research on Technology in Education, 53*(1), 8–20. https://doi.org/10.1080/15391523.2020.1809033

Howland, J. L., Jonassen, D., & Marra, R. M. (2012). Goal of technology integrations: Meaningful learning. In J. Howland, D. Jonassen, & R. Marra (Eds.), *Meaningful learning with technology* (4th ed., pp. 1–19). Pearson.

Kafyulilo, A., & Fisser, P. (2019). Developing TPACK in science and mathematics teacher education in Tanzania: A proof of concept study. In J. Pieters, J. Voogt, & N. Pareja Roblin (Eds.), *Collaborative curriculum design for sustainable innovation and teacher learning* (pp. 139–155). Springer International Publishing. https://doi.org/10.1007/978-3-030-20062-6_8

Kirkwood, A., & Price, L. (2013). Technology-enhanced learning and teaching in higher education: What is 'enhanced' and how do we know? A critical literature review. *Learning, Media and Technology, 39*(1), 6–36. https://doi.org/10.1080/17439884.2013.770404

Lampert, M., Franke, M. L., Kazemi, E., Ghousseini, H., Turrou, A. C., Beasley, H., Cunard, A., & Crowe, K. (2013). Keeping it complex: Using rehearsals to support novice teacher learning of ambitious teaching. *Journal of Teacher Education*, *64*(3), 226–243. https://doi.org/10.1177/0022487112473837

Lavie, I., Steiner, A., & Sfard, A. (2019). Routines we live by: From ritual to exploration. *Educational Studies in Mathematics*, *101*(2), 153–176. https://doi.org/10.1007/s10649-018-9817-4

Loewenberg Ball, D., & Forzani, F. M. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education, 60*(5), 497-511. https://doi.org/10.1177/0022487109348479

Marron, S., & Coulter, M. (2021). Initial teacher educators' integrating iPads into their physical education teaching. *Irish Educational Studies*, *40*(4), 611–626. https://doi.org/10.1080/03323315.2021.1971103

McCulloch, A., Leatham, K., Bailey, N., Cayton, C., Fye, K., & Lovett, J. (2021). Theoretically framing the pedagogy of learning to teach mathematics with technology. *Contemporary Issues in Technology and Teacher Education*, 21(2), 325-359. https://citejournal.org/volume-21/issue-2-21/mathematics/theoretically-framing-the-pedagogy-of-learning-to-teach-mathematics-with-technology

Mensah, F.S. (2024). Learning to teach mathematics with instructional technology: A praxeological analysis of a Swedish mathematics teacher education course. In T. Evans, O. Marmur, J. Hunter, G. Leach, & J. Jhagroo (Eds.). *Proceedings of the 47th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 3, pp. 217-224).

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Miyakawa, T., & Winsløw, C. (2019). Paradidactic infrastructure for sharing and documenting mathematics teacher knowledge: A case study of "practice research" in Japan. *Journal of Mathematics Teacher Education*, *22*(3), 281–303. https://doi.org/10.1007/s10857-017-9394-y

Mouza, C., Yang, H., Pan, Y.-C., Yilmaz Ozden, S., & Pollock, L. (2017). Resetting educational technology coursework for pre-service teachers: A computational thinking approach to the development of technological pedagogical content knowledge (TPACK). *Australasian Journal of Educational Technology*, *33*(3). https://doi.org/10.14742/ajet.3521

Msafiri, M. M., Kangwa, D., & Cai, L. (2023). A systematic literature review of ICT integration in secondary education: what works, what does not, and what next? *Discover Education*, *2*(44), 1-17. https://doi.org/10.1007/s44217-023-00070-x

Niess, M. L. (2008). Guiding preservice teachers in developing TPCK. In M. J. Koehler & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 223–250). Routledge.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The

PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*(1), 89. https://doi.org/10.1186/s13643-021-01626-4

Pepin, B., Choppin, J., Ruthven, K., & Sinclair, N. (2017). Digital curriculum resources in mathematics education: Foundations for change. *ZDM Mathematics Education 49*, 645–661. https://doi.org/10.1007/s11858-017-0879-z

Quaicoe, J. S., & Pata, K. (2020). Teachers' digital literacy and digital activity as digital divide components among basic schools in Ghana. *Education and Information Technologies*, *25*(5), 4077-4095. https://doi.org/10.1007/s10639-020-10158-8

Ruiz-Munzón, N., Bosch, M., & Gascón, J. (2013). Comparing approaches through a reference epistemological model: The case of algebra. In B. Ubuz, C. Haser, & M. A. Mariotti (Eds.). *Proceedings of the 8th Congress of the European Society for Research in Mathematics Education* (pp. 2870–2879). Middle East Technical University.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Sterne, J. A., Hernán, M. A., Reeves, B. C., Savović, J., Berkman, N. D., Viswanathan, M., Henry, D., Altman, D. G., Ansari, M. T., Boutron, I., Carpenter, J. R., Chan, A.-W., Churchill, R., Deeks, J. J., Hróbjartsson, A., Kirkham, J., Jüni, P., Loke, Y. K., Pigott, T. D., … Higgins, J. P. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*, *355*, i4919. https://doi.org/10.1136/bmj.i4919

Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Martínez Monés, A., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, *28*(6), 6695-6726. https://doi.org/10.1007/s10639-022-11431-8

Tondeur, J., Scherer, R., Baran, E., Siddiq, F., Valtonen, T., & Sointu, E. (2019). Teacher educators as gatekeepers: Preparing the next generation of teachers for technology integration in education. *British Journal of Educational Technology*, *50*(3), 1189–1209. https://doi.org/10.1111/bjet.12748

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2017). A comprehensive investigation of TPACK within pre-service teachers' ICT profiles: Mind the gap! *Australasian Journal of Educational Technology*, *33*(3). https://doi.org/10.14742/ajet.3504

Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*(1), 134–144. https://doi.org/10.1016/j.compedu.2011.10.009

Tondeur, J., van Braak, J., Siddiq, F., & Scherer, R. (2016). Time for a new approach to prepare future teachers for educational technology use: Its meaning and measurement. *Computers & Education*, *94*, 134–150. https://doi.org/10.1016/j.compedu.2015.11.009

Voogt, J., & McKenney, S. (2017). TPACK in teacher education: Are we preparing teachers to use technology for early literacy? *Technology, Pedagogy and Education*, *26*(1), 69–83. https://doi.org/10.1080/1475939X.2016.1174730

Wijayanti, D., & Winslow, C. (2017). Mathematical practice in textbook analysis: Praxeological reference models, the case of proportion. *REDIMAT*, *6*(3), 307–330.

Yenmez, A. A. (2017). An examination of the effectiveness of instruction in which pre-service mathematics teachers use technology to overcome student difficulties. *Journal of Education and Practice*, *8*(15), 1-21.

Yildiz Durak, H. (2021). Preparing pre-service teachers to integrate teaching technologies into their classrooms: Examining the effects of teaching environments based on open-ended, hands-on and authentic tasks. *Education and Information Technologies*, *26*(5), 5365–5387. https://doi.org/10.1007/s10639-021-10511-5

Appendix A
Publications Included in the Critical Analysis

Açikgül, K., & Aslaner, R. (2019). Investigation of relations between the technological pedagogical content knowledge efficacy levels and self-efficacy perception levels of pre-service mathematics teachers. *Cukurova University Faculty of Education Journal*, *48*(1), 1–31. https://dergipark.org.tr/en/pub/cuefd/issue/44511/409949

Açıkgül, K., & Aslaner, R. (2020). Effects of GeoGebra-supported micro-teaching applications and technological pedagogical content knowledge (TPACK) game practices on the TPACK levels of prospective teachers. *Education and Information Technologies*, *25*(3), 2023–2047. https://doi.org/10.1007/s10639-019-10044-y

Agyei, D. D., & Voogt, J.M. (2012). Developing technological pedagogical content knowledge in pre-service mathematics teachers through collaborative design. *Australasian Journal of Educational Technology*, *28*(4). https://doi.org/10.14742/ajet.827

Agyei, D. D., & Voogt, J. M. (2015). Pre-service teachers' TPACK competencies for spreadsheet integration: Insights from a mathematics-specific instructional technology course. *Technology, Pedagogy and Education*, *24*(5), 605–625. https://doi.org/10.1080/1475939X.2015.1096822

Agyei, D. D., & Voogt, J. M. (2016). Pre-service mathematics teachers' learning and teaching of activity-based lessons supported with spreadsheets. *Technology, Pedagogy and Education*, *25*(1), 39–59. https://doi.org/10.1080/1475939X.2014.928648

Akapame, R., Burroughs, E., & Arnold, E. (2019). A clash between knowledge and practice: A case study of TPACK in three pre-service secondary mathematics teachers. *Journal of Technology and Teacher Education*, *27*(3), 269–304.

Akkaya, R. (2016). Research on the development of middle school mathematics pre-service teachers' perceptions regarding the use of technology in teaching mathematics. *EURASIA Journal of Mathematics, Science and Technology Education*, *12*(4). https://doi.org/10.12973/eurasia.2016.1257a

Akyuz, D. (2018). Measuring technological pedagogical content knowledge (TPACK) through performance assessment. *Computers & Education*, *125*, 212–225. https://doi.org/10.1016/j.compedu.2018.06.012

Bonafini, F. C., & Lee, Y. (2021a). Investigating prospective teachers' TPACK and their use of mathematical action technologies as they create screencast video lessons on iPads. *TechTrends*, *65*(3), 303–319. https://doi.org/10.1007/s11528-020-00578-1

Bonafini, F. C., & Lee, Y. (2021b). Portraying mathematics pre-service teachers' experience of creating video lessons with portable interactive whiteboards through the TPACK. *New Educator*, *17*(4), 327–352. https://doi.org/10.1080/1547688X.2021.1980167

Bozkurt, G., & Yiğit Koyunkaya, M. (2022). Supporting prospective mathematics teachers' planning and teaching technology-based tasks in the context of a practicum course. *Teaching and Teacher Education*, *119*, 103830. https://doi.org/10.1016/j.tate.2022.103830

Kafyulilo, A., Fisser, P., Pieters, J., & Voogt, J. (2015). ICT use in science and mathematics teacher education in Tanzania: Developing technological pedagogical content knowledge. *Australasian Journal of Educational Technology*, *31*(4). https://doi.org/10.14742/ajet.1240

Kartal, B., & Çınar, C. (2022). Preservice mathematics teachers' TPACK development when they are teaching polygons with GeoGebra. *International Journal of Mathematical Education in Science and Technology*, 1–33. https://doi.org/10.1080/0020739X.2022.2052197

McDonald, S. (2012). The challenge to situate digital learning technologies in preservice teacher mathematics education. *Contemporary Issues in Technology and Teacher Education, 12*(4), 355-368. https://citejournal.org/volume-12/issue-4-12/mathematics/the-challenge-to-situate-digital-learning-technologies-in-preservice-teacher-mathematics-education

Meagher, M., Ozgun-Koca, A., & Edwards, M. T. (2011). Preservice teachers' experiences with advanced digital technologies: The interplay between technology in a preservice classroom and in field placements. *Contemporary Issues in Technology and Teacher Education (CITE Journal)*, *11*(3), 243–270. https://citejournal.org/volume-11/issue-3-11/mathematics/preservice-teachers-experiences-with-advanced-digital-technologies-the-interplay-between-technology-in-a-preservice-classroom-and-in-field-placements

Mouza, C., Karchmer-Klein, R., Nandakumar, R., Ozden, S. Y., & Hu, L. (2014). Investigating the impact of an integrated approach to the development of preservice teachers' technological pedagogical content knowledge (TPACK). *Computers & Education*, 71, 206-221. https://doi.org/10.1016/j.compedu.2013.09.020

Rocha, H. (2020). Using tasks to develop pre-service teachers' knowledge for teaching mathematics with digital technology. *ZDM: Mathematics Education*, *52*(7), 1381–1396. https://doi.org/10.1007/s11858-020-01195-1

Smith, R. C., Shin, D., & Kim, S. (2017). Prospective and current secondary mathematics teachers' criteria for evaluating mathematical cognitive technologies. *International Journal of Mathematical Education in Science and Technology*, *48*(5), 659–681. https://doi.org/10.1080/0020739X.2016.1264635

Wentworth, N., & Monroe, E. E. (2011). Inquiry-based lessons that integrate technology: Their development and evaluation in elementary mathematics teacher education. *Computers in the Schools*, *28*(4), 263–277. https://doi.org/10.1080/07380569.2011.620938

Yenmez, A. A., Özpınar, İ., & Gökçe, S. (2017). Examining changes in preservice mathematics teachers' technological pedagogical content knowledge from their microteaching. *Educational Sciences: Theory & Practice*, *17*(5), 1699–1732. https://doi.org/10.12738/estp.2017.5.0454

Zambak, V. S., & Tyminski, A. M. (2020). Examining mathematical, technological knowledge of pre-service middle grades teachers with *Geometer's Sketchpad* in a geometry course. *International Journal of Mathematical Education in Science and Technology*, *51*(2), 183–207. https://doi.org/10.1080/0020739X.2019.1650302

Zengin, Y. (2018). Examination of the constructed dynamic bridge between the concepts of differential and derivative with the integration of GeoGebra and the ACODESA method. *Educational Studies in Mathematics*, *99*(3), 311–333. https://doi.org/10.1007/s10649-018-9832-5

Appendix B
Search Description

Database	Boolean Description	Applied Filters
ERIC via ProQuest	(‘technologies’ OR ‘technological’ OR ‘technology’ OR ‘digitalisation’ ‘digitalization’ OR ‘digital tools’ OR ‘ICT’) AND ('mathematics teacher education’ OR ‘mathematics teacher training’ OR ‘mathematics teacher preparation’ OR ‘teacher preparation in mathematics’) AND (‘pre-service teachers’ OR (‘preservice teachers’ OR ‘pre?service teachers’ OR ‘prospective teachers’ OR ‘teacher candidates’ OR ‘novice teachers’ OR ‘teacher student’ OR ‘student teachers’)	(Scholarly Journals) NOT (Reports AND Speeches & Presentations AND Encyclopedias & Reference Works AND Books AND Conference Papers & Proceedings AND Other Sources) 2010-01-01 - 2022-12-31 (Article OR Report) NOT (Instructional Material/Guideline AND Speech/Lecture AND Editorial AND Statistics/Data Report) NOT (feedback (response) AND covid-19 AND pandemics AND student projects AND scores AND design AND grade 5 AND teacher surveys AND grade 6 AND physics AND learning processes AND educational change AND electronic learning AND interdisciplinary approach AND active learning AND scientific concepts AND student surveys AND outcomes of education AND handheld devices AND engineering education AND student motivation AND cooperative learning AND models AND inquiry AND skill development AND validity AND interaction AND student teacher attitudes AND teacher characteristics AND computation AND reflection AND manipulative materials AND classroom techniques AND communities of practice AND high schools AND elementary education AND grade 8 AND visualization AND beliefs AND student attitudes AND pedagogical content knowledge AND thinking skills AND minority group students AND student characteristics AND student interests AND textbooks)
Scopus	(technologies OR technological OR technology OR digitalisation OR digitalization OR digital AND tools OR ict) AND (mathematics AND teacher AND education OR mathematics AND teacher AND training' OR mathematics AND teacher AND preparation OR teacher AND preparation AND in AND mathematics) AND (pre-service AND teachers OR preservice AND teachers OR pre?service AND teachers OR prospective AND teachers OR 'teacher AND candidates OR novice AND teachers OR teacher AND student OR student AND teachers) AND PUBYEAR > 2009 AND PUBYEAR < 2023 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j"))	Year: 2022–2010 Articles Final Publication English Journal
WOS	((ALL=(‘technologies’ OR ‘technological’ ‘technology’ OR ‘digitalisation’ OR ‘digitalization’ OR ‘digital tools’ OR ‘ICT’)) AND ALL=(‘mathematics teacher education’ OR ‘mathematics teacher training’ OR ‘mathematics teacher preparation’ OR ‘teacher preparation in mathematics’)) AND ALL=(‘pre-service teachers’ OR ‘preservice teachers’ OR 'pre?service teachers’ OR ‘prospective teachers’ OR ‘teacher candidates’ OR ‘novice teachers’ OR ‘teacher student’ OR ‘student teachers’)	Year: 2022–2010 Articles English Open Access Education and Educational Research

Appendix C
Overview of Research Characteristics

Study Included [a]	Preparation/ Teaching Context	Participants	Risk of Bias Assessment	Research Approach	Data Collection Instrument
Açikgül and Aslaner (2019)	Method Course	88 PSTs	*	Quantitative	Multiple Choice Achievement Test, Lesson Plan, Participation Report, TPACK Scale about Geometry
Açıkgül and Aslaner (2020)	Method Course	88 PSTs	* & **	Quantitative	Lesson Plan, Participant Form, and TPACK Scale for Geometry
Agyei and Voogt (2012)	Workshop	129 PSTs	*	Mixed	Experimental Teacher Interview, Experimental Teacher Evaluation Questionnaire, and Researcher's Logbook
Agyei and Voogt (2016)	Workshop	12 PSTs	*	Mixed	Lesson Plan Rubrics, Observation Rubrics, TPACK Survey, Teacher Interviews, and Researchers' Logbook
Agyei and Voogt (2015)	Method Course	104 PSTs	*	Mixed	TPACK Lesson Plan Rubric, TPACK Observation Rubric, TPACK Survey, Teachers' Attitudes toward Computers (TAC) Questionnaire, and Design Team Reports
Akapame et al. (2019)	Mathematical Modelling Course, Methods Course, and Practicum Course	3 PSTs	*	Qualitative	Two Individual Lesson Plans and PSTs' Reflections on the Lessons, Teaching Philosophy Statements, Responses to Open-Ended TPACK Questions, Observation of the Implementations of the Lesson Plans, and Interviews
Akkaya (2016)	Method Course	34 PSTs	*	Mixed	Perception Scale for Technology Use and Interview
Akyuz (2018)	Method Course	138 PSTs	*	Quantitative	Lesson Plan and Self-Assessment Survey
Bonafini and Lee (2021a)	Method Course	3 PSTs	*	Qualitative	Pre-service teachers' Lesson Plans, Video Lesson Files, Written Feedback Received from Classmates, Reflection upon Video Creation and Received Written Feedback from Peers, and Answers to Ungraded open-ended post-survey
Bonafini and Lee (2021b)	Method Course	4 PSTs	*	Qualitative	Participants' Lesson Plans, Screencast Video Lesson Files, and Reflection on own Video Creation
Bozkurt and Yiğit Koyunkaya (2022)	Practicum Course	4 PSTs	*	Qualitative	PSTs' Technology-Based Mathematical Tasks in Lesson Plans, Video Records of Microteaching, Classroom Teaching of PSTs, Video Records of Individual/Group Interviews and Discussions.
Kafyulilo et al. (2015)	Workshop	22 PSTs	*	Mixed	TPACK Survey, Observation Checklist, and Reflection Questionnaire
Kartal and Çınar (2022)	Method Course, Mathematics Content Course, Pedagogy	33 PSTs	*	Qualitative	Interviews, Lesson Implementations, and Lesson Plans

Study Included [a]	Preparation/ Teaching Context	Participants	Risk of Bias Assessment	Research Approach	Data Collection Instrument
	Course, and Workshop				
McDonald (2012)	Method Course	88 PSTs	*	Mixed	Prequestionnaire, Postpresentation reflections, Postquestionnaire
Study Included (Full references in Appendix A)	Preparation/ Teaching Context	Participants	Risk of Bias Assessment	Research Approach	Data Collection Instrument
Meagher et al. (2011)	Method Course	22 PSTs	*	Qualitative	Field Experience Reports, Activity Write-Ups, Graphing Calculator Teaching Projects, Lesson Plans, Mathematics Technology Attitudes Survey, Short Surveys, and Open-Ended Exit Survey
Mouza et al. (2014)	Method course, Field experience, educational technology course	88 PSTs	*	Mixed	TPACK survey, Performance assessment: case reports
Rocha (2020)	Method Course	10 PSTs	*	Qualitative	Participants' Written Work, Recording of PSTs' Group Discussions, and Notes were taken by the Researcher
Smith et al. (2017)	Method Course	15 PSTs	*	Qualitative	Preconstructed Dynamic Geometry Sketch and Accompanying Task Sheet, A Sequence of Video Clips of a Pair of Eighth-Grade Students, Video Recordings, Video of Stimulated-Recall Interviews
Wentworth and Monroe (2011)	Method Couse	38 ISTs & 84 PSTs	*	Qualitative	Completed Lesson Reports, A Joint Lesson Plan and Individual Reflections, Lesson Observation
Yenmez et al. (2017)	Method Course	52 PSTs	*	Mixed	Self-Efficacy Scale, Computer-Assisted Mathematics Instruction Questionnaire, Observation Form, Microteaching Videos, Self-Evaluation Form, Semistructured Interviews and Instructional Plan
Zambak and Tyminski (2020)	Method Course	16 PSTs	***	Qualitative	MCK Assessment in Geometry, Non-participant Observations, and Course Artefacts
Zengin (2018)	Content Course	33 PSTs	***	Qualitative	Open-ended Questionnaire, Knowledge Test, Tasks, and Participants' Dynamic Constructions

Note: * represents studies conducted by MTE/researcher on their own students, ** represents studies involving a control group, and *** represents an exception to * and **
[a] Full references in Appendix A