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Reclaiming agency in instructional technology integration: a praxeological analysis of pre-service mathematics teachers' roles in a GeoGebra-based model lesson

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The integration of instructional technology in mathematics teacher education is often guided by demonstration-based approaches that centralize authority and limit opportunities for Pre-Service Teachers (PSTs) to engage meaningfully with pedagogical decision-making. Such practices risk reducing instructional technology integration to performance rather than empowering future educators to develop techno-didactic competence. This study critically examines how a GeoGebra-based model lesson shaped PSTs' experiences of participation, agency, and learning. It investigates the extent to which the instructional design enabled or constrained the development of autonomous techno-didactic praxeologies. A qualitative case study design was employed, drawing on video observations of a model lesson and a subsequent focus group interview with PSTs. The analysis used a dual-layered coding strategy grounded in the Anthropological Theory of the Didactic (ATD), combining deductive praxeological coding (tasks, techniques, technologies, and theory) with inductive thematic analysis of emergent constraints and expressions of agency. The results reveal a tightly controlled didactic contract that limited PSTs' engagement with the epistemic justifications underlying teaching decisions. While the model lesson effectively demonstrated the use of GeoGebra, it positioned PSTs as passive observers rather than co-constructors of knowledge. However, retrospective reflections showed emerging critical awareness and imagined alternatives to the instructional structure, indicating latent forms of agency shaped by constraint rather than enactment. The study highlights the need for teacher education practices that move beyond transmission to foster reflective, participatory, and design-oriented engagement with instructional technology. Implications point to a dual need: investment in material infrastructure and a reconfiguration of pedagogical routines that legitimize PSTs' agency. Future research should explore structured interventions that support the co-construction of techno-didactic knowledge through iterative, reflective practice.

KEYWORDS

instructional technology, mathematics teacher education, praxeologies, pre-service teachers, teacher agency

1 Introduction

Instructional technologies are increasingly positioned as essential to mathematics education, credited with fostering conceptual understanding, learner engagement, and innovative pedagogy. In this paper, instructional technology refers to the purposeful integration of digital tools and resources in the classroom to enhance didactic and pedagogical processes as well as learning, or to promote cognitive engagement and support deeper conceptual understanding or both (see Mensah et al., 2024). International and national policy frameworks reinforce this view, designating digital competence as a core outcome of teacher education (European Union, 2020; OECD, 2019, 2023; UNESCO, 2018). The COVID-19 pandemic further accelerated this trajectory, transforming digital readiness from a desirable skill into a structural necessity for professional practice (Eşki et al., 2025; Ivanov et al., 2025; McCarthy et al., 2023; Tomczyk, 2024).

However, research, particularly from low- and middle-income contexts, reveals a persistent gap between policy rhetoric and the realities of teacher education (Agyei, 2021; Hennessy et al., 2022; McCowan et al., 2022; Nopas and Kerdsomboon, 2024; Oubibi et al., 2024). While digital literacy is often mandated, instructional technology integration tends to be delivered through stand-alone modules or instrumental demonstrations detached from authentic teaching scenarios (Forkosh-Baruch et al., 2021; Lehmann et al., 2020; Mensah et al., 2024; Wilson et al., 2025). In mathematics teacher education, "model lessons" have become a common means of showcasing technology-mediated instruction. Typically led by teacher educators, these lessons demonstrate "best practices" but often retain a transmissive format, positioning Pre-Service Teachers (PSTs) as passive observers rather than active participants in pedagogical reasoning or decision-making (Hähnlein and Pirnay-Dummer, 2024; Mensah et al., 2024).

This paper questions the pedagogical and institutional arrangements underpinning such model lessons. It argues that understanding how PSTs experience and respond to these settings requires more than tracking tool adoption or surface-level engagement. Instead, attention must be paid to how instructional knowledge is structured, enacted, and made available for appropriation, particularly when digital tools are embedded within complex practices that entail not only technical skills but also epistemic justifications and pedagogical decision-making.

To this end, the study draws on the Anthropological Theory of the Didactic (ATD) (Chevallard, 1992) to examine how PSTs interpret their roles within a model mathematics lesson centered on GeoGebra. Specifically, it asks how the lesson's design and enactment structure access to praxeological elements [see theoretical framework section] and how these shape PSTs' sense of competence, agency, and professional orientation. The lesson was analyzed through a dual-lens approach: its internal didactic structure (as captured via video observation) and PSTs' reflective accounts (elicited through a video-recall focus group interview). The latter offered a unique empirical window into how instructional intentions were received, interpreted, or resisted by PSTs and how this shaped their emerging capacity to act with didactic agency.

By foregrounding the relational dynamics between participation structures, knowledge organization, and technological mediation, this study contributes a critical and contextually grounded perspective on the integration of instructional technology in mathematics teacher education. Rather than evaluating whether instructional technology was "used well," it asks whether PSTs were enabled to meaningfully engage with the knowledge and didactical and pedagogical possibilities that instructional technologies might afford. It reframes instructional technology as a mediator of professional identity and didactic reasoning, not simply as a delivery mechanism.

To guide this inquiry, the following research question is posed:

> How do PSTs interpret and respond to the didactic roles and rationales presented during a model GeoGebra-based mathematics lesson, and what do their reflections reveal about the emergence of didactic agency in teacher education?

2 Theoretical framework: A praxeological lens on agency

The integration of instructional technology into teacher education should not be understood solely as a matter of access, training, or tool proficiency. Instead, it presents a deeply didactic challenge, implicating how knowledge is constructed, organized, legitimized, and rendered learnable within institutional settings. The ATD provides a robust conceptual framework for analyzing these dynamics. Central to the ATD is the notion of praxeology, defined as a structured combination of types of tasks (t), techniques for solving them (τ), the justifications for these techniques (θ), and the overarching theoretical discourses (Θ) that give coherence and legitimacy to practice (Bosch and Gascón, 2006; Chevallard, 1992, 1999). In mathematics teacher education, such praxeologies are not spontaneously developed but are orchestrated within meta-didactic systems—institutional arrangements where teaching becomes the object of teaching (Arzarello et al., 2014; Barquero et al., 2019). Curricular scripts, pedagogical ideologies, assessment regimes, and material conditions shape these systems. The introduction of instructional technologies into this environment creates techno-didactic praxeologies wherein digital tools co-constitute the organization of tasks, shape the range of admissible techniques, and reconfigure the rationales and theoretical discourses that frame pedagogical activity.

However, the integration of such instructional technology does not inherently foster meaningful engagement. Many teacher education programmes rely on demonstration-based instruction, wherein PSTs observe model practices without opportunities to question or reconstruct them. In such settings, access to the logos (θ, Θ) is often restricted, leaving PSTs with procedural familiarity but limited insight into the epistemic or didactic rationales that guide instructional choices. This phenomenon is governed in part by the didactic contract—a set of explicit and implicit norms that delineate permissible forms of participation, questioning, and authorship within a given instructional context (Brousseau, 2002; Chevallard, 1992). This study brings into focus the concept of didactic agency to question PSTs' capacity to initiate, adapt, and critically reflect upon the praxeologies they encounter. Building on Winsløw and Grønbæk (2014), didactic agency is understood here

not as a universal disposition but as a contextually situated capacity that depends on the extent to which learners are invited to engage with all dimensions of praxeological knowledge. Agency, in this sense, entails access to and appropriation of the justifications and theoretical discourses underlying didactic activity, as well as the capacity to modify or reorient those structures in practice.

This operationalization of agency as praxeological access, particularly to the logos dimension, speaks to but does not exhaust wider accounts of agency. In Emirbayer and Mische (1998) temporal—relational framework, agency comprises iterative (past-patterned), projective (future-oriented), and practical—evaluative (present-contingent) dimensions. The study data primarily capture practical—evaluative moves, which are themselves heavily conditioned by lesson structures. Similarly, Priestley et al. (2015) ecological model emphasizes the interplay of personal capacities, relational—cultural resources, and structural conditions; the current analysis specifies how didactic configurations mediate these resources by opening or closing access to logos. Figure 1 illustrates how ATD's praxeological components (t, τ, θ, Θ) intersect with these broader dimensions of agency in technology-rich lessons. It visually locates the study's analysis within a wider theoretical landscape, clarifying the analytical trade-offs and complementarities involved in using a praxeological lens.

By foregrounding the praxeological structuring of instructional activity, this framework enables us to examine the institutional, epistemic, and interactional conditions under which PSTs' agency can emerge, be constrained, or remain unrealized. The next section outlines the methodological design used to investigate how PSTs engaged with techno-didactic praxeologies and negotiated their didactic agency within the context of a GeoGebra-based model lesson.

3 Methodology

3.1 Research design

This study employs a qualitative single-case study design to question how PSTs engage with, interpret, and respond to a GeoGebra-based model mathematics lesson within a teacher education setting. A qualitative approach is especially appropriate for investigating processes of meaning-making, professional positioning, and emergent agency in contextually rich and institutionally mediated environments. Rather than seeking generalizable predictions, the study is oriented toward interpretive depth—an understanding of how instructional knowledge and agency are co-constructed in specific pedagogical configurations (Merriam and Tisdell, 2015). The case study, conceptualized as an in-depth exploration of a bounded system (Creswell and Poth, 2016), enables detailed analysis of how techno-didactic praxeologies unfold in situ and how they are appropriated or resisted by PSTs.

Situated within an interpretivist paradigm, the study acknowledges knowledge as socially constructed, relational, and contingent upon the discursive, institutional, and material arrangements of the educational context. The use of the ATD does not merely inform the conceptual framing; it shapes the methodological logic of the study itself. The ATD foregrounds the didactic system as a structured configuration of roles, norms, and knowledge practices. As such, the unit of analysis extends beyond individual learners to encompass the dynamic interplay between PSTs, praxeologies (t, τ, θ, Θ), and the institutional settings in which their professional dispositions are formed. This relational focus permits a more nuanced understanding of how agency is either fostered or constrained within model instructional scenarios.

3.2 Empirical context and participants

The study was situated at a public teacher education university in Ghana and focused on a core third-year course within the Bachelor of Education (Mathematics) program, referred to here pseudonymously as MA 335. Positioned strategically within the program's curriculum, MA 335 is designed to develop PSTs' capacity to design, select, and implement both physical and digital instructional resources, with particular emphasis on the pedagogical integration of instructional technology. GeoGebra, as one of the featured tools in the course, is foregrounded as a means of fostering dynamic mathematical visualization and facilitating inquiry-oriented teaching practices.

A GeoGebra-based model lesson, designed and facilitated by the course instructor, served as the empirical anchor for the study. The lesson aimed to demonstrate the meaningful integration of instructional technology in the teaching of geometry, aligning with the course's stated objectives of promoting technological fluency, pedagogical flexibility, and innovative instructional design. Delivered in a blended format that combines live demonstrations, digital simulations, and collaborative group tasks, the lesson was intended not merely as a showcase of instructional technology use but as a structured opportunity for PSTs to engage with evolving techno-didactic praxeologies.

Fifteen PSTs participated in the study. They were purposively selected based on their active enrolment in MA 335, observable engagement during the model lesson, and their expressed willingness to participate in post-lesson research activities. Participation was entirely voluntary, and ethical protocols were rigorously followed. Ethical approval was obtained from the Institutional Review Board of the Council for Scientific and Industrial Research in Ghana, with formal authorization from the hosting university. Informed consent was secured from all participants for each stage of the data collection process, including video recordings of the model lesson and audio-visual documentation of the subsequent video-recall focus group interview.

3.3 Data source and collection strategy

The primary data source for this study was a video-recorded model lesson followed by a video-recall focus group interview. Together, these constituted a rich corpus for examining how PSTs experienced and interpreted their participation in a techno-didactic instructional setting. The choice to rely on video-recorded model lesson and a video-recall focus group interview was intentional and theoretically grounded. This combination allowed

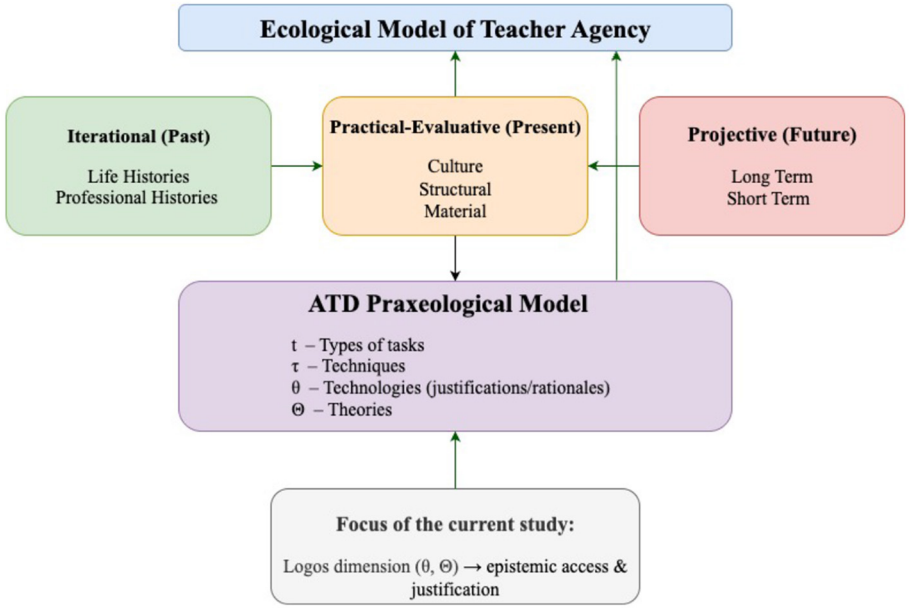

FIGURE 1
Praxeological–ecological interface on teacher agency.

for methodological triangulation (Denzin, 2012), linking observed action to participants' meaning-making processes. Other artifacts, such as lesson plans or worksheets, while useful for documenting the educator's intended design, would have been less directly relevant to the study's focus on PSTs' enacted and perceived agency. By integrating observational and reflective accounts, this dataset captures both the situated and interpretive dimensions of agency, consistent with the praxeological analytical frame guiding the study.

The video data provided a situated and fine-grained record of PSTs' participation, positioning, and interactional moves during the model GeoGebra lesson, enabling systematic coding of tasks, techniques, and participation structures as enacted. The video was recorded using a single camera positioned behind the classroom to capture both instructor-led activities and student interactions. This recording was used not only for observational analysis but also as a stimulus for the subsequent focus group interview, enabling participants to revisit and reflect critically on key moments of the lesson. By grounding PSTs' reflections in concrete visual cues, the video-recall format allowed the study to elicit not just retrospective opinions but situated reasoning about pedagogical intent, task structure, and perceived roles within the lesson.

The focus group interview conducted 2 weeks after the model lesson offered complementary access to participants' interpretive framings, reflections, and imaginative projections of alternative practices. Focus-group interviews lasted approximately 75 m. It involved fifteen PSTs who had participated in the lesson, creating a shared reflective space that mirrored the collective nature of the original classroom experience. During the session, selected video clips were paused at strategic moments, particularly those corresponding to task introductions, GeoGebra tool demonstrations, and group-based problem solving. PSTs were invited to articulate their interpretations, challenges, and decisions during these segments. The facilitation was deliberately open-ended yet theoretically informed, prompting discussion around praxeological dimensions such as technique choice, rationales for actions, and perceived constraints or opportunities for adaptation.

All audio data were transcribed verbatim and pseudonymised to protect participant confidentiality. Field notes and analytic memos taken during and after the interview further informed the interpretive process, supporting triangulation and thematic saturation. The combined dataset enabled the study to move beyond surface impressions of instructional technology use to uncover how praxeological structures were encountered, appropriated, or resisted by PSTs within a real instructional context. All data collected was stored and processed following the European Union's General Data Protection Regulation (GDPR), with participants' identities pseudonymised and securely stored to prevent unauthorized access.

3.4 Description of the model lesson

The observed lesson, facilitated by the teacher educator, was explicitly framed as a model of how instructional technology—specifically GeoGebra—could be pedagogically integrated into mathematics teaching. Rather than simply demonstrating software functionality, the MTE used GeoGebra to mediate conceptual engagement with quadratic functions, thereby modeling both mathematical reasoning and classroom practice for the participating PSTs. To support analytical clarity, the lesson is segmented into five instructional episodes, each demarcating a shift in focus or instructional intention. Table 1 summarizes the five episodes used to structure the empirical analysis.

TABLE 1 Content and timing of instructional episodes.

Episode	Time	Focus of PST's engagement
1	0:00–23:00	PSTs are divided into groups, encounter lesson goals and mathematical context, and observe real-life applications of quadratic functions.
2	23:00–42:30	MTE directs PSTs to observe the effect of a continuous change of the parameter 'a' in $f(x) = ax^2$, on the graph; this observation is followed by discussion and additional collaborative task on worksheet tasks; Some answers are shared, where the MTE asks for notation and substantiations.
3	42:30–54:00	PSTs observe the MTE manipulation of parameter c in $f(x) = ax^2 + c$ and observed graph shifts; extended reasoning from the previous episode and collaboration on worksheet tasks.
4	54:00–1:15:00	PSTs observe the MTE manipulation of parameter b in $f(x) = ax^2 + bx + c$, including the line of symmetry and collaboration on worksheet tasks.
5	1:15–1:17:15	PSTs are asked to summarize the mathematical learning of the lesson; no explicit engagement with pedagogical reflections.

3.5 Analytical approach

This study employed a layered analytical approach that combined deductive praxeological coding with inductive thematic analysis to examine how PSTs engaged with, reflected on, and reimagined the techno-didactic praxeologies enacted during a model GeoGebra-based lesson.

A dual-layered codebook was developed through an iterative, three-cycle process. In Cycle 1, open coding was applied to segments of the video-recorded model lesson and corresponding focus-group excerpts to capture observed actions, pedagogical techniques, and didactic techniques, while also noting emergent thematic elements (e.g., agency constraints, enabling conditions). In Cycle 2, these provisional codes were aligned with the ATD's praxeological components (t, τ, θ, Θ) and with inductively derived thematic categories, using side-by-side analysis of segments of the video-recorded model lesson and focus-group transcripts. In Cycle 3, definitions and anchor excerpts were refined and finalized.

The deductive strand followed the ATD's praxeological model to determine which aspects of the modeled praxeology were foregrounded or obscured, with particular attention to access to the logos (technology and theory). The inductive strand explored how PSTs positioned themselves in relation to the modeled practice, using sensitizing constructs such as the didactic contract, didactic configuration, and meta-didactic systems. Themes including peripheral positioning, imitative learning, constrained justification, pseudo-participation, instructional reimagination, and reflexive stance were developed through iterative transcript readings.

For reliability, a second coder, supported by methodological input from a research team, independently analyzed 20% of the dataset, stratified across the video-recorded model lesson and focus-group data, using MaxQDA. Raw percent agreement reached 93% for praxeological codes and 81% for thematic codes. Discrepancies were resolved through negotiated consensus, and revisions were incorporated into the final codebook. A comprehensive audit trail of codebook versions, coding memos, and analytic decisions supported rigor and transparency. Memos documented evolving interpretations, linked observational and interview data, and traced patterns across episodes. This multi-analyst, multi-stage process, combined with triangulation of the video-recorded model lesson and focus-group data, ensured the analysis was transparent, replicable, and grounded in the data. By integrating the deductive and inductive strands, the analysis revealed both which components of the techno-didactic praxeology were operationalized or withheld and how PSTs navigated and contested their positioning. Table 2 presents the coding scheme that guided the analysis.

4 Results

4.1 Peripheral positioning and the didactic contract

PSTs' reflections on the model GeoGebra-based lesson suggest that the instructional arrangement conveyed a didactic contract in which the teacher educator retained central control over the techno-didactic praxeology. While the lesson projected clarity and confidence in using GeoGebra, the distribution of roles and responsibilities appeared to reinforce asymmetrical participation. PSTs were primarily positioned as observers of the teacher's enactment of tasks, techniques, and implied justifications, with limited opportunities to engage directly in constructing or questioning the pedagogical approach being modeled.

This positioning was articulated by several PSTs who commented on their distance from the core instructional activity. One noted,

> We didn't use the GeoGebra ourselves. He [teacher educator] was the one doing the demonstrations.

This remark highlights more than the absence of hands-on experience—it points to a broader passivity in their role. Another student added, "Even when we had questions, we had to wait until the end of the demonstrations." As expressed in the focus group, the sequencing of the lesson may have limited spontaneous inquiry, subordinating students (PSTs) questions to the pre-set logic of the teacher's delivery.

PSTs further described a gap between physical presence and participatory engagement. As one PST observed,

> We were more like viewers… You could see what was happening, but you didn't feel part of it.

This sense of peripheral positioning was echoed in their accounts of group work and task design. Although the lesson included collaborative activities, these were often structured around the repetition of previously demonstrated content. As one PST commented,

> We were put in groups, but we didn't decide what to do. It was more like 'you discuss what he [teacher educator] showed already.

TABLE 2 Coding scheme for interview data analysis.

Code category	Description	Count	Example from transcript
Task (t)	Descriptions of the mathematical or didactic activity PSTs were expected to engage with.	12	"He gave us tasks on the worksheet to do collaboratively." "He [teacher educator] shared his worksheets with the students and made judicious use of them. Often, we see teachers enter the classroom with teaching and learning materials, only to finish the lesson without using some of them. But in this case, I could see he was making effective use of his teaching resources, such as the worksheet, throughout the lesson"
Technique (τ)	Specific strategies or actions taken to address a task.	25	"He used GeoGebra to show how the parabola changes when "a" increases." "The fact that he [teacher educator] is using the projector allows all students to see exactly what he [teacher educator] is doing or demonstrating. I think this is the best approach because it keeps everyone's attention on the board and ensures we are all working at the same pace. If students were using their laptops or PCs instead, attention to what he [teacher educator] is doing might drop. Some might start doing their things, others might focus partly on the lesson, and some might not follow what's happening at all. With the single projector demonstration, however, everyone can concentrate on the same task at the same time."
Technology (θ)	Justifications or rationales for techniques used, often pedagogical or epistemological.	17	"He [teacher educator] related it to basketball so we could see how graphs connect to real life." "I also learned that before you use any technology or modern technology in the classroom, you should be good at it before you go ahead to use it in the classroom, so that students can observe"
Theory (Θ)	Explicit or implicit references to broader conceptual frameworks legitimize practices.	12	"He [teacher educator] wanted us to discover the formula ourselves instead of giving it straight away." "Okay. In the last part of the video, I think he [teacher educator] was relating the concept of playing basketball to real-life situations. He was relating basketball to mathematics. You realize that the person was aiming to shoot at the basket, and that act can be drawn mathematically when we look at graphs. He was trying to relate graphs to real-life situations and the nature of graphs to real-life situations. That is what I can also say."
Participation	Descriptions of PSTs' roles, involvement, or perceived positioning within the lesson.	28	"We were just looking on… he [teacher educator] was doing everything." "I also observed that he [teacher educator] assigned tasks to the students, grouped them, and invited them to the board to demonstrate their answers. This approach fosters motivation and engagement, as students often explain concepts more effectively to their peers than to the teacher. Seeing everything together on the board helps the whole class, and it is beneficial for a teacher to involve students in demonstrating their knowledge in this way."
Agency	Indicators of PSTs initiating, adapting, or critically reflecting on didactic decisions.	7	"He [teacher educator] asked us to think of other names for the curve… so we could explore our ideas." "Okay, I said I realize that after teaching, he [teacher educator] asked learners what they learned, which is a nice tool for ending the lesson. To get a basic idea of what the learners have picked from the lesson. Also, I observed that when it was going around the end of the lesson, a few learners had laptops on their desks, which meant they would have had a chance to practice some of what was happening, which means that there was an effort for learners to have machines for the lesson. So I think next time the effort should be a little bit better. The lesson could have been held in the computer laboratory to help all learners access machines, which would have made the lesson a little bit better."
Constraint	References to limitations imposed by the instructional design, institutional norms, or tools.	11	"It was more teacher-centered… we didn't get to use the GeoGebra ourselves." "Mine has to do with how he taught the class. They always talk about these twenty-first-century skills. So he [teacher educator] is using GeoGebra to teach. With me, I thought it should be something that, though he [teacher educator] is competent, should also be in the form of him [teacher educator] helping us to operate or, let me say, work with the app or something like that. But what he was doing was the smallest, like just giving the content and some parts. It's all just like it was, mostly teacher-centered because he was doing everything, doing one thing or the other. And for the students to just say what they have seen. So, for me, the problem was that he was just focusing on the content. Let me say he was not considering how we would use the GeoGebra or something like that. We were just looking at him doing it, but it will be difficult when we get back to our hostels or various places. He was using it himself without guiding us on how to use it. That is my problem."

Rather than generating new directions or reasoning collectively, group activities were often experienced as extensions of the teacher's authority, reinforcing a fixed trajectory.

Similarly, the worksheet intended to scaffold engagement was experienced by some as overly directive. One PST remarked,

> Even the worksheet was more about following the observation than thinking. We just wrote what we observed; there was no room to try something and make a mistake.

In this case, the design of materials may have shaped PSTs' perceptions of the lesson's openness: the tasks and techniques were observable, but the underlying justifications and theoretical framing remained tacit and instructor-owned. This design suggests that the experience of 'learning to teach' was more about witnessing competence than practicing it.

Nevertheless, PSTs also expressed appreciation for certain aspects of the lesson. Some highlighted the coherence and fluency of the presentation. One participant remarked,

> The way he introduced the lesson was smooth and step-by-step, and everything was in order.

Another noted the use of context as a helpful anchor:

> He used the basketball scenario to illustrate the shape of the curve, which made it more relatable.

These comments indicate that the lesson was not uniformly exclusionary; it offered models of clarity and real-life relevance. However, as noted by another PST,

> It ended up showing how he [teacher educator] teaches with GeoGebra, not how we could teach with it.

This distinction implies that while the demonstration was instructive, it may not have supported PSTs in adapting or questioning the approach for their future practice.

Taken together, these reflections suggest that the model lesson offered a polished example of technology-mediated teaching, yet provided limited opportunities for interpretive engagement. According to the PSTs' accounts, the didactic contract privileged teacher control and coherence, but at the expense of shared inquiry and pedagogical reasoning. While some productive features were recognized—such as clarity, pacing, and contextual relevance—the overall configuration appeared to prioritize demonstration over dialogue, transmission over experimentation. PSTs' comments suggest that these dynamics shaped not only how they perceived their roles but also what they took away from the lesson as future mathematics educators.

4.2 Observation without practice: limits of imitative learning

The model lesson's emphasis on teacher-led demonstration appeared to limit PSTs' opportunities to move from observation to pedagogical enactment. Although the GeoGebra presentation was described as visually clear and logically sequenced, many PSTs expressed uncertainty about how they might reproduce or adapt the activity in their teaching. The lesson structure seemed to prioritize accurate replication over exploratory engagement, which may have made it difficult for students to internalize and transform the demonstrated techniques.

This tension surfaced most clearly in PSTs' reflections on their imagined teaching practice. As one PST put it,

> It's one thing seeing how it's done, but if I were to stand in front of a class, I'm not sure I could repeat it.

Rather than simply indicating nervousness, this comment suggests a recognition that witnessing a polished demonstration does not necessarily prepare one for the contingent realities of teaching.

Several participants also expressed a desire to manipulate the tool themselves. One noted,

> We only saw what happens when you change the values. But if I were to do it on my own, I wouldn't know where to start.

This lack of hands-on experience may have hindered their ability to grasp not only how GeoGebra works, but also why specific values were manipulated and what learning goals those changes were intended to support. The demonstration provided exposure to the software's functionality, but, according to participants, it offered limited opportunity to explore its pedagogical affordances.

Some PSTs began to articulate a more refined awareness of instructional sequencing as a pedagogical decision. One participant commented,

> He [teacher educator] showed how changing *"a"* changes the shape, and we could see that. However, we didn't discuss why we started with *"a" and not "b" or "c."*

This observation suggests an emerging attention to the logic of didactic progression—a recognition that the order of content presentation is purposeful and can shape mathematical understanding. However, as framed in this comment, that rationale remained implicit and was not discussed during the session.

PSTs also commented on how the apparent ease of the demonstration may have masked the underlying complexity of teaching with instructional technology.

> He [teacher educator] made it look easy, but if I had to explain it, I think I'd confuse the students.

While the comment acknowledges the teacher educator's fluency, it also signals concern about their preparedness to communicate the material. In this way, what was meant to model effective teaching may have unintentionally widened the perceived gap between observing a method and mastering its pedagogical application.

This concern was echoed in reflections on the limits of observation-based learning. One noted,

> Watching doesn't mean you can teach it. You need to try and fail first.

This comment underscores a widely held belief among participants that teaching competence is developed through active experimentation rather than passive observation. Another added,

> We could see the constructions, but we didn't talk about what students should learn from them.

These reflections suggest that while the session succeeded in demonstrating what GeoGebra could do, it left open questions about how to link those visualizations to student understanding.

Overall, participants' comments point to a perceived disconnect between viewing instructional techniques and developing the pedagogical capacity to adapt and implement them. Although the lesson illustrated a coherent use of technology, PSTs described the experience as lacking the space for trial, justification, and pedagogical reflection. According to their accounts, this limited their ability to move beyond replication toward more critical and responsive teaching with GeoGebra.

4.3 Constrained access to the logos

While the model lesson introduced PSTs to a sequence of mathematical tasks and visually compelling GeoGebra techniques, many participants expressed that the deeper pedagogical rationale underpinning these choices remained opaque. Although the session showcased the what and how of using technology in instruction, the why—that is, the justification for selecting specific tasks, sequencing parameters, or contextualizing concepts—was less

explicitly communicated. As a result, PSTs described difficulty in accessing the inner configurations of the lesson's design, particularly the logos (technology [in the ATD terms] and theory) dimensions of the techno-didactic praxeology.

This difficulty was reflected in how PSTs discussed sequencing decisions. One participant noted,

> He started with changing "*a*" and then later moved to "*c*" and "*b*", but we didn't discuss why it had to be in that order.

The observation signals an emerging awareness that didactic sequencing carries instructional consequences. While the progression appeared seamless, its underlying rationale—why certain variables were prioritized or introduced at particular moments was not made explicit. For some PSTs, this lack of explanation gave the impression of arbitrariness rather than intentional scaffolding.

Participants also commented on the use of real-life examples, which, while appreciated for their relevance, were described as underexplored in pedagogical terms. One PST recalled,

> He [teacher educator] used a basketball scenario to explain the curve, and that made it real, but we didn't talk about what kind of example it is supposed to help students understand.

This distinction between recognizing an illustrative analogy and understanding its didactic function points to a gap in accessing the theoretical reasoning behind the example. From the ATD perspective, the praxis (task and technique) was observable, but the logos—the rationale for choosing that specific representation—remained underdeveloped in the instructional discourse.

Similarly, the overall lesson structure appeared to limit opportunities for pedagogical interpretation. One participant remarked,

> We could follow the steps, but we didn't talk about why those steps were chosen or how they help students learn.

This comment highlights a recurring theme in the focus group: the perception that instructional decisions were presented as fixed rather than open to scrutiny and adaptation. While PSTs could replicate procedural elements, they were less sure about how to justify or modify them in different classroom contexts.

> Some reflections pointed to the absence of structured debriefing or pedagogical closure. As one PST described,

We concluded the lesson with a mathematics summary, but we didn't reflect on how the teaching was conducted.

While the mathematical content was revisited, the teaching process itself was not opened up for discussion. For this participant, the lack of reflection appeared to signal that the teacher's methods were not intended to be examined, thereby reinforcing a more passive approach to instructional knowledge.

At the same time, several PSTs expressed a clear interest in understanding the pedagogical intent behind the lesson's design. One student speculated,

> Maybe he [teacher educator] used real-life examples so that we could see how to link geometry to the world outside. But we didn't discuss why or how to choose those examples ourselves.

This comment suggests that some participants were actively trying to make sense of the didactic rationale, even in the absence of explicit guidance. The willingness to question the teacher's representational choices points to an incipient capacity for didactic reasoning.

Overall, the focus group reflections suggest that the model lesson succeeded in demonstrating content delivery and instructional technological fluency, but may have limited PSTs' access to the logos. Although several students attempted to infer the teacher's rationale, their comments imply that these inferences remained speculative. Without structured opportunities to unpack decisions, reflect on alternatives, or rehearse pedagogical choices themselves, PSTs described difficulty in moving from observation to appropriation. Their reflections highlight the importance of making justifications and theoretical considerations visible—not just the techniques themselves—if instructional models are to function as resources for professional growth.

4.4 Reflections on instructional configuration and participation

As PSTs revisited the model lesson in the focus group, their reflections extended beyond content and delivery to the broader instructional configuration—that is, the relational dynamics, communicative norms, and participatory structures embedded in the lesson design. While the model appeared organized and inclusive on the surface, participants began to question how interaction was framed, whose contributions were legitimized, and what forms of participation were enabled. Without being explicitly prompted to critique the structure, PSTs voiced a range of perspectives that suggest an emerging capacity to analyze the pedagogical architecture of the modeled practice.

Several participants commented on the nature of whole-class dialogue, raising concerns about the pedagogical implications of practices such as chorus responding. As one PST observed,

> He [teacher educator] was asking questions, but most of the time it ended up with everyone answering together, like a chorus answers.

While such moments might signal engagement, other participants questioned their effectiveness. One noted,

> Chorus answers make it seem like everyone understands, but maybe some people are just following along.

These reflections suggest a recognition that surface-level interactivity does not necessarily promote individual comprehension. In the ATD terms, such routines may reflect an implicit didactic contract in which pseudo-participation substitutes for deeper epistemic engagement.

The structure of group tasks was also a point of reflection. Although these were intended to promote active involvement, several PSTs expressed that they felt constrained in the amount of agency they could exercise. One participant recalled,

> Some groups just went to the board and repeated what he [teacher educator] had shown earlier. There wasn't enough space to try something different.

This statement suggests that the space allocated for student-led activity may have been too tightly framed to support exploration. While students were active in performing techniques, their ability to modify, justify, or reimagine those techniques appeared limited by the task structure and expectations.

At the same time, some PSTs identified productive dimensions within these constraints. One remarked,

> I think the grouping helped us explain the ideas to each other. Even if we didn't choose the task, we tried to break it down among ourselves.

This comment highlights a layer of peer-led interpretation that occurs within the boundaries of externally defined tasks. While the overall configuration limited decision-making, it may have created moments of collaborative sense-making, during which informal pedagogical reasoning began to emerge. Such exchanges could represent early traces of didactic agency, albeit constrained and situational.

Reflections on the teacher educator's classroom presence were also mixed. On the one hand, some participants valued the circulating support during group work. One PST noted,

> He went around the class to see what groups were doing, and sometimes gave feedback, which helped us correct our mistakes.

On the other hand, others questioned the distribution of this support. A different student commented,

> He would help some groups more than others, and some of us didn't get much guidance.

These contrasting views highlight the dual potential of teacher movement: it can serve as a scaffold for engagement, but may also reinforce uneven participation if not intentionally structured.

Taken together, these reflections suggest that the lesson's configuration offered limited but meaningful opportunities for PSTs to begin questioning the structures of teaching they experienced. Although their participation during the session was shaped by pre-defined roles and routines, the reflective space of the focus group appeared to prompt a shift from passive enactment to analytical interpretation. In recounting their experience, PSTs demonstrated an increasing awareness of how participation was structured, the various forms of engagement available, and the distribution of authority over instructional choices. This movement—from noticing constraints to questioning their design—may indicate the early formation of a more critical stance toward pedagogical practice.

4.5 Emergent agency and the reimagination of practice

Despite the structurally limited nature of the model lesson, several PSTs began to express tentative, retrospective insights that pointed toward alternative ways of engaging with instructional technology. These reflections did not stem from direct experimentation with GeoGebra or active co-construction during the session; instead, they emerged through a critical re-examination of their peripheral role and the lesson's instructional configuration. Although speculative and uneven, these moments suggested a shift in some PSTs' orientation—from passive recipients of demonstration to emerging designers and interpreters of didactic practice.

Some PSTs responded to the lesson's centralized structure by imagining more participatory alternatives. One student remarked,

> We could have been asked to create our examples using GeoGebra and explain why we chose them.

This suggestion, although hypothetical, implies a move toward instructional planning and justification. The participant not only imagines performing a task but also articulating the rationale behind it—an initial foray into the logos of practice. While this was not an opportunity afforded during the lesson itself, the reflection points to a developing awareness that teaching involves principled choices rather than merely replicating demonstrated content.

Another PST expressed interest in reconfiguring the sequencing and ownership of exploration:

> If I were teaching it, I would ask students to try the steps and make errors first, then explain with GeoGebra.

This vision disrupts the tightly controlled demonstration logic of the original lesson by foregrounding experimentation and student agency. The proposal implicitly values struggle and uncertainty as productive elements of learning—elements largely absent in the observed session. While this reconstruction remains untested, it may indicate that some PSTs are beginning to conceptualize teaching as an iterative process involving decision-making, feedback, and adaptation.

Similarly, the structure of group work was reimagined by another participant:

> We were grouped, but we were not working together. It would be better if each group had different tasks and then shared how they solved them.

This reflection introduces the idea of distributed praxeologies, where task variation could create space for interpretive dialogue across groups, rather than reproducing a single technique. Such a structure might allow for a multiplicity of approaches and justifications. The comment suggests a growing sensitivity to how participation can be configured to enable deeper engagement.

However, these imaginative proposals were also tempered by a recognition of contextual limitations. One PST reflected,

> Maybe if we had more time or smaller groups, we could try using GeoGebra ourselves. But in that setting, it was difficult.

The comment highlights the ecological constraints of the teacher education context, including large group sizes, limited time, and a performance-oriented lesson design. These structural factors appeared to delimit not only what was enacted but also what could realistically be envisioned. Even as some PSTs proposed richer instructional configurations, they remained aware that such innovations might require institutional support beyond individual initiative.

Notably, several reflections shifted from specific activity suggestions to considerations of meta-didactic structure. One PST suggested,

> After the lesson, there could have been a session to discuss the teaching, not just the mathematics, but also why things were done in that way.

This observation highlighted the absence of a reflective post-lesson dialogue as a missed opportunity to unpack instructional choices. It points to a desire for institutional routines that extend beyond task performance to include pedagogical reasoning and design justification. This form of reflection may indicate a preliminary engagement with the vertical dimension of praxeology—the transition from praxis to logos—as PSTs begin to view teaching not simply as a sequence of actions but as a space for intentional decision-making.

Taken together, these reflections do not signal mastery, but they may represent the early formation of pedagogical agency. While the lesson itself offered limited avenues for active participation or design input, the focus group became a space in which PSTs could begin to voice alternative visions, critique inherited structures, and consider the conditions necessary for more meaningful engagement. Their agency, in this sense, was not enacted within the lesson but was constructed in response to its limitations. These retrospective insights, though emerging under constraint, may reflect a growing disposition to treat teaching with instructional technology as a context-sensitive, reflexive, and design-oriented activity.

5 Discussions

5.1 Praxeological asymmetry and teacher-centered instructional technology use

The model lesson under study exemplifies a highly centralized didactic configuration, marked by what can be described as praxeological asymmetry: the teacher educator maintained exclusive control over the tasks, techniques, technology, and overarching theoretical discourses, while PSTs were relegated to a peripheral, observational role. Although the instructional performance was coherent and technically proficient, its structure foreclosed meaningful opportunities for PSTs to access, appropriate, or reconstruct the underlying rationale of teaching with instructional technology. In other words, the surface visibility of practice concealed its epistemic rationale—a condition emblematic of a rigid didactic contract that equates exposure with understanding (Bosch and Gascón, 2014; Chevallard, 1999). This pattern is symptomatic of broader tensions in teacher education, particularly in technologically mediated contexts where performativity often overrides participatory depth. While modeling remains a widely accepted pedagogical tool (Loughran, 2010), its value depends not on mere observation, but on the scaffolding that invites deconstruction and recontextualisation by learners (Korthagen, 2016; Korthagen et al., 2013; Loughran and Berry, 2005). In this case, modeling functioned less as a generative resource and more as a monologic performance, whereby GeoGebra became an instrument of display rather than a shared object of inquiry.

The framing of instructional technology further entrenched the asymmetry, positioning it as a domain of teacher expertise to be admired rather than interrogated. This result aligns with a "show-and-tell" model of technology integration, wherein digital tools are positioned as vehicles for demonstrating polished teaching rather than facilitating collective knowledge production (Pepin et al., 2017). Such arrangements risk reinforcing the teacher's authority while diminishing the potential for dialogic interaction, experimentation, and error conditions that are essential for cultivating pedagogical agency (Boaler, 2016; Borko et al., 2014). Importantly, this structure reveals not only a restricted pedagogical architecture but a missed opportunity to induct PSTs into the praxeological reasoning that makes instructional decisions meaningful and adaptable. The demonstration rendered the techniques visible but left the logos inaccessible, thus presenting teaching as a fixed performance rather than a contingent, situated activity requiring interpretation and justification. This epistemic closure resonates with Adler's (2017) critique of "surface participation" in teacher education, where PSTs appear engaged but remain excluded from the deeper work of instructional design and reflection.

Moreover, this teacher-centered use of technology obscures its potential as a mediating artifact for collaborative exploration. As Aldon et al. (2021) argue, digital tools like GeoGebra can serve as dynamic spaces for negotiating mathematical meaning, provided learners are allowed to engage actively, manipulate parameters, and make instructional choices. In the absence of such opportunities, PSTs are effectively positioned as spectators of teaching rather than emerging professionals developing their techno-didactic praxeologies.

5.2 Conditions for nurturing the PST agency

The emergence of agency among PSTs in this study was not a direct result of the model lesson itself, but rather a fragile and retrospective development that evolved through collective reflection. This belated appearance of agency, surfacing after, rather than during, instructional engagement, exposes a structural shortcoming in the lesson's design: the absence of authentic opportunities for participatory knowledge construction. As Borko et al. (2014) argue, the development of pedagogical agency hinges not on exposure to teaching performances but on structured enactment, iterative experimentation, and reflective articulation. Without these, agency becomes a discursive possibility rather than a situated competence. While some PSTs tentatively questioned the rationale behind sequencing choices, group dynamics, and the use of real-life contexts, these reflections emerged in a vacuum, unguided by dialogic interaction, formative feedback, or a clear meta-didactic frame. From the perspective of the ATD, this amounts to symbolic access to the logos of practice without the institutional or pedagogical conditions for its appropriation. Their speculative critiques, though promising, remained effectively and epistemically detached from the praxeology that was modeled. The didactic structure presented teaching as a polished product, rather

than a generative process open to contestation and co-construction (Bosch and Gascón, 2014; Gueudet et al., 2014).

Importantly, the model lesson's linear, teacher-centered format foreclosed the development of pedagogical reasoning—the capacity to make, justify, and revise instructional decisions (Loughran, 2010). The agency was thereby restricted not by a lack of individual initiative but by the absence of institutional spaces for PSTs to design, experiment, and fail meaningfully. The model lesson's structure reflected a unidirectional epistemic flow: from the teacher educator's demonstration to the PSTs' passive reception, with no space for iterative engagement or inquiry-based modification (Aldon et al., 2021; Kafyulilo et al., 2015). Contemporary research on digital pedagogy underscores that agency develops through recursive engagement with artifacts, peers, and pedagogical discourse (Damşa et al., 2021; Väätäjä and Ruokamo, 2021; Voogt et al., 2015). Iterative design cycles where PSTs test assumptions, receive feedback, and reconfigure their tasks are essential to developing not only technical fluency but also pedagogical adaptability. However, in the present study, the absence of hands-on manipulation of GeoGebra, coupled with highly structured group tasks focused on replication, limited the emergence of such reflective cycles.

Even when the teacher educator moved between groups, offering sporadic guidance, the interaction lacked systematic scaffolding. Some PSTs received support, while others were left without entry points for clarifying or extending their understanding. As Langer-Osuna et al. (2020) caution, informal circulation does not equate to dialogic engagement; it risks reinforcing hierarchies of epistemic access unless embedded within a pedagogical model that values open questioning, negotiated understanding, and the redistribution of authority. Moreover, the lesson failed to distinguish between surface participation and substantive engagement. While group work was formally integrated, the tasks were uniformly defined and centrally controlled, thus neutralizing opportunities for epistemic divergence. As Cong-Lem (2021) and Cochran-Smith et al. (2022) argue, authentic agency in teacher education requires not only involvement but autonomy, defined by the capacity to choose, justify, and adapt praxeological elements within meaningful boundaries of uncertainty.

5.3 Institutional and ecological constraints

While it is tempting to attribute the limitations observed in the model lesson solely to infrastructural constraints, such a diagnosis risks obscuring the more entrenched pedagogical and institutional forces at play. PSTs indeed referenced large class sizes, limited access to computers, and time pressures as impediments to hands-on engagement with instructional technology challenges widely acknowledged in the literature on sub-Saharan African teacher education (Abedi, 2024; Adarkwah, 2021; Fokuo et al., 2023; Mensah et al., 2024; Oubibi et al., 2024). These ecological constraints undeniably limit the feasibility of dialogic, student-centered approaches, especially in resource-scarce environments where instructional efficiency often takes precedence over pedagogical experimentation.

However, these material limitations cannot be disentangled from didactic routines and institutional logics that actively shape classroom interaction. As the findings reveal, decisions such as deferring questions, choreographing error-free demonstrations, or assigning replicative group tasks are not merely pragmatic responses to contextual difficulties—they are manifestations of deeper epistemological commitments. These include a preference for performative teaching over exploratory learning and an implicit adherence to transmission-based models of instruction (Adler, 2017; Stein et al., 2008). Such choices are often normalized within teacher education by a confluence of pressures: the demand to 'cover' curricular content, the valorisation of authoritative pedagogical performance, and the absence of institutional routines that legitimize critical reflection on teaching itself (Ball and Forzani, 2011; Loughran, 2010).

These choices suggest a broader institutional ecology in which knowledge is not only unevenly distributed but also hierarchically guarded. The asymmetries in the model lesson—where PSTs were positioned as observers rather than co-constructors—cannot be addressed solely by providing more devices or extending the time. Instead, they demand a fundamental reconfiguration of the didactic system: one that shifts from showcasing pedagogical perfection to embracing uncertainty, contestation, and co-inquiry. As Clarke and Hollingsworth (2002) argue, meaningful professional learning requires more than access to technological artifacts; it hinges on disrupting established norms of interaction and authority. Unless PSTs are systematically engaged in the design, justification, and evaluation of instructional practices—including those involving digital tools—they will remain peripheral figures in a system that ostensibly prepares them for central roles.

6 Limitations

This study provides valuable insights into how PSTs engage with instructional technology through model lessons; however, it is limited by several limitations that should be acknowledged. First, the study focused on a single model lesson within a single institutional setting, which limits the generalizability of the findings. While the aim was not to produce representative claims, the depth of analysis is necessarily context-specific. The extent to which the observed praxeological patterns and institutional constraints are transferable to other teacher education programs either within Ghana or in comparable sub-Saharan African contexts remains an open question.

Institutionally, large class sizes, hierarchical teacher–student relations and limited digital infrastructure shape the affordances of instructional technology in ways that may differ from contexts with smaller cohorts or more decentralized pedagogical cultures. Curricularly, tightly prescribed syllabi and high-stakes assessments can constrain exploratory uses of digital tools, contrasting with systems that operate under more flexible curricular frameworks. Culturally, norms of deference to authority may limit PSTs' willingness to challenge or adapt modeled techniques. Materially, the availability and reliability of tools such as GeoGebra depend on hardware provision and internet access, conditions that vary widely across teacher education environments.

Second, the study relied primarily on post-lesson focus group interviews without triangulating PSTs' reflections with evidence from their teaching practice. While these discussions yielded rich accounts of emerging orientations and critical awareness, they capture primarily practical—evaluative agency in a reflective mode rather than enacted agency in classroom action. This approach means the analysis reflects what PSTs imagine or desire, rather than what they are demonstrably able to perform in real teaching contexts.

Third, the data collection and analysis were framed through the ATD, which offered conceptual precision but may also have foregrounded certain dimensions (e.g., task—technique—technology—theory relationships) while underemphasizing others, such as emotional and relational aspects of teacher learning. This theoretical lens, while analytically robust, invites further supplementation from frameworks that attend more closely to identity, affect, or sociocultural positioning.

Finally, the structural constraints of the institutional setting, including time limitations, high student—teacher ratios, and restricted opportunities for PSTs to manipulate instructional technology themselves, shaped both the lesson dynamics and the nature of the data that could be collected. Nevertheless, certain aspects of the lesson design, such as collaborative problem-solving, scaffolded public demonstrations, and embedding mathematical tasks in meaningful contexts, represent enabling conditions that could be adapted to other teacher education environments. By making these contextual affordances and constraints explicit, the study strengthens its analytic generalization by clarifying which features of the Ghanaian case are context-specific and which offer transferable design principles.

7 Conclusion and implications

This study has illuminated the fragile but emergent forms of agency that pre-service mathematics teachers (PSTs) begin to develop when reflecting on their peripheral participation in a technology-mediated model lesson. Central to the analysis is the argument that PST agency is not a natural by-product of observation, but a necessary condition for the meaningful appropriation and enactment of techno-didactic praxeologies. Without opportunities to question, design, and experiment with instructional technology, PSTs remain epistemically marginal—capable of mimicking techniques but not of recontextualising or justifying them within authentic teaching scenarios.

7.1 Didactic implications

The findings underscore the need to rethink teacher education practices to move beyond performance-oriented demonstrations. Activities such as collaborative lesson design, iterative trials with digital tools like GeoGebra, and post-lesson pedagogical debriefs must become central rather than peripheral components of instructional design in teacher preparation programs. This shift requires not only access to technology, but a didactic reorganization that invites PSTs into the logos of practice—that is, the rational and theoretical underpinnings of teaching decisions. Only through structured engagement with tasks, techniques, technology, and theories can PSTs develop the capacity to adapt and evolve their techno-didactic praxeologies.

7.2 Policy implications

At the policy level, investment in digital infrastructure must be matched by investment in pedagogical innovation. It is insufficient to equip teacher education institutions with devices and software if the instructional practices remain wedded to hierarchical, transmission-based models. Policies must prioritize capacity building that fosters teacher educator competence in facilitating co-constructive learning environments, where PSTs are not merely recipients of expertise but participants in didactic inquiry. This approach involves reconfiguring curricula, professional development, and assessment standards to recognize collaborative meaning-making and reflective experimentation as essential indicators of professional growth.

7.3 Future research

Future studies should examine how structured interventions such as guided lesson design with iterative peer feedback and scaffolded GeoGebra integration can cultivate PST agency over time. Longitudinal research could trace how repeated cycles of co-design, enactment, and reflection affect PSTs' ability to justify, adapt, and critique technology-integrated instruction. Moreover, cross-contextual research is necessary to investigate how institutional ecologies either support or hinder such interventions, particularly in low-resource settings where ecological and didactic barriers intersect in complex ways.

Ultimately, this study contributes to a growing body of literature that recognizes teacher learning as a socially situated, epistemically mediated, and politically entangled process. Supporting PSTs in becoming designers, not just imitators of techno-didactic practice, is not a peripheral concern; it is a central imperative for equitable and future-oriented mathematics education.

Data availability statement

Due to ethical considerations and confidentiality agreements, the original data cannot be shared. However, anonymised transcripts may be made available upon reasonable request.

Ethics statement

The studies involving humans were approved by Institutional Review Board for the Council for Scientific and Industrial Research in Ghana with reference number CSIR025/2023. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed

consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

FSM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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