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Technology Use for Teacher Professional Development in Low- and Middle-Income Countries: A systematic review

Sara Hennessy [a,*], Sophia D'Angelo [b], Nora McIntyre [a,#], Saalim Koomar [c], Adam Kreimeia [d], Lydia Cao [b], Meaghan Brugha [c], Asma Zubairi [d]

[a] EdTech Hub and Faculty of Education, University of Cambridge, 184 Hills Road, Cambridge CB2 8PQ, UK
[b] EdTech Hub and Open Development & Education (ODE), 3 York Terrace, Cambridge, CB1 2PR, UK
[c] EdTech Hub and Jigsaw Consult, Work.Life Hammersmith, Kings House, 174 Hammersmith Road, London W6 7JP, UK
[d] Overseas Development Institute (ODI), 203 Blackfriars Rd, London, SE1 8NJ, UK

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ABSTRACT

Pre-service education and in-service teacher professional development (collectively termed teacher professional development or TPD here) can play a pivotal role in raising teaching quality and, therefore, learning outcomes for children and young people in low- and middle-income countries (LMICs). However, TPD opportunities in LMICs are limited, unsustained, and often not informed by recent research evidence, and outcomes are mixed. Educational technologies offer potential to enhance formally provided programmes and informal peer-learning forms of TPD. We present the first systematic review of the literature pertaining to technology-mediated TPD for educators of school-aged learners in LMICs, aiming to characterise appropriate and effective uses of technology along with specific constraints operating in those contexts.

An in-depth synthesis of 170 studies was undertaken, considering macro-, meso- and micro-level factors during TPD design and implementation in the 40 LMICs represented. Volume of publications increased dramatically over the review period (2008–2020), indicating that the field is rapidly developing. Results largely showed benefits for teachers, but evidence for sustainability, cost-effectiveness or tangible impacts on classroom practice and student outcomes was thin. Promising, locally-contextualised forms of technology-mediated TPD included virtual coaching, social messaging, blended learning, video-stimulated reflection, and use of subject-specific software/applications. We report on the variable effectiveness of programmes and limited attention to marginalised groups. To maximise effectiveness of technology-enhanced TPD, the role of facilitators or expert peers is paramount – yet often glossed over – and the interpersonal dimension of teacher learning must be maintained. Recommendations are made for researchers, policymakers, teachers and teacher educators.

1. Introduction

Learning outcomes for children and young people in low- and middle-income countries (LMICs)[1] are well below expected levels [251]. UNESCO Institute for Statistics (UIS) estimates that more than 380 million children worldwide (56% on average and 85% in sub-Saharan Africa [SSA]) will finish primary school without being able to read or do basic mathematics [221]. Myriad reasons underlie low educational attainment, including the quality of teaching, but the all-too-prevalent deficit model is inappropriate [178,212].

Pre-service education and in-service teacher professional development (TPD) can be pivotal in supporting teachers to be effective educators [50,178]. Teacher education interventions are associated with positive effects on primary school learning outcomes in LMICs [6,51, 129]. However, teachers in LMICs often lack access to in-service TPD opportunities and, as in high-income countries (HICs), there has been

Abbreviations: DBR, design-based research; EiE, education in emergencies; HIC, high-income country; LMICs, low- and middle-income countries; LIC, low-income country; MIC, middle-income country; MOOC, Massive Open Online Course; OER, open educational resource; SSA, sub-Saharan Africa; TPD, (pre-service and in-service) teacher professional development; VLE, virtual learning environment.

* Corresponding author: Faculty of Education, University of Cambridge, 184 Hills Road, Cambridge CB2 8PQ, UK
E-mail address: sch30@cam.ac.uk (S. Hennessy).
Present address: Southampton Education School, University of Southampton, University Road, Southampton SO17 1BJ

[1] LMICs are defined as those listed in the World Bank's country inventory.

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considerable variation in the efficacy of programmes for both teacher and student learning [127,201,251].

Increasing the use of technology across education systems offers potential benefits for mediating TPD. Educational technology (EdTech)[2] can facilitate the effective delivery of TPD, especially in remote areas and for teacher peer support, one-to-one coaching and reflection – through exploiting affordances[3] such as two-way communication, audiovisual media capability and ease of access to mobile devices.[4] Technology integration brings additional needs to upskill teachers. For example, learning gains from personalised, adaptive technology use are greater when an experienced teacher is available to offer contextualised input and feedback [121]. A systematic review of research on EdTech to support learners with disabilities in LMICs likewise emphasises the pressing need for TPD [116]. However, EdTech interventions that focus only on hardware/software are ineffective compared with those coupled with other measures to promote pedagogic change or teacher development [6,51,129,252]. Lack of appropriate, sustained support for teachers to develop confidence in using digital technology before classroom implementation is a major obstacle to effective technology use in the classroom [10,36] and to widespread rollout of technology-supported initiatives in schools [229]. The Covid-19 pandemic and widespread school closures have rapidly escalated the need to offer teachers various support options for using technology for remote teaching and learning, including digital pedagogical strategies and mental wellness support [33]. However, teachers in LMICs have been consistently asked to communicate with – and offer instruction to – learners during the ongoing pandemic without the appropriate training [234].

Professional learning mediated through technology use can potentially contribute to improving teaching quality and student learning outcomes. In this review, we critically appraise the evidence in the field, using a broad definition of the shorthand term 'TPD' to encompass all forms of pre- and in-service teacher development that support teaching and student learning and on-/off-site provision including formal programmes, mentoring and coaching as well as informal teacher learning, for instance through online peer communities of practice. We conducted a comprehensive review of the literature published between 2008–2020 pertaining to EdTech as a means of delivering initial teacher education or professional development ('Tech for TPD') in LMICs. This included improving subject knowledge and/or classroom pedagogy.

Over the past decade the number of publications on EdTech for TPD in LMICs has increased significantly (see Figure 4 and publications such as [4,178]). However, there are few evidence reviews within the field, and those few are often limited in their scope, for instance through focusing on a specific TPD modality (e.g., MOOCs: [76]; or mobile instant messaging: [211]), on region (e.g., [228]) or on target skill (e.g. teachers' critical thinking: [204]) or group (e.g. learners with disabilities: [116]). Most reviews related to EdTech for TPD do not focus on LMICs nor even include many LMICs in the mix with HICs; in some, no studies from Latin America or Africa are represented [41].

This is the first systematic review of the literature across the field of technology-mediated TPD in LMICs. It makes significant contributions by:

- taking stock of the research field and consider its key themes, messages, strengths, weaknesses and gaps.
- identifying promising uses of technology in TPD in LMICs; formats and outcomes of TPD initiatives, including design principles for scalable and sustainable design; and the enabling and constraining factors that impact on effectiveness.
- offering rigorous evidence to inform future programming and research concerning new professional learning initiatives.

The prior research and the focus of the review are outlined in Section 2. The methodology of this review is elaborated in Section 3 and an overview of the demographic characteristics and research designs in the 170 publications appears in Section 4. The findings (Section 5) report the development and efficacy of technology for TPD models across diverse cultures and contexts. The article concludes by offering practical recommendations to policy makers, researchers, teachers and teacher educators (Section 6).

A further, unique contribution to the field is the full resulting database with detailed thematic coding and quality assessment which is made openly available (Supplementary material) for researchers and other stakeholders.

2. Conceptual framework

2.1. Characteristics of effective TPD in LMICs

There is a strong consensus across the field concerning the characteristics of effective contemporary models of TPD (listed in Table 1). However, impact tends to focus on teaching practices rather than student outcomes, where causality is hard to determine (as Schwille and Dembele [193] highlight). Moreover, the impact of specific factors

Table 1
Key characteristics of effective TPD

Characteristic	Article sources
Programme content and relevance to teachers' needs	
Informed by research evidence concerning effective pedagogy	[75,164]
Builds on teachers' existing knowledge, expertise and practices	[35,215]
Integrates subject knowledge and pedagogy	[54,163]
Participatory and addresses teachers' needs, constraints, interests and agendas	[5,178];
Engages with difference and ensures linguistic, socio-cultural and other context-specificity	[220,233]
Recognises that students have diverse learning needs	[94,226]
Mode of delivery and support mechanisms	
Focuses on imminent practical application, supporting iterative cycles of trial and refinement of new approaches through reflective inquiry and rehearsal within a safe environment	[37,176]
Programme design models the pedagogic approaches being promoted, taking a learner-centred approach	[73,155]
Emphasises peer dialogue and collaboration within a community of practice (including coaching)	[94,235]
Opportunities for discussion and critique of alternative approaches	[125,241]
School-based and teacher-led	[5,32]
Institutional and external support for participation	
Alignment with national policy, curriculum standards and assessment frameworks	[106,228]
Alignment with institutional strategic goals and support from school leaders, striving for school-wide participation and impact	[107,127]
A conducive culture for professional learning, reflection and feedback based on trust and support	[108]
Dedicated time for professional development and collaborative inquiry	[39,184]
Programmes are sustained over time through regular sessions and ongoing scaffolding	[201,219][5]

[5] This source synthesised findings from Cordingley et al., [31], Hall [62], McCormick et al., [128], Murchan et al., [148], Ofsted [156], Opfer et al., [161], Pedder et al., [170], and Williamson & Morgan [244].

[2] 'EdTech' is defined as technologies – including hardware, software and digital content – that are either designed or appropriated for educational purposes. We deliberately use a broad definition of EdTech that includes any use of information and communications technologies (ICT) at any point within the education system – in ministries, schools, communities and homes, including between individuals and for self-study. Most EdTech relates to digital technologies but low-tech devices like non-digital radio and television are included as potentially appropriate for the most marginalised groups such as those in remote rural areas [53].

[3] In this article we conceptualise affordances as the perceived, i.e., fluid rather than fixed, properties of a technology that can be exploited for a specific purpose in a specific context [55].

[4] See blog by Patil & Kaye (2021).

cannot easily be distinguished and evidence for some characteristics in LMICs is weak [90,201], with much of the research coming from HICs. Nevertheless, the evidence base on these characteristics is growing in LMICs.

While these same principles seem to apply across geographies (e.g., [63,143]), they require certain considerations and adaptations to attend to the diverse socio-cultural and economic contexts of LMICs. A scarcity of teaching and learning resources, limited technology infrastructure (especially internet and electricity connections), and limited funding for TPD are common examples (see Section 2.3). A further consideration arises concerning the intended outcomes of TPD programmes. Teachers in LMICs often experience inadequate, theory-heavy pre-service education, and, as a result, can have low levels of pedagogical or subject content knowledge (Westbrook et al., 2014). While TPD programmes focusing exclusively on subject content knowledge tend to have less effect on student learning [90], pedagogically-focused TPD benefits from practical application to specific subjects, especially at secondary level. In-service provision is not always linked to classroom applications though, nor sustained over time ([90,163];). These constraints become exacerbated in remote regions or areas of extreme poverty, where there is often an absence of both equitable opportunities for TPD and incentives to participate in those that do exist [178].

Further tensions concern the most valuable kinds and levels of TPD support for teachers in LMICs, including facilitation by advanced teacher peers or external experts/coaches. The value of leveraging external expertise in exposing teachers to new ideas is recognised, enabling groups to avoid becoming overly inward-looking [32] and challenging local norms and shared values [180]. We argue, though, that it is important to construe *all* teachers as professionals capable of reflecting on, critiquing and developing their own practice and recognising their own agency to effect change. This includes adapting and testing new approaches in their own contexts to solve local problems [108,192], and identifying and addressing gaps in their own knowledge and skills [64]. That said, teachers are a heterogeneous group. They vary in their confidence, knowledge and skill levels, along with their workloads and time available for engaging in professional learning and reflection. Thus, some may require more support and perhaps more structured resources than others; whether less structured approaches can scale up is an open question to be addressed. This thorny issue of how to offer effective TPD at scale while maintaining sensitivity to the local context is explored in the next section.

2.2. Coherent TPD systems

The characteristics discussed above are derived from research but their adoption does not always guarantee positive outcomes. Indeed, top-down, 'one-size-fits-all' or 'best practice' programmes without built-in opportunities for local contextualisation are problematic (e.g., [215]). Thus, the core characteristics outlined above must not be considered prescriptive, nor universal, but rather adaptive and flexible. Context-specificity is *the* paramount characteristic that determines the possibility to engage with and adopt the other important facets we know bring about effective professional learning and its classroom application.

Approaching TPD holistically, from a 'systems' perspective, helps us understand the people and processes that both influence and are influenced by the system. A review by Opfer & Pedder [162] proposed three overlapping systems involved in professional learning. First, the authors describe the **individual teacher** as a system that encompasses their prior experiences, worldviews, beliefs, attitudes and (pedagogical and content) knowledge. Second, the **school-level system** includes a collective culture of beliefs, norms and practices. The third system of activities within the TPD design consists of the **activities and materials** used, and the frequency with which they are employed. This multilevel lens shows the considerations needed to establish a coherent TPD system. Missing from Opfer & Pedder's [162] review, however, is a discussion of the role of technology use in TPD. Nor do the authors discuss how macroscopic systems (e.g., political environments and infrastructure) influence the teacher, school and TPD activities.

The concept of "coherence" in TPD [112], furthers Opfer & Pedder's [162] systems narrative. Coherence manifests threefold:

1) external coherence at both the national (macro-) level (e.g., with policy, curriculum standards and evaluation systems) and local (meso-) level (e.g., with school leadership and resources);
2) internal coherence (e.g., between activities within the TPD programmes);
3) coherence creation – the development of goals that are either predetermined or negotiated together with individual teachers (micro-level).

At the micro level, Lindvall and Ryve suggest that only through "coherence creation" are teachers given the requisite agency in making decisions regarding their professional development. Again, though, they do not address the role of technology.

Teachers know their own contexts, learners and needs best. Needs assessments and participatory approaches to TPD are likely to be fruitful in delivering strong outcomes, especially in the challenging and diverse contexts of teaching in LMICs (e.g. Anamuah-Mensah et al., 2013). However, teachers' voices are often neglected in the design of – and decision-making around – TPD programmes. Related system-level barriers to effective TPD include a potential misalignment among government policy statements, institutional cultures and individual professional responsibility, and varying degrees of autonomy within a school or for schools themselves [219]. In some schools, teachers may be restricted to delivering lessons and initiatives planned by their school or district, constraining the testing and development of new pedagogical approaches that TPD aims to foster.

Participatory approaches to TPD include culturally relevant, linguistically accessible and suitably pitched content and they involve teachers in decisions around what student-centred practice might look like within their context [21,73]. In essence, TPD must be designed *with* teachers, not *for* them because the structures and cultures within which teachers work inevitably shape their everyday practices ([18], p. 39). Thus, co-design is construed as a significant element of a well-functioning education system, where teachers' voices are heard and listened to at the school and wider policy levels (e.g., [82]). This helps create a reciprocal transfer of knowledge, experience and learning. However, in both LMICs and HICs, teaching is a low-status profession [42,188] and teachers lack opportunities to actively participate in shaping decisions that affect them.

We have blended concepts from Lindvall and Ryve, and Opfer and Pedder – and included a technological lens – for this review Figure 1. illustrates the importance of considering TPD programmes as existing within a broader system and shows how micro-level factors such as teachers' individual beliefs or backgrounds fit into a wider school or community culture (meso-level). This can then generate a broader workforce culture in which teachers are situated (macro-level).

This section has suggested how coherence between the different levels of educational systems can produce effective, scalable and equitable TPD. If these levels are all considered, the specific contexts in which key educational stakeholders operate should complement – rather than constrain – one another. The present review emphasises consideration of how the different notions of coherence affect the position of teachers within tech-supported TPD initiatives in LMICs and what this implies for associated learning outcomes for both teachers and students.

2.3. The role of technology in the TPD system

Technology has been integrated into TPD models for over two decades (see historical overview of publications in Appendix A). A number of publications explored the role of technology within TPD, including in

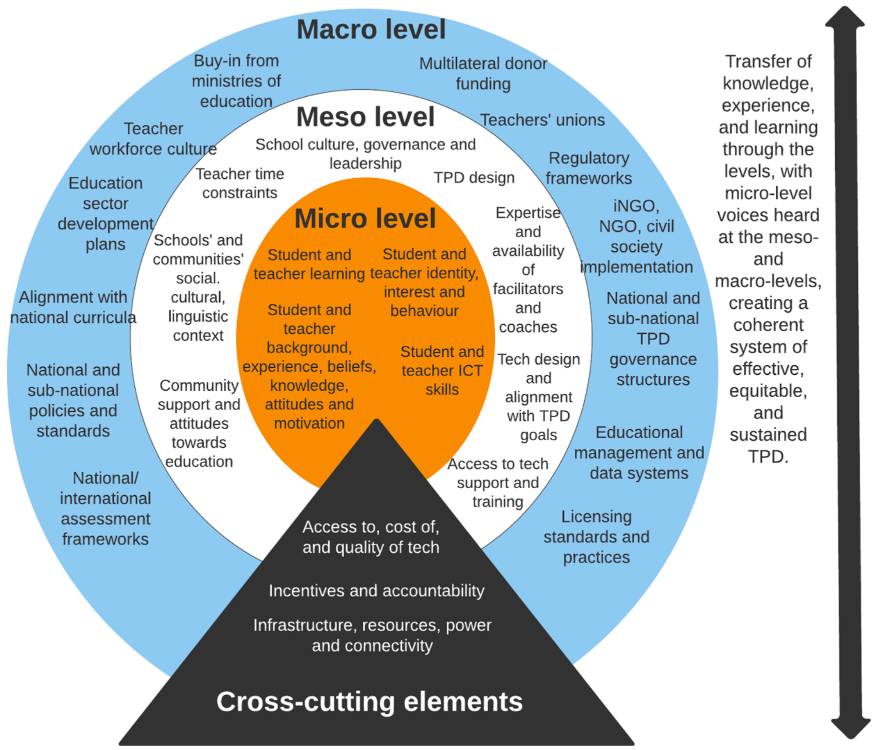

Figure 1. A coherent tech-supported TPD system

LMICs, in the early 2000s (e.g [53,94,228].). These incorporated many of the important characteristics, principles and considerations noted in Section 2.1 that remain pertinent for contemporary education planning and practice. For instance, a 2015 World Bank [250] guide focused on the use of computers, internet, broadcast media (radio and television), video and online distance learning [53]. While new technologies such as tablets and smartphones have risen rapidly in prominence, the field of technology-mediated TPD has lagged behind. This prompts further questions and highlights the importance of identifying and addressing barriers to adopting effective approaches and advancing innovation in the field.

A noticeable – and expected – trend across publications over the past two decades has been a shift from theoretical and conceptual guides and frameworks, to research addressing specific, persistent issues and identifying effective practices drawing on evidence from TPD initiatives [106,127,216,235]. For instance, a distinction between publications focusing on LMICs from the early 2000s and late 2010s is the relative emphasis placed on the technology itself versus human factors involved in TPD. Later research focuses more on understanding teachers as individuals, listening to their needs, promoting professional autonomy and enabling collaboration. This demonstrates that there have been significant – yet often subtle – changes over time in understanding how technology can effectively support TPD in LMICs. This highlights the need for analysis on the extent to which these changes are being implemented in practice.

The field studies, like much research in EdTech generally, often take an uncritical, aspirational approach to the use of technology [194]. Many gloss over the actual added value of technology, or its cost and reliability implications compared to non-digital modes [74]. These considerations are vital, since LMICs have limited technological infrastructure; computers in particular are expensive and school systems often struggle to integrate the technology into teaching and learning [252]. TPD programmes reliant on technology availability will likely cost more than in HICs [68,122]. Costs of software/digital content may be prohibitive unless these are openly available [183]. Low-tech devices and resources that run on low bandwidths or do not rely on continuous power supply may be more reliable and cost-effective [27]. Low-cost technology such as broadcast media reaches mass audiences in remote areas[5] (e.g. the Rising on Air programme: [104]), however it can be less interactive than high-tech options.

Many digital divides exist between (and within) LMICs and HICs; for instance, limited access to technology results in lower levels of digital skills in teachers [115,225]. The time needed for teachers to familiarise themselves with new technologies is thus greater. Basic mobile phones, TV and radio (or 'lower tech' modalities), which tend to be more ubiquitous in LMICs than 'higher tech' modalities – such as tablets and smartphones – may therefore be desirable, albeit under-exploited, options. For example, access to mobile devices among adults has reached 100% in some African countries (e.g., South Africa, Namibia and Zimbabwe), although a rural-urban divide persists in most, and women and girls often have less access than men [105]. Nevertheless, even when teachers have access to mobile technologies, they may be reluctant to use them for professional purposes, for reasons including having access only to a shared device and the high costs of data [120,134].[6]

EdTech has a potential role to play in LMICs when addressing needs of marginalised communities. Laurillard et al. [105] argue that online learning at scale can address the issue of equity in teacher education. Female higher education teachers in Pakistan, for instance, reported that digital platforms gave them a voice whereas negative gender attitudes prevented them from engaging in face-to-face discussion with peers [93]. TPD can also be used to improve teachers' ability to exploit technology in adapting to diverse learners' needs, tackling prevalent barriers to access to education for marginalised children and young people. There is promising evidence concerning remote or online learning in fragile and/or conflict-affected settings supporting learning

[5] Some radio shows or TV broadcasts, for example, may allow students or teachers to call in for individualised support or instruction.

[6] Data costs in many LMICs, especially in SSA, are much higher than in the UK and Western Europe, for instance, see: https://www.cable.co.uk/mobiles/worldwide-data-pricing/.

of both displaced teachers and students [106,214]. However, caution is needed since research indicates that many kinds of technologies are disproportionately used by the most privileged learners *within* each LMIC [25,113,195].[7] Differential access to all technologies along geographical (urban/rural, district/national/regional) divides is well documented and was exacerbated during the Covid-19 pandemic [44, 234]. In addition, the digital gender divide may affect female teachers' attitudes towards, and use of, digital technologies [230]. Millions of teachers, like learners, are further disadvantaged by the fact that most software and online content is only available in English and Chinese and not culturally appropriate in many contexts [183].

New challenges arise with the use of technology for TPD in LMICs, beyond the obvious technical demands. At the micro- or individual actor-level (as per Figure 1), teachers' beliefs about the nature of learning determine whether or not they will use technology to implement learner-centred pedagogies [47]. Teachers' attitudes toward technology have also very commonly been found to influence their use of EdTech in the classroom (e.g., [14,134,217]). At the meso or school/teacher college level, institutional culture influences the degree to which technology is adapted and implemented [95], and institutional leaders play a significant role in this culture setting [127]. At the macro or district/national level, the degree to which micro- and meso-level data are collected and used effectively can inform sustained effectiveness of programmes [34]. The interaction between different levels of context must be coordinated in order to enable the coherent system required for successful implementation.

2.4. Focus of the review

The conceptual framework and gaps in the literature outlined above led us to the following overarching research question (RQ) for the review:

How can the use of technology support TPD in LMICs, including improving subject knowledge and/or classroom pedagogy? ('Tech for TPD')

Sub-questions are depicted in Table 2. First, we addressed a set of descriptive questions in order to (quantitatively) summarise the main characteristics of the studies reviewed (RQ1). Then we addressed the main RQ through an in-depth narrative synthesis. The scope included the modes and outcomes of (in)effective programmes (RQ2). The team conducting this review is part of EdTech Hub, whose mission addresses the pressing need to build robust evidence concerning EdTech interventions that improve learning outcomes for the most marginalised learners in LMICs. Hence RQ3 was framed to focus on equity. Finally, local contextualisation, sustainability, scalability and cost-effectiveness (RQ4) are all crucial considerations in any form of teacher learning or technology use, especially in LMICs [74].

Table 2
Research questions of this study

#	Research Question and sub-questions
RQ1	**What are the key characteristics of the emerging 'tech for TPD' studies in LMICs?** When and where (country/region) was the research published? Which technology devices and resources were used? Who designed the TPD programmes? Were designs participatory? What was the scope of the samples researched? Which teacher populations did the TPD initiatives reach? What education levels and subjects did they teach? Which outcomes have been promoted?
RQ2	**Which forms of technology-mediated TPD are effective for teacher learning?** Which modalities and uses of technology are effective in promoting teacher learning? How can technology support coaches/facilitators or virtual coaching of teachers? How can technology support peer communities of practice? How can technology support teacher reflection? How can technology be used to improve subject knowledge and subject pedagogy? Can technology support the development of new resources in low-resourced contexts? If so, how? How can technology be used to offer flexible learning environments with the appropriate support and levels of structure to meet teachers' needs?
RQ3	**Do any technology-mediated TPD initiatives help foster more equitable education systems?** If so, how do they help reach teachers in remote/rural contexts? How do they support teachers' development in the language of instruction? In what ways do they support marginalised teachers (e.g., refugee teachers, teachers with disabilities, etc.)? How do they support teachers in addressing the needs of marginalised learners?
RQ4	**In what ways are TPD initiatives systemic in their approach, considering macro-, meso-, micro- and cross-cutting factors during design and implementation?** Are technology-mediated TPD initiatives targeted to teachers' needs and locally and culturally contextualised? Which multilevel factors are pertinent? Is there evidence for which modalities and uses are cost-effective in LMICs? Which technology-mediated TPD initiatives are sustainable and scalable?

3. Method

An initial *systematic mapping review* [96] provided a holistic overview of the whole research field: use of EdTech related to teacher learning in LMICs (including teacher learning about technology that supports both student learning and teaching, planning and assessment practices, as well as technology for mediating TPD itself). The quantitative outcomes from that review are presented in a separate technical report [71]. The mapping review informed the decision to subsequently focus on the most prominent theme emerging: EdTech use as a medium for TPD. We conducted an in-depth *systematic review* of this literature and that is the focus of this article. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology [139] employed involved two rounds of screening against inclusion criteria followed by in-depth thematic coding and data extraction. We then appraised the quality and synthesised the findings from the research evidence. This prioritised the higher quality research studies. The overall review process of eight steps, from defining the review scope to selecting the final papers for analysis, is illustrated in Figure 2.

Three elements of the methodology – screening, thematic coding and quality scoring – were carried out by 3–5 researchers, each handling a subset of the data. The fourth element – data extraction – was conducted by a single team member. In each case, an extensive training and calibration period (lasting several weeks) preceded data processing. Researchers familiarised themselves with the relevant scheme (inclusion/exclusion criteria in screening, coding scheme, quality scoring framework, data extraction variables) and contributed to its development through pilot testing and discussion. In this stage, blind parallel processing of the same papers by team members facilitated close alignment between them and iteratively eliminated any ambiguities within the schemes. During this stage and subsequently, all questionable cases were resolved through discussion among the team and consultation of the lead author where appropriate. Ongoing calibration between team members was ensured through regular spot checks involving blind screening, coding or scoring of the same records, before moving on to the next round of the process. Finally, four researchers shared leadership of the narrative synthesis, each focusing on one of the main themes emerging (Section 5).

[7] Increasingly stratified education systems mean that both learners and teachers in elite private/international schools are differentially able to take advantage of resources, including access to technology.

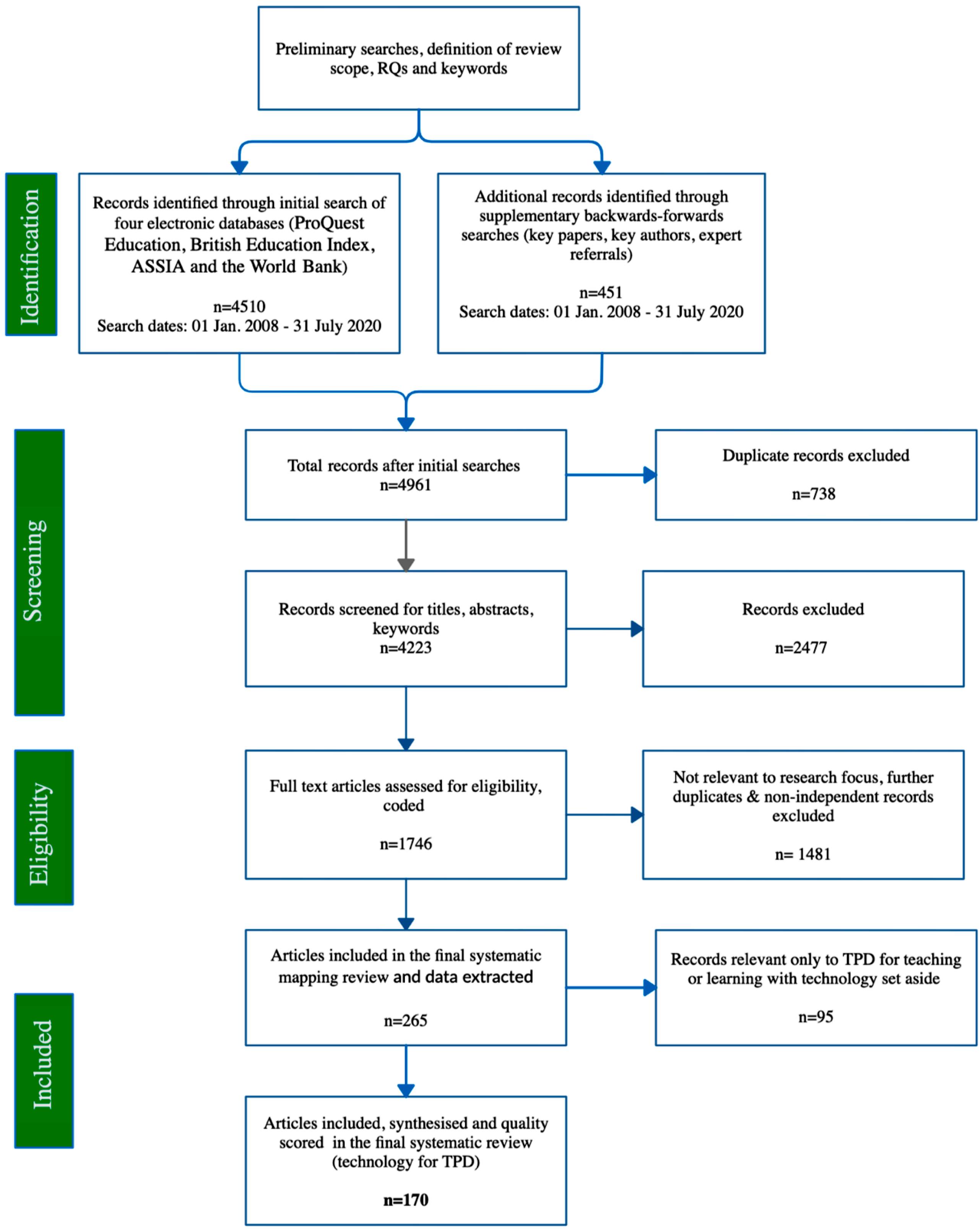

Figure 2. PRISMA diagram

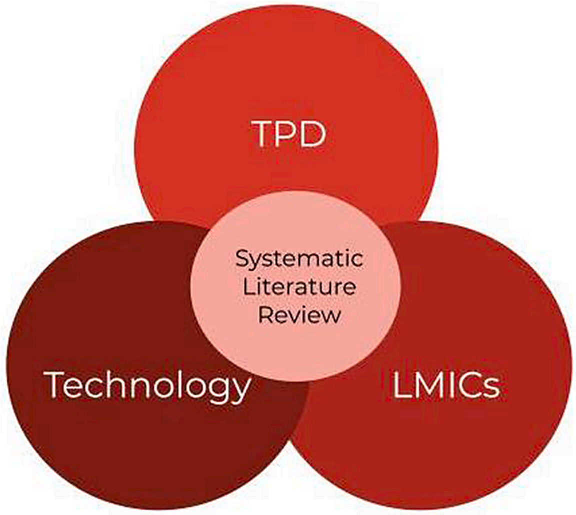

Figure 3. Intersecting target search areas

Table 3
Search terms used in the review

Theme no.	Theme name	Search terms[17]
1	LMIC	LMIC OR low middle income countr* OR sub*saharan africa OR latin america OR [Actual LMICs fully listed]
2	TPD	teacher development OR teacher training OR teacher education OR teacher learning OR teacher professional learning OR [teacher OR educator OR classroom practitioner OR school OR instructor] AND [professional development OR in*service training OR pre*service training OR in*service education OR pre*service education OR coach* OR mentor*]
3	Tech	technolog* OR digital OR device OR software OR hardware OR phone OR ICT OR comput* OR video OR radio OR TV OR televis* OR laptop OR tablet OR learner management system OR LMS OR virtual learning environment OR VLE OR e*learning OR blended learning OR online learning OR mobile learning OR social network* OR messenger OR messag* OR SMS OR MOOC OR social media OR professional learning network OR remote learning OR distance learning

[17] The use of an asterisk (*) denotes a wild character used to locate all singular/plural forms of a term.

3.1. Literature search

3.1.1. Search strategy

The focus of our search was the intersection of the three fields (depicted in Figure 3). A provisional a priori set of associated key terms was generated by the team based on knowledge and perusal of titles, abstracts and keywords of key literature in the field; it was trialled and iteratively refined through a series of preliminary searches using ProQuest.

The resulting terms for the primary search are listed in Table 3. These were applied to locate academic and grey literature from four electronic databases: ProQuest Education, British Education Index, Applied Social Sciences Index & Abstracts (ASSIA) and the World Bank. Supplementary searches comprised backward-forward searching (using Google Scholar, based on seeking papers by 8 key authors in the field) and a snowballing technique to identify references from seminal literature reviews in the field. These searches collectively yielded 204 papers, of which 10 were independent, met the inclusion criteria and were included in the wider systematic mapping review. Of these, 9 focused on 'tech for TPD 'and thus were ultimately included in the systematic literature review reported in this article. We also contacted 11 experts in the field, largely nominated by the first author, and 7 responded with a total of 75 recommended sources, of which 15 were independent, met the inclusion criteria and were included in the mapping review. Of these, 13 were ultimately relevant for the systematic review. (Note: both the expert referrals and the supplementary searches included many relevant papers that duplicated the initial search outcomes and were therefore discounted).

3.1.2. Eligibility screening

In correspondence with this review's focus, our eligibility criteria comprised three thematic foci.

- Theme 1: Studies were included if they collected data from at least one low- and/or middle-income country listed in the World Bank's [252] country inventory. The search thereby spanned a range of 136 countries in SSA, South Asia, Latin America and the Caribbean, Middle East and North Africa, East Asia and the Pacific, Europe and Central Asia (listed in Appendix B).
- Theme 2: Studies were included if they investigated teacher learning – i.e., teacher education, teacher professional development, mentoring or coaching, or peer learning initiatives – linked to technology use. This included situational and contextual factors influencing teacher learning through or for using technology, skills and substantive knowledge, and technology to motivate teachers in their own learning. Excluded were studies that only reported (without any link to some form of teacher education/learning) teachers' attitudes, beliefs or perceptions of technology; their self-efficacy, digital skills, approach to technology use, and intention or readiness to use technology; or snapshot assessments of knowledge about how to use technology.
- Theme 3: Technology used for teacher development/learning (e.g., devices such as computers, video, tablets, or phones, and/or digital media and software resources). Low-tech devices like non-digital radio and television were also included since these are often the only available technologies in remote rural areas. Excluded was technology for educational management (e.g., data systems, registration software, emails to parents).

Additional eligibility criteria included:

- Literature published in English (2008–2020, with a cut-off date of 31 July 2020);
- Empirical investigations, including primary and secondary data; excluding reviews and papers that are primarily narrative or theoretical in nature;
- Peer-reviewed academic journal articles, books and book chapters, PhD theses, peer-reviewed conference papers, grey literature (excluding blogs and very short briefing reports);
- Focus on pre-service and in-service teachers of students aged 3–18, including teaching assistants but excluding school leaders when researched alone without an accompanying focus teachers;
- Formal taught programmes, workshops or informal education/learning taking place on- or off-site (e.g., in government/private schools, teacher training colleges, district/community centres), including through peer communication and support (e.g., via online communities of practice).

In Stage 1, titles, abstracts and keywords were screened by three authors to exclude irrelevant texts. In Stage 2, full texts were read by three authors to exclude further records. Duplicate and non-independent records were eliminated. Journal articles were prioritised over other sources such as book chapters and conference papers reporting the same study. Eligibility screening was carried out in an open-source, dedicated, systematic review platform, ColandR.

3.2. Data synthesis

Data extraction and thematic categorisations were conducted in ColandR.

3.2.1. Data extraction

Data extraction was conducted by one author after iterative piloting testing and refinement of the framework by three authors. There is a wide diversity of settings within reviews of research in international development, and consequent challenges in determining relevance and generalisability of findings across a range of different populations and 'real world' contexts [236]. Thus, we paid particular attention to describing contextual characteristics in detail.

The final terms included: publication type, TPD audience, TPD setting (type of institution, country), sampling strategy, sample size, clustering basis if applicable (e.g., teaching experience), teacher age and gender, study design, qualitative data sources, quantitative data sources and data analytic techniques. A brief summary of findings from each study was formulated at the same time. See Appendix C for details.

3.2.2. Thematic coding

Thematic coding of the studies consisted of the broad application of established qualitative approaches to textual coding [15] through careful reading and annotation of full texts by three authors. The substantive expertise among the authors was harnessed to develop a draft, a priori, thematic framework with high potential for applicability to the studies. The framework was then tested on increasing 'sample sizes' of the studies. During the first iteration, ten studies were coded using this framework, which was amended and augmented before being applied to update the same studies and ten more. Between each new cycle, potential changes and 'emerging codes' were logged for whole-team discussion and agreement. This iterative framework development process took place over four cycles. Coding of all studies was then finalised during the fifth cycle (producing the framework detailed in Appendix D) before exporting thematic data for the whole database of studies.

The framework included: TPD audience, Education Level, TPD context, Subject, Tech devices, Tech resources, Tech for communication, TPD modes and methods, TPD design, TPD peer support, TPD outcomes, Factors at system level, Factors at local level, Marginalised learners. Cross-tabulations were carried out to explore key relationships of interest.

Table 4
Quality scoring dimensions

No.	Description
1	*Research conceptualisation,* including whether the research report took a critical approach to the technology use and addressed cultural contextualisation.
2	*Contextual components* in the research methodology, including considerations regarding the sampling strategy as well as reported participant and setting details.
3	*Research design,* assessed using the MMAT [78], including qualitative studies, RCTs, non-randomised studies, quantitative descriptive studies and mixed-methods studies.
4	*Methodological bias*; including whether study limitations and researchers' own positioning were considered and safeguarded against.
5	*Methodological sensitivity to culture and ethics*, including whether data collection and analyses were culturally appropriate and ethically sound.
6	*Claims and conclusions*, including whether these were linked sufficiently with prior evidence and evidence emerging from the study.

3.3. Quality assessment

Studies underwent quality assessment using a criteria checklist iteratively developed with colleagues across our wider research programme (EdTech Hub). This drew in particular on the Building Evidence in Education (BE^2) [77] and Mixed Methods Appraisal Tool (MMAT) [78] frameworks, in consultation with the Research Quality Plus framework for international development research MacLean & Sen [119]. As a result, six dimensions were considered and iteratively refined until a final version (see Appendix E) was reached and systematically applied across the dataset by five researchers. Dimensions are summarised in Table 4. One of the dimensions (research design) was double-weighted due to its particular importance in shaping the academic rigour of the evidence. In light of the discussion in Section 2, our quality framework includes the dimension of 'methodological sensitivity to culture and ethics'. Scores were awarded up to a total of 21 and banded into four rating categories (1 = Low, 2 = Low-medium, 3 = Medium-high, 4 = High) for the purpose of synthesis. Appendix E includes a summary of the outcomes of the quality scoring (mean scores on each dimension and banding distribution) for all articles; detailed scores for each record are presented in the literature database in the Supplementary Material.

The quality scoring process included a seventh dimension rating *relevance* of the content to the review's scope and focus on technology use for teacher learning in LMICs at three levels (1 = low, 2 = medium, 3 = high). This judgement determined how central or peripheral the study was to our concerns and how much useful information was provided (see Appendix E for details and outcomes of the relevance ratings). Low proportions of the 170 records were low quality and/or low relevance.

Each record was then given an overall rating from 2–6 calculated by adding its numerical quality and relevance ratings together; this rough measure was used simply for our purpose of sequencing the synthesis through prioritising the most relevant, highest quality papers. In order to make the challenging task of synthesising across 170 sources manageable in writing the article, we left aside those rated 2–3 (although these were still subjected to thematic coding and data extraction). We started at the other end of the spectrum with the high relevance plus high-quality records (rated 6), adding in findings from the other literature (rated 4–5) in descending order until saturation point was reached for themes.

Note that although the quality assessment framework is pioneering in its holistic nature, a limitation of this tool is that shorter publications, such as conference papers, unfortunately score lower than extended reports such as journal publications. We recognise that some sources designated 'low quality' or 'low relevance' may provide important insights. Thus, all of the remaining publications (rated 2-4) were skim read to ascertain any added value, and a few further points and citations were added.

3.4. Methodological limitations

The review focused only on publications in English. Systematic reviews commonly appear to favour publications from English-speaking researchers in HICs [3]. We experienced difficulties in gaining access to grey literature: it is unclear whether it did not exist or was publicly unavailable. However, publication of reports to sponsors is often prohibited. It is also possible that some TPD programmes initiated and led by nongovernmental organisations (NGOs), local partners, and schools were not published.

The study only reviewed published works and thus could not incorporate teachers' voices, other than indirectly through reporting on the small body of research that offered models for co-design of TPD. It would be useful in the future to solicit feedback and input directly from practitioners in LMICs. The cut-off date for literature screening meant that the review also does not cover published works pertaining to the

Covid-19 context that came into being in Spring 2020. Many of the principles underpinning distance/blended learning models of TPD will still apply, however. Finally, the large number of records returned meant that it was not feasible to read all 170 in the same depth; this was mitigated through closest examination of the most relevant and highest quality studies (see 3.3).

4. Results – characteristics of the research (RQ1)

This section answers RQ1 by outlining the key characteristics of emerging 'tech for TPD' studies. Information concerning further extracted variables and codes is available in Appendix F: sampling strategy and size, teacher age and experience, study design, research methods, methodologies, data sources, methods of analysis, full geographic distribution of studies by country, tech devices and communication modes (by context and region), forms of peer support, TPD outcomes (by region), and local-/system-level factors influencing tech-mediated TPD. The database of 170 sources, complete with coding, quality scoring and data extraction results, is available in the online supplementary material here. Readers may wish to use it to conduct their own targeted analyses.

4.1. Publication numbers and originators

The findings in this section offer highlights derived from the data extraction described in 3.2.1, with fuller outcomes tabulated in Appendix C.

4.1.1. Number of studies published by year

This systematic review found that from 2012 onwards the number of studies on tech for TPD in LMICs has increased (Figure 4). The figures confirm that the choice of the time period captured the field, which is at an early stage compared to other work on TPD and on uses of EdTech.

4.1.2. Publication types

Figure 5 shows that an overwhelming majority of the studies emerging (83%) were published via academic journals although journal quality varies significantly. While our search criteria included grey literature, non-academic publications (e.g. technical reports) made up a surprisingly small proportion (6%): see Methodological limitations above.

4.2. Characteristics of the TPD studies

The findings here derived largely from the thematic coding exercise described in 3.2.2; highlights are presented, while frequencies (*f*) for

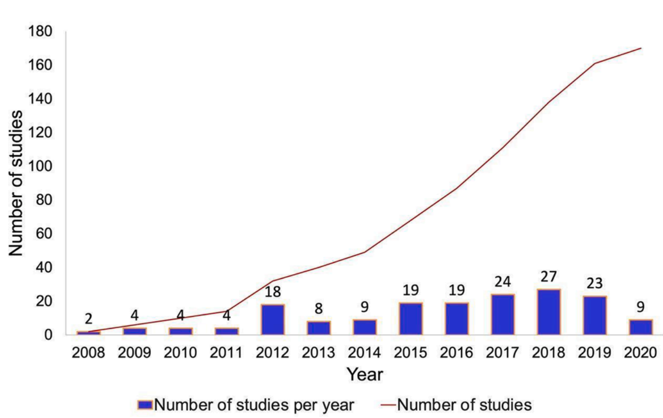

Figure 4. Number of studies published per year: Raw and cumulative frequencies
Note: The tailing off of studies published in 2020 is attributable to this review only including studies up until July 2020.

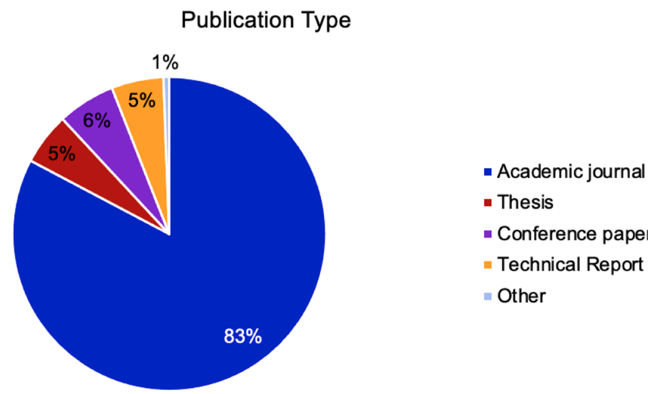

Figure 5. Distribution of publication types

each individual code across the sample are shown in Appendix D. It is important to note that frequencies will in most cases exceed the number of studies found for this systematic review since a single variable may contain more than one code. Thus, the **percentages displayed in the figures depict the proportions of each code out of the total numbers of codes applied within that category.** For example, a single study could have used multiple sampling strategies (e.g., purposive and volunteer); as a result, it might have more than one code under the variable of sampling strategy. The figure used would then be the percentage of all instances of sampling strategy that were coded as purposive, rather than the percentage of studies. On the other hand, ***n*** **indicates the number of studies** where this is more relevant.

4.2.1. Geographic distribution of research in LMICs

It was notable that 96 out of 136 (71%) LMICs had no studies Figure 6. breaks this down by region.

Aside from South Asia, all other regions with LMICs had no studies conducted in the majority of their countries. While more than two-thirds of countries in SSA had no research, over one-third of the 40 LMICs with a study were situated within the SSA region.[8] The criteria applied for this systematic review included only studies in the English language. This may explain why no studies emerged for the majority of Francophone, Lusophone, Spanish or Arabic-speaking LMICs. The findings may also be influenced by inequitable availability of research funding and access to publications across countries [3].

Across the 40 countries where a study was based, the majority (28) had between 1 and 4 studies (Figure 7). See Table 1 in Appendix F for details on the distribution of studies across the 40 countries. The review identified just 5 countries which had 10 or more studies – China, India, Kenya, South Africa and Turkey. All of these are classified as MICs and sit within the top 30 countries globally as far as population size is concerned (Figure 8). Despite the high levels of research outputs for these five countries, a question arises as to how far-reaching these studies are when considering research produced per capita. This is particularly relevant when considering marginalised groups, and the extent to which the studies address the high levels of inequality in educational access and learning outcomes in some of these countries.

4.2.2. Technological devices and resources

Computers were the most common among all mentions of devices included in studies (Figure 9), followed by smart (internet-enabled) devices (e.g., smartphones or tablets). Computers (laptops/desktops) were particularly prevalent in informal education settings (75% mentions). Smart devices – which have greater reach – were at least as

[8] This is partly due to SSA accounting for the largest number (over one-third) of global LMICs. Conversely, the higher proportion of LMICs in South Asia with a study is in part due to the region's relatively small number of countries.

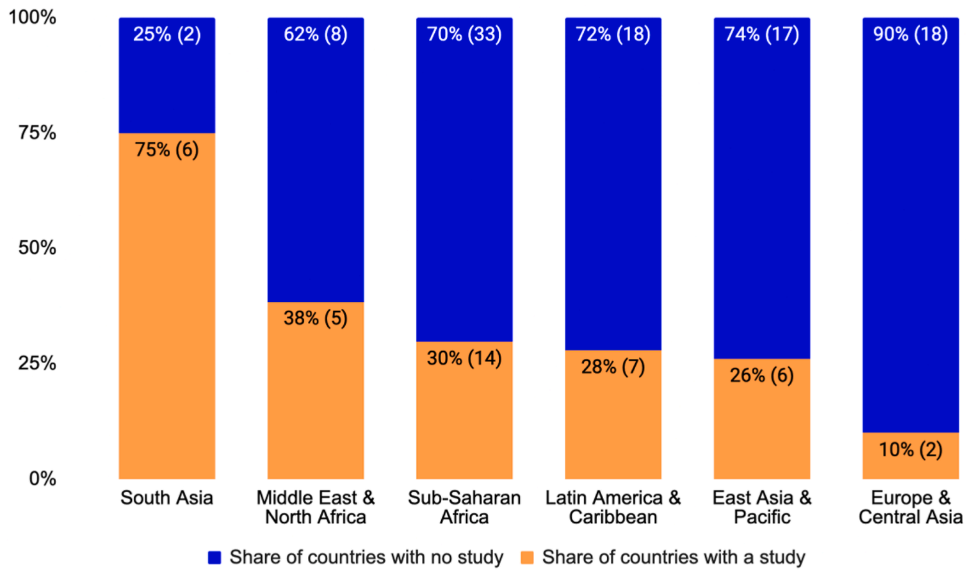

Figure 6. Share of LMICs by region with and without a study

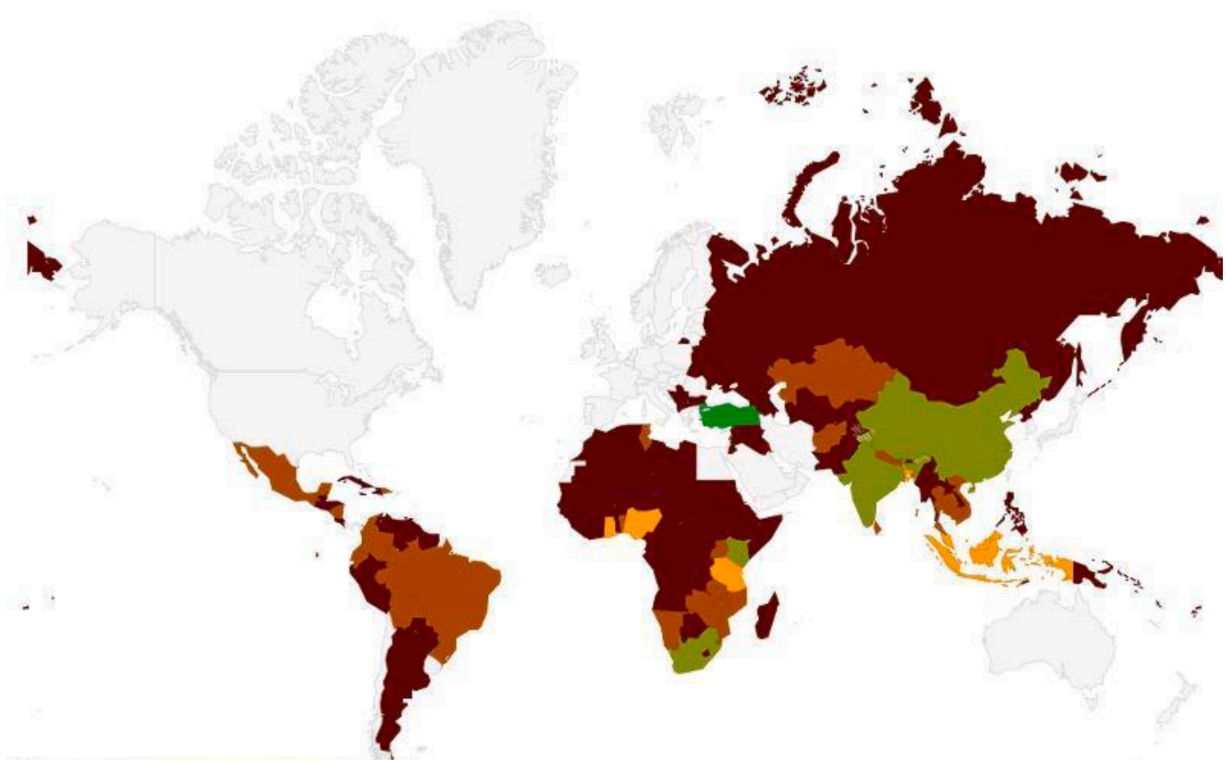

Figure 7. Numbers of studies by LMIC
Key: No studies, 1–4 studies, 5–9 studies, 10–14 studies, 15 or more studies.

popular as computers in remote/rural areas and community schools, though (see details, plus regional breakdowns, in Appendix F). More than half (54%) of the studies that mentioned computers used them alone. Research featuring all other types of devices (interactive whiteboards, projectors, printers, storage disks, etc.) used them in combination with other forms of technology.

Studies tended to be concentrated around certain tech resources (Figure 10). In particular, video resources, web resources and software app resources collectively comprised 175 out of 294 (60%) references to tech resources. Other tech resources (e.g., audio resources, Open Educational Resources [OERs], digital presentations) were frequently mentioned in combination.

4.2.3. Educational level and subject

A total of 45 studies did not specify the educational level Figure 11. shows that primary and secondary education levels accounted for approximately 90% *(f=68 and 77 respectively)* of mentions. Early childhood education and vocational education were much rarer foci (4% and 6% of mentions respectively).

Apart from the 56 studies that did not specify the subject, we found that the use of technology for teacher learning appears concentrated around a few subjects. As Figure 12 indicates, second language learning

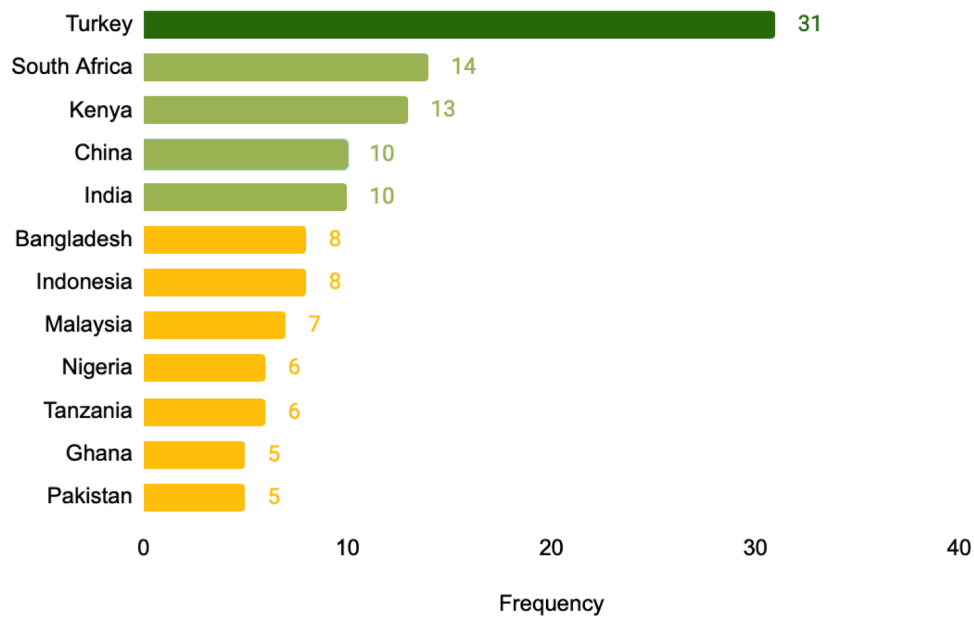

Figure 8. Countries with the largest numbers of studies

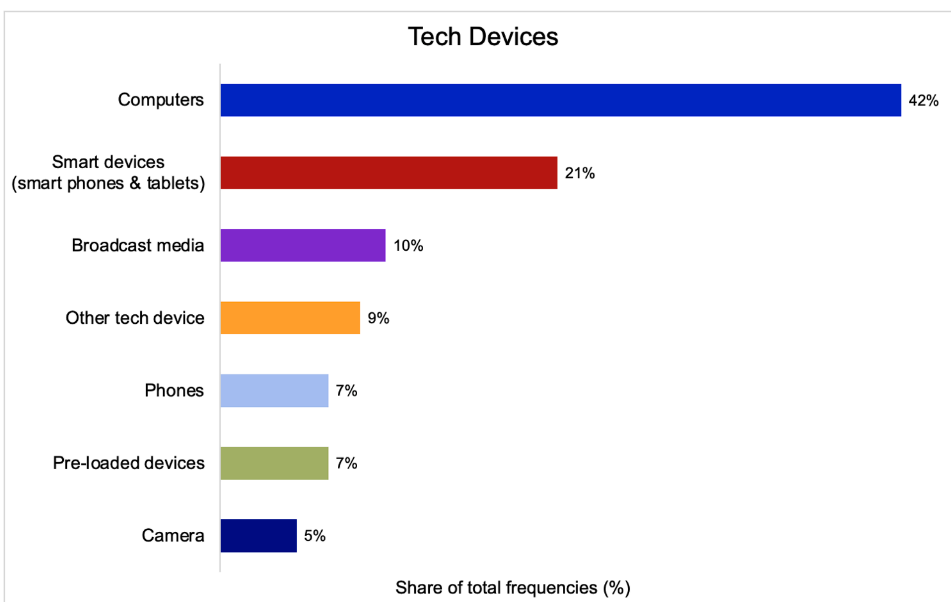

Figure 9. Frequencies of tech device mentions

(SLL) *(f=45)* and mathematics *(f=43)* made up over half of all mentions of subjects. Literacy appeared as a low proportion of total studies overall, especially in secondary education. Focus subject areas varied by region Figure 13. shows that more research in SSA than other regions focused on literacy (often in English as the medium of instruction, often called EAL or English as an additional language). EAL/SLL was the main focus of studies in East Asia and the Pacific, Middle East and North Africa, and South Asia. The large concentration of TPD studies on EAL/SLL in South Asia was related to Bangladesh *(f=8),* where much research focused on the *English in Action* programme [199].

4.2.4. TPD stakeholders

4.2.4.1. TPD designers. In keeping with the concentration of research in journals (4.1.2), an overwhelming majority of TPD programmes in LMICs were designed by academic researchers (78%) Figure 14. shows that participation of local partners (including local community, organisations and teachers), NGO research groups and governments was low. School-initiated TPD programmes were also scarce. Accordingly, participatory methodologies such as design-based research (4%) or action research (2%) were rarely used, despite the importance of teachers' input to TPD outlined in Section 2.2 (see Appendix F for further discussion).

4.2.4.2. Marginalisation. Only 21 of the 170 studies reviewed distinguished the characteristics of target students. These references (*f*=26) were mainly in the context of socio-economic status *(f=11)*, followed by learners with disabilities (*f=4)*, orphaned children (*f*=2), refugee (*f*=2), and indigenous community (*f*=1). A disparate group of studies also focused on girls, children from remote communities, ethnic minorities,

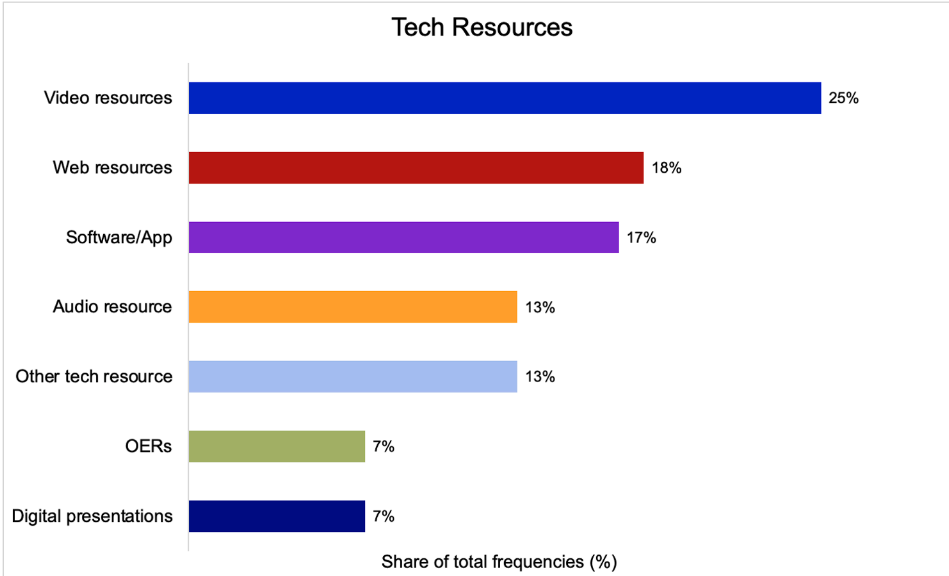

Figure 10. Tech resources used in studies

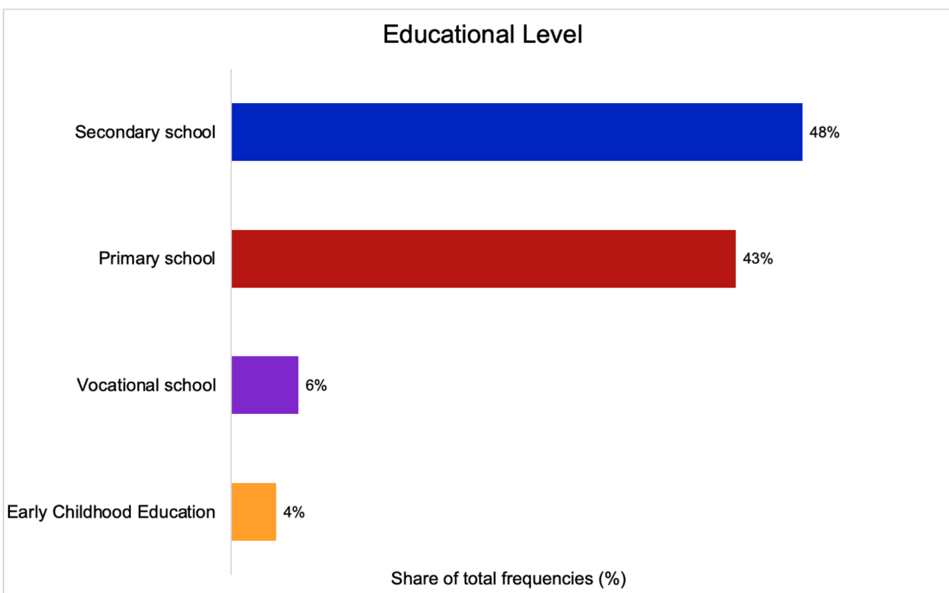

Figure 11. Educational level of studies

children living in conflict situations or orphans (total $f=6$). The numbers of studies focusing on specific marginalised teacher groups did not reach the threshold (3 or more) to be included within the coding process. Therefore, they are not featured in final frequencies (although examples appear in Section 5.2.4.1).

4.2.4.3. TPD audience. In-service teachers formed the main focus of studies *(f=105)*. There were notably fewer studies with pre-service teachers *(f=74)*. Comparatively few studies focused on unqualified in-service teachers *(f=5)* or on teacher educators *(f=14)*. Yet, 25% of in-service primary teachers in 2019 were estimated to be unqualified in LICs and 16% for MICs (UNESCO Institute for Statistics [[222], 2019]. The findings highlight a need for more studies specifically relating to unqualified teachers.

4.2.5. TPD settings

Government schools *(f=63)* and teacher colleges *(f=80)* emerged as the dominant research settings. At the other extreme, there was a dearth of research focusing on community schools *(f=2)* or informal contexts *(f=4)*. From an equity perspective, it is important to note that student populations in such contexts are likely to come from marginalised groups.

4.2.6. TPD outcomes

While no single outcome emerged as a majority focus, 'changed classroom practices', 'teacher tech skills/awareness,' 'changed pedagogical knowledge' and 'teacher motivation' were the outcomes most commonly addressed (see Figure 15). Considering the two TPD outcomes generally deemed most desirable [60], 'changed teacher practices' *(f=47)* appeared more than twice as often as 'student outcomes' *(f=21)*. However, together they made up only 17% of the total number

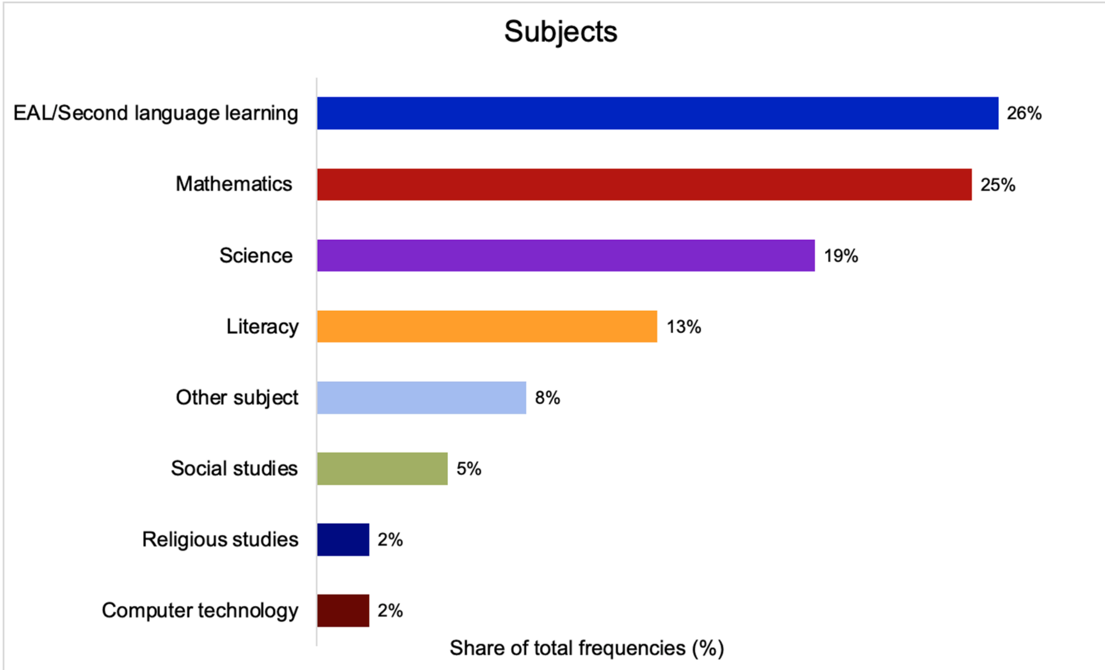

Figure 12. Subject distribution of studies

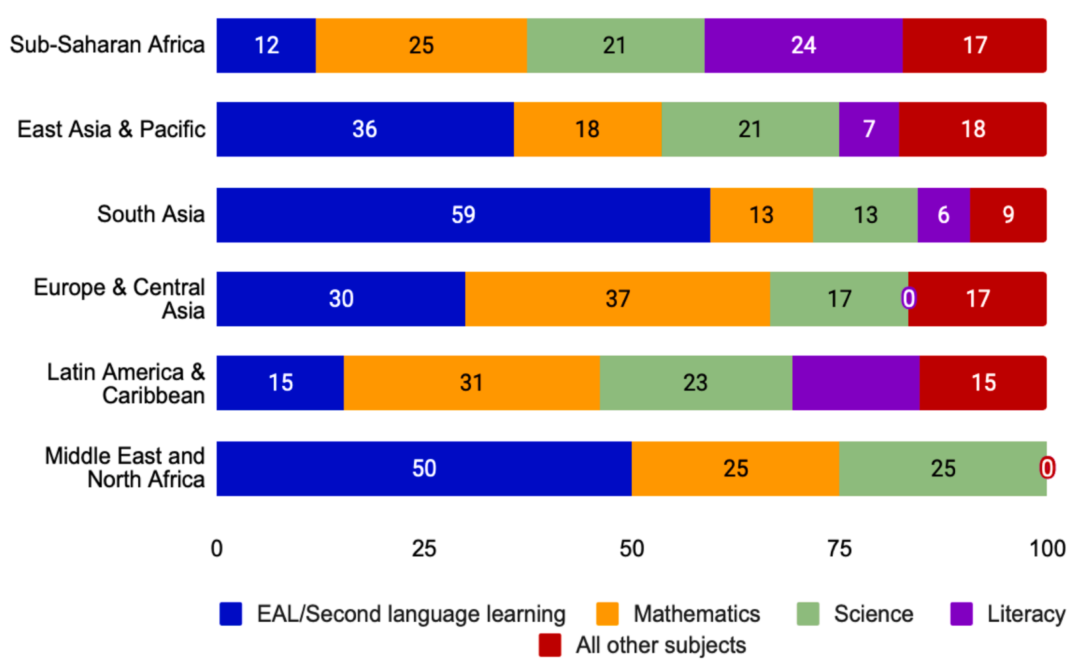

Figure 13. Subject distribution by region

(f=392) of mentions of TPD outcomes. There were also notable regional differences (see Appendix F for more detail).

In terms of assessing TPD outcomes, most studies reviewed relied on self-reporting to measure changes in teacher knowledge and practice. Self-reporting methods made up 62% of qualitative data (including interview, focus group, open-ended survey, reflection) and 63% of quantitative data (including questionnaires comprising multiple-choice questions and rating scales). See Appendix F for details on methods of data collection. Self-reporting has well-known limitations in terms of validity. For example, questionnaires used by one reviewed study [56] demonstrated teachers' improved feelings of self-efficacy towards using mobile phones as pedagogical tools without linking to actual changes in classroom practices. 45% (27/60) of the studies that targeted changes in classroom practice as a TPD outcome were assessed through researcher observations.

5. Results – synthesis of literature on technology use for TPD

Section 5 presents the outcomes of the detailed narrative synthesis carried out in order to identify, compare and interpret the main findings and methodological trends emerging across the 170 studies in the systematic review. Three main themes emerged: modes of TPD (5.1),

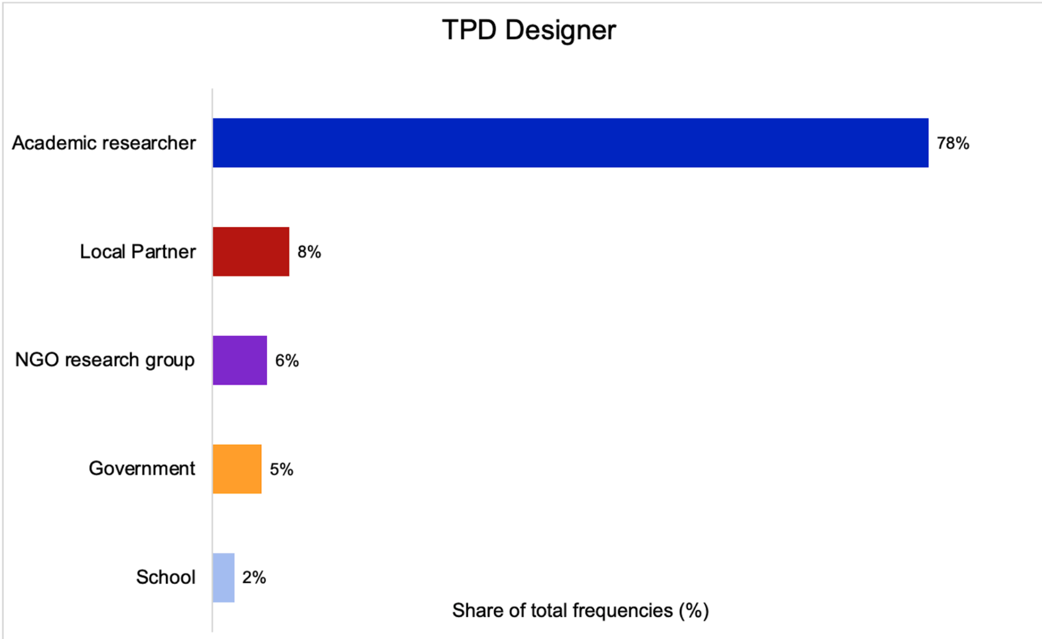

Figure 14. Distribution of TPD designers

equitable systems (5.2) and multi-level factors (5.3). Throughout, we use Exemplars (in boxes) to spotlight promising tech for TPD practices that build on these trends in LMICs. These models were chosen because they meet at least one of three criteria: (i) the model innovatively leverages and combines technology uses with TPD programme designs that are appropriate for LMIC contexts; (ii) the TPD programme led to changes in teachers' classroom practices or students' learning outcomes; (iii) efficacy of the programme was found to be sustainable, scalable or cost-effective. Although not representative, these models serve as aspirational case studies for researchers, practitioners and policymakers. We recognise, however, that – due to myriad contextual and interdependent factors affecting TPD – rarely will the exact design or structure result in the same outcomes. It is notable that three of the six initiatives chosen are (unintentionally) based in Kenya. This partly reflects the high frequency of studies in the country, but also that high-quality studies were conducted there, indicating a strong research landscape to build on and learn from.

The sections below summarise the headline findings. We re-address briefly but do not elaborate upon the various contextual factors discussed in Section 2 when describing the 'tech for TPD' models. Instead, Section 5.3 summarises these contextual 'multi-level factors influencing tech for TPD' (RQ4). Again, we recognise the complexities of the TPD system (see Figure 1). For example, take-up varies greatly across contexts and between individual teachers (as with any educational intervention). Likewise, logistical issues (e.g. timing, transportation, costs) shape whether or not a TPD model is implemented effectively. We also recognise that the technology itself may be used as a modality, and thus agency is dependent upon the TPD facilitator or coach who leverages that modality for teacher learning. Yet, the critical role of the facilitator or teacher educator – and how tech can support it – is a highly under-researched area. Lastly, few studies took a critical approach to the EdTech used in interventions, rarely detailing any negative or harmful effects (e.g., safeguarding risks when engaging with online content). It is important that these risks are documented and understood so that interventions can provide a balanced assessment of the threats and opportunities that the use of EdTech presents.

5.1. Effective modes of technology-mediated TPD (RQ2)

The following sections examine the diverse forms of technology-mediated TPD that have been found to be effective for teacher learning. It examines variations of TPD models that serve five common purposes emerging from the synthesis: to support virtual coaching and coaches, to foster remote communities of practice, to develop teachers' reflective skills, to improve teachers' pedagogical subject content knowledge, and to provide flexible learning environments.

5.1.1. Using technology for virtual coaching

5.1.1.1. Virtual coaching and messaging for teachers. Pedagogical coaching, which typically involves observing, modelling, supporting, evaluating and offering focused, personalised feedback on teachers' practices iteratively over time, is associated with student learning gains as well as changes in teachers' practices. A meta-analysis by Kraft et al., [102] found similar outcomes for both virtual and in-person coaching. TPD models that used virtual coaching – especially through video conferencing *(f=13)* – were quite common in the literature reviewed. There is a promising, growing body of evidence regarding their effectiveness. For instance, in a key study in South Africa providing lessons plans and other resources on tablets across 180 schools in low-income communities, a virtual coaching model proved cheaper and as effective after 1 year as on-site coaching in improving teachers' instructional practices and learners' proficiency in EAL [100]. Coaching included fortnightly follow-up with individual teachers on TPD focus areas, weekly group messages for motivational support, and sending video clips relating to teaching areas that teachers found particularly difficult. However, a recent follow-up study of this programme by [29], published after the literature review period, indicates that trusting relationships and lesson observations are harder to secure without face-to-face interaction. Blended approaches with some in-person visits ensure that the social aspect of peer support is not lost and they appear to be more effective[9] although, like leveraging of video-recorded observations, they

[9] Mary Burns, personal communication regarding an unpublished comparison study in Indonesia.

are under-researched. (See also Section 5.3.4 on cost-effectiveness and sustainability of virtual coaching.)

Given the ubiquity of mobile devices in LMICs, Short Message Service (SMS) text messages *(f=9)* in particular emerged as a low-cost, quick, accessible and familiar form of EdTech to support, prompt or reinforce new teacher practices [202]. Text messages may best be used to offer constant, timely reminders or nudges concerning instructional strategies during or following TPD ([80], Exemplar 1), to hold teachers accountable for implementing planned classroom activities [152], or to connect teachers from rural areas (ibid.). Messaging also allows two-way multimodal communication, including via emoticons, photographs, videos and files [211]. However, it is only a small part of coaching and cannot facilitate the observational and feedback elements. It may also be less effective in addressing complex social issues such as gender norms (e.g., [28]).

Studies in Nigeria and Zimbabwe found that pre-service teachers were intrinsically motivated to use their mobile phones to access social media for educational purposes, despite challenges related to ICT infrastructure and internet costs [149,242].

Teachers' knowledge, (ICT) skill sets, and overall dispositions shape their engagement with social media platforms [206,238,243]. Moodley [141] found that teachers' attitudes towards using an online social media network (e.g. WhatsApp) to support a virtual community of practice are dependent on their awareness of the context within which the community exists and the willingness of the participants to accept differing views and opinions. Because active participation in online discussions can provide benefits Bett & Makewa [16], incentives to participate in online TPD (e.g., through promotion opportunities) may be more effective for teachers who lack professional autonomy or ICT skills [243]. However, a review of social media use raises the risk of teacher-led models spreading inaccurate content when communication channels are not monitored by expert teachers [124].

Exemplar 1
The Health and Literacy Intervention (HALI) project in Kenya

An intervention in Kenya employed training workshops, semi-scripted lesson plans and weekly SMS text-message support for teachers providing brief instructional tips and motivation to implement lesson plans. Despite a relatively low level of in-person support, it significantly impacted classroom practices. It raised primary children's literacy outcomes after two years, and reduced school dropout rates [80]. Teachers considered the weekly text messages a good source of new teaching ideas and the bidirectional SMS model created a supportive community. The effect of using technology could not easily be isolated, however, as is common. (See another study of the HALI project in Exemplar 7.)

5.1.1.2. Technology support for pedagogical leaders. Tech-enhanced TPD may also be used to support coaches, mentors and facilitators, for example by providing more structured observation tools or feedback guides. In Uganda, Tangerine:Tutor (now 'Coach') improved the quality of in-person coaching through coaches using guided observation protocols [185]. Quantity and coverage of coaching were increased through receiving automatically generated, relevant feedback after lesson observations and case management summaries via a central web-accessible dashboard. However, coaches visited schools less often compared to previous paper-and-pencil methods, possibly because the digital classroom observation tool required more data input and increased the time spent per school. Nevertheless, the tablets and software resources made the work easier and increased coaches' commitment and accountability (Section 5 discusses accountability further).

A second study with highly promising results is Bruns et al.'s [22] randomised evaluation of a programme in Brazil that provided secondary schools with classroom observation feedback and virtual coaching. External expert coaching of the schools' pedagogical coordinators via Skype cost $2.40 per student, proving cost-effective in raising teachers' classroom effectiveness and producing significant student learning gains in mathematics and Portuguese.

5.1.2. Using technology to foster communities of practice

5.1.2.1. Teacher-led uses of social media to share practice. Social media *(f=38)* – such as Facebook or WhatsApp – may be an effective approach to TPD due to its versatile nature [61,87]. Research suggests that individual factors tend to play a role in the effectiveness of such TPD models, including how teachers access social media from their mobile devices for professional learning [8]. Social media is generally an easily accessible and hence motivating platform. In Ghana, for example, pre-service teachers' use of smartphone applications such as WhatsApp to share resources supported their professional development through both formal college courses and informal off-campus group interaction [210].

5.1.2.2. Uses of social media in formal programmes. Social media can be beneficial in blended learning pre-service TPD models for peer assessment of teaching materials. Facebook groups were used this way in a series of studies (predominantly in Turkey) for pre-service teachers [38, 81]. Pre-service teachers' engagement in face-to-face teaching sessions increased [38], and closed Facebook groups enabled peer evaluation to extend beyond classroom hours [49].

University lecturers in Malaysia have used social media platforms to facilitate remote lectures and supervision of pre-service teachers' online teaching [138]. Social media is also used to incentivise participation in TPD programmes. In-service teachers in Indonesia felt more incentivised to engage with an online platform when social media was paired with in-person TPD – and monitored by a teacher educator; however, text messaging (and phone calls) did not improve participation in online TPD that provided access to resources on pedagogy and classroom inquiry [243].

Research also suggests that different social media platforms may have different affordances. Sun et al., [207] found that both online discussion forums and a mobile instant-messaging app facilitated collaborative learning among pre-service teachers. However, the online discussion forum resulted in more communication aimed at knowledge construction, while using WhatsApp resulted in more social interactions. Likewise, a South African study concluded that using WhatsApp meets pre-service teachers' needs and supports collaboration, but does not adequately develop digital literacy skills [117]. Yahoo Group was used asynchronously (i.e., responses to posts were not immediate) by in-service teachers in Iran both to construct knowledge and provide peer support [150]. Teachers discussed diverse topics including the use of ICT, the creation of teaching and learning materials, and classroom management. Again, impacts on practice are unknown (see Section 5.1.4).

Six studies used social media and other online platforms (wikis, open

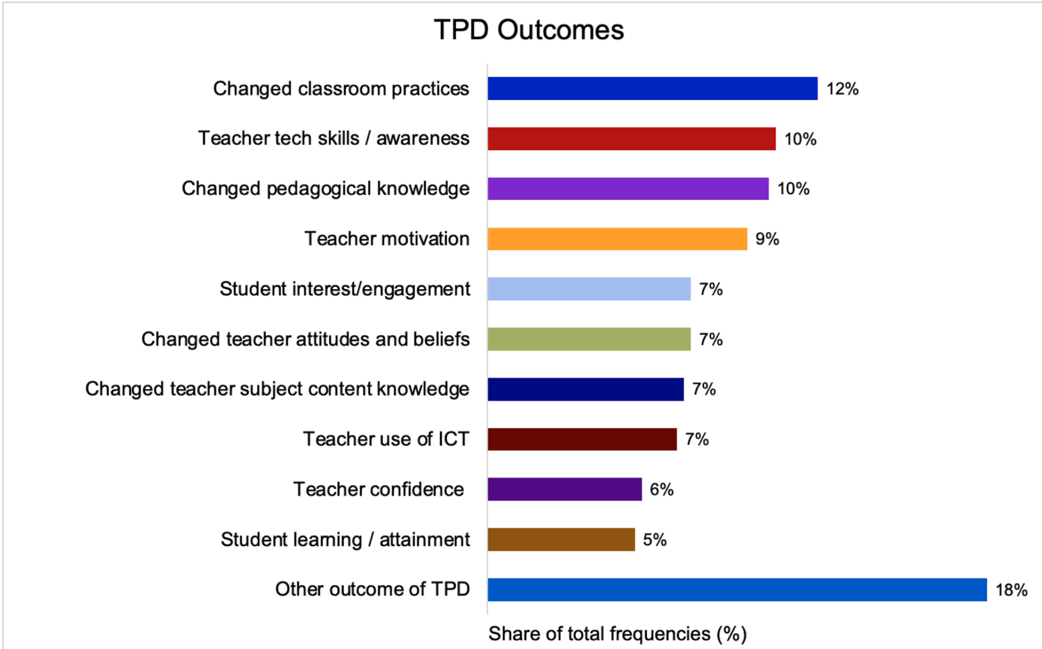

Figure 15. TPD outcomes

and distance learning [ODL], virtual learning environments [VLEs]) to connect teachers from LMICs to peers in HICs [17,23,132,190,205,232]. Despite evidence that teachers prefer face-to-face meetings [23], sharing practices using multimedia (including videos and images) was effective in mitigating interpersonal distance, which can cause misunderstanding and disengagement [190]. Such transnational remote-learning communities can allow peers from different cultural settings to identify common concerns and deconstruct their assumptions or unexamined beliefs, leading to more profound self-knowledge [205]. In other words, a deeper, more critical reflection is possible when tech supports TPD to foster reflection across geographical and cultural borders.

Exemplar 2
OER4Schools in Zambia

In the multimedia OER4Schools programme in Zambia, unique videos of interactive teaching by local teachers offered an external stimulus for teacher discussion, reflection with peers, and inquiry. Learning was guided by built-in prompts for both teachers and facilitators, and the materials explicitly linked theory to practice. Teachers collaboratively designed and trialled new pedagogical strategies. After one school year, teachers adapted to learners' knowledge levels, and used more practical and group work. In turn, pupils built deeper understandings of subject matter, collaborated and used digital technologies for problem solving [68,73]. The extensive multimedia materials helped the programme become self-sustaining after the intervention (see 5.3.4.2).

5.1.3. Using technology to support teacher self- and peer-reflection

Video-based, self-reflective TPD is common *(f=73 studies)* and has proven especially useful for teachers to see themselves teach and evaluate their own practice (e.g., [85]). It can also be used to assess peers or view expert teachers modelling effective pedagogy. This is especially helpful for pre-service teachers in contexts where quality teaching may be elusive [165]. Reflecting on videos can lead to changes in teachers' beliefs, subject knowledge, and/or students' perceptions of teachers' practices (Ragatz and Sugiarti, 2015). Several studies examined how videos were effective when paired with structured opportunities for reflection, questioning and discussion [110,165,209]. Additional artefacts – such as lesson plans or journals – were used to facilitate reflection [59]. One TPD model provided lecture notes at the beginning and end of the video, making clear links to theory to support teachers' knowledge of the scientific approach [209]. Conversely, another study was found to increase teachers' theoretical knowledge (on inclusive education); however, the videos did not provide examples of practical application of the theory [98]. Video-based TPD that is linked to imminent classroom testing of new approaches and reflection with peers may lead to more sustainable change in teachers' pedagogy (Exemplar 2).

The type of video resource and the design of the TPD model play a role in shaping outcomes. Research in Cambodia found that teachers working in small groups and watching videos of expert teachers who modelled effective pedagogy were most effective [114]. Without observers' physical classroom presence, teachers' authentic pedagogical skills are better exposed and the information gathered and feedback provided to teachers are likely to be more credible [110]. Nevertheless, major ethical and technical considerations arise with teacher surveillance of this kind. Factors that shape the effectiveness of videos in TPD models include an institutional culture and leadership supportive of peer learning, and the costs of tech infrastructure and maintenance (e.g., [110,123,187]). Further factors in effectiveness include the content and clarity of videos or other tools used to facilitate reflection [98], the expertise of teacher educators [208] and the activities used to facilitate reflection [123]. It also takes time to develop skills in critical reflection and constructive peer feedback [218].

Research suggests there may be limitations to the level of reflection that teachers can reach. A study in India found teachers were able to reflect on the social, institutional and economic challenges they faced. Yet further reflection around solutions to address those problems required more structured and scaffolded support from the TPD facilitator (e.g., through prompts and probing questions) [123]. The use of more active types of technology such as digital diaries, storytelling [79, 118] or blogging [92,169,208] may afford a deeper level of critical reflection, while maintaining the social dimension of peer interaction [154]. However, teachers' levels of participation in blogging may be largely influenced by cultural factors, time, enforcement by school administrators, and their need for an online community [91]. While blogging supports teacher networking, traditional institutional cultures may prioritise teacher independence over collaboration [92].

5.1.4. *Using technology to improve subject knowledge and subject pedagogy*

Software applications to improve teachers' pedagogical content knowledge [200] were predominantly used in mathematics *(f=19)* or science subjects *(f=15)* (e.g., [30,97]). This compares to a total frequency of 35 for all six other subjects mentioned. A series of studies of pre-service teachers in Turkey indicated the particular promise of regular use of open-source geometry software 'GeoGebra', used in 190 countries to date. In conjunction with certain pedagogies and support structures, use appears to improve teachers' conceptual understanding across a range of topics [9,99,213,256,257], although controlled studies are rare. Similarly, using other software has been found to improve teachers' knowledge of geometry [203,231].[10] Nevertheless, evidence suggests that despite the potential for software to support teacher learning, especially in science and mathematics, its scope may be limited to specific concepts or theories, without evidence of changing practice. Also, initial weaknesses in subject content knowledge may preclude more than superficial uses, again inhibiting impact on teacher learning [97].

TPD models are more likely to effectively facilitate changes in both subject knowledge and pedagogy when teachers have opportunities for "creation of digital teaching and learning materials" (theme extracted from the literature reviewed). Studies specifically referenced the use of "OERs" *(f=20)* and "editable web pages" (blogs and wikis: *f=14)*. TPD models that use tech-supported problem-based learning [86] and collaborative design teams [2,82,83] have proved effective in improving teachers' technological pedagogical content knowledge (TPACK) and digital skills.[11] The (under-researched) role of the teacher educator – and the accompanying support materials – are paramount for success, as measured through improved classroom technology use, teacher tech skills/awareness, and/or TPACK. Nevertheless, the effectiveness of computer-mediated TPD models is often shaped by teachers' prior training in computer use, and the time they spend using computers [57]. A key factor for success in these tech-based TPD models is teachers' collaborative creation and sharing of digital lesson and TPD resources through experiential learning (e.g., [58]). On the other hand, experiential learning may be less effective in developing teachers' TPACK in the absence of rich practical teaching experiences [168].

Empowering teachers to collaborate, create and share resources has the potential to engage teachers, foster agency and promote TPD in low-resource contexts in particular. Installing computers in schools may enable teachers to develop new digital skills (e.g. Nigeria, [153]) and access web-based materials, overcoming challenges in contexts where other teaching and learning resources are scarce (e.g. Rwanda, [151]). Technology can provide TPD to stimulate teachers' creative use of both digital and non-digital resources. Examples include video-based TPD in rural Nicaragua [111] and multimedia player use in rural Malawi [24].

Research emphasises the importance of enabling ownership and agency in the design processes ([57,111,186]) and providing teachers with adequate time to learn how to effectively use technology for content design [49]. Furthermore, knowledge sharing on open licensing was found to positively influence teacher adoption and adaptation of OERs ([65,249];). The potential benefits of content creation to enhance equity include empowering actors to create contextually-relevant resources that represent marginalised groups (see Section 5.2 for more on equity). Nonetheless, few studies explored this and many suggested that the localisation of content using technology can be complex, time-consuming and resource-intensive [159,245]. Further, larger-scale research is required to better understand the potential that technology can offer to support teachers' development and foster inclusive practices.

Pre-loaded devices encouraged experiential learning opportunities in 17 (10%) of the 170 studies. The purposes of these models for teachers were often twofold: to experiment with exemplary multimedia resources provided in the device, and to create their own resources (School-to-School International [[189], 2017 [56];]. Nonetheless, evidence was again limited to self-reported data rather than observational changes in classroom practice. One exception to this is the jiFUNzeni blended learning approach described in Exemplar 3.

Exemplar 3
jiFUNzeni blended learning: Creating EdTech resources for learner-centred pedagogy

The jiFUNzeni approach utilises solar-powered tablets, OERs and open-source software to provide teachers with opportunities to create multimedia resources (PDFs, video clips, podcasts and images). These are either embedded in HTML content or electronically published [157, 158]. This initiative enabled teachers in Kenya to build instructional capacity across subjects through the thoughtful development and delivery of relevant content. One year after the intervention, follow-up interviews with teachers and TPD facilitators revealed teachers still used cooperative learning and activity-based learning strategies. Key factors for success and sustainability of this programme included selecting appropriate technology and viewing teachers as creators of innovative learning content.

[10] In LMICs especially, there are various contextual factors that may shape the effectiveness of software use (e.g. teachers' ICT skills, gender, prior knowledge, access to internet connectivity, quality of the software design: [231]). However, in neither of these articles were these contextual factors addressed.

[11] In these studies, technology is used as a modality to support teacher learning, but the role of the teacher educator or TPD facilitator is unexamined, albeit pivotal in ensuring the technology is used effectively. Problem-based learning, for example, requires a high level of pedagogical knowledge of the facilitator. Tech is simply the delivery system for more difficult tasks such as building teachers' critical thinking skills.

Despite teachers' subject content knowledge being a popular intended outcome of the TPD models reviewed, there were notable methodological limitations. Only 23 (35%) studies with subject content knowledge as one of the TPD outcomes utilised teachers' test data to assess their learning.

5.1.5. Using technology to foster flexible learning environments

Technology has facilitated new, flexible and innovative approaches to TPD, particularly for pre-service teachers, including through independent or self-study TPD *(f=22)*, blended learning *(f=32)*, or virtual learning environments (VLE) *(f=33)*. Technology access can motivate teachers to pursue self-study TPD opportunities [149] and to remain in these programmes until completion. Experimental studies have found that the flexible nature and enhanced interaction offered by blended learning environments improve teachers' knowledge of a range of topics, including ICT (e.g., Yemen, [179]), science (e.g., Pakistan, [135]), and classroom management theory (e.g., Turkey, [103]). Flipped classrooms, for example, allow teachers to watch lectures or engage with other multimedia content off-site before discussing them in teaching sessions; increasingly popular in HICs, these proved less common in LMICs *(f=7)*. Flipped models allow time to use more participatory teaching and learning methods in lectures [135] (where lecturers know how to use these methods). They enable lecturers to select the combination of virtual and in-person activities that maximises student engagement and learning [103]. Despite these benefits, evidence and explanations for changes in practices remain limited in many studies reviewed.

VLEs (also referred to as Learning Management Systems or LMS) – the most common of flexible approaches – have been used increasingly in flipped, blended or distance TPD models. Like social media, carefully designed VLEs can provide rich learning opportunities outside of the physical classroom. VLEs can connect pre-service teachers with the lecturer outside of class and make it easier to follow teaching content and assignments or access additional study materials and learning activities [13,52]. While VLEs can be used for direct transmission, they can also be used to foster collaborative e-learning environments. Such environments can support the development of teachers' problem-solving skills and metacognitive strategies for self-regulated learning, and increase motivation [146]. Nonetheless, individual factors such as teachers' epistemic beliefs (on how knowledge is developed) and attitudes toward tech may mitigate VLEs' effectiveness (ibid). More experienced or motivated peers – or even adolescent students who may have more advanced ICT skills than their teachers [159] – may serve as an important support. This can increase teacher engagement, facilitate teacher learning with ICT [147], and ultimately foster changes in classroom practice [238]. In the latter study in a Chinese secondary school, an online community supported structured activities focused on collective lesson planning, individual reflection, peer critique and resource sharing by teachers of the same subject.

5.2. Using technology-mediated TPD for more equitable systems (RQ3)

A global focus on educational quality and enrolment rates has shone a light on the magnitude of disparities existing within and between education systems. This has led to recognition that "teachers are a foundation of an inclusive education system" and require support to develop skills to cater for needs of all learners ([227], p. 153). This section explores how technology can help foster more equitable education systems (RQ3, Table 1) – a common goal of education reforms, but practice often lags within TPD initiatives, as we demonstrate below.

5.2.1. Using tech to provide TPD through remote learning

Technology has the potential to widen access to professional learning opportunities for teachers remotely. The literature relating to remote learning contained research studies where distance *(f=30),* blended *(f=34)*, remote/rural *(f=23)*, and Massive Open Online Courses (MOOCs) *(f=10)* were referenced and coded. The literature generally included little detail on demographic or socio-economic characteristics of teacher participants, and rarely disaggregated data regarding intervention effects. Moreover, *why* teachers engaged in remote learning and *how* adaptation could meet diverse needs remained unevidenced.

Remote learning can provide access to TPD sustainably throughout teachers' careers, for instance through MOOCS [89,167,237,248]. Different instructional design frameworks are required for different learner types, though. For example, more experienced teachers may be more open to experimentation [237]. Linguistically- and culturally-adapted MOOCs have been found to contribute to high participation and completion rates [246]. Many initiatives highlight the importance of ensuring local support and engagement, which are central factors in effective MOOCs based in India (ibid) and Uganda [167].

A prominent challenge for purely remote TPD is the lack of opportunity for teachers to apply learning, flagged earlier in Kok & Blignaut's [98] study of 15 teachers in rural communities in Namibia. Participants there reported that the DVD-based TPD afforded no chance to apply theoretical knowledge on teaching learners with Special Educational Needs and Disabilities (SEND). By contrast, Henaku & Pobbi [70] found minimal differences between the classroom management skills of Ghanaian teachers who undertook distance learning programmes versus traditional in-person TPD. The large sample (n=500) analysis was based on self-reported surveys rather than observational data, but findings were triangulated via head teacher assessment, mitigating the methodological limitations somewhat. There are also tensions around the structure of distance-based TPD. For instance, Sri Lankan and American teachers in the international collaboration initiative previously discussed found that highly regulated and frequent assessment could make interactions too formal and reduce teachers' freedom of expression [190]. Conversely, Harley & Barasa [65] observed that the highly structured version of the Teacher Education in Sub-Saharan Africa (TESSA) programme was effective in distance education programmes (see Exemplar 6). Finally, logistical issues for remote learning can impact teacher motivation and learning, evidenced through Mokoena's (2017) research on 65 pre-service teachers in South Africa [140]a. Communication problems with the teacher education office and a lack of placement visits demotivated teachers.

Blended learning programmes can provide teachers with opportunities not possible through purely distance or in-person TPD. The Teacher Education through School-based Support in India (TESS-India) programme used a combination of digital forums and physical learning spaces to merge global knowledge and local support; the MOOC completion rate increased and classroom teaching practices improved as a result [246,248]. The opportunity to apply new knowledge and pedagogical practices in the classroom and later reflect (virtually/in person) with peers and facilitators resulted in improved teaching practices in Bangladesh [196], Kenya [159] and Pakistan [7].

However, issues with blended TPD initiatives included pre-service teachers in Turkey reporting that certain aspects of the online environment made them feel isolated and hindered learning Yılmaz and Malone [254]. Teachers in Indonesia had low levels of participation in online learning, due to various factors including "reduced commitment to the programme because of the absence of formal consequences." ([243], p. 388). Again, motivational and social dimensions of technology use need to be carefully considered to ensure blended TPD is effective (see Section 5.1.5). Moreover, experimental designs examining the relative impact across in-person, blended and remote TPD models were uncommon. Exceptions include previously discussed studies by Kotze et al., [100] and Qasem & Viswanathappa [179].

Providing TPD in rural settings has potential to significantly address equity issues; nonetheless, few studies were coded both "remote/rural area" and either "distance" *(f=3)* or "blended" *(f=4)*. Generally, only 23 papers (14% of total) involving teachers in "rural/remote" contexts were identified. Thematic coding of the research highlighted that rural contexts can often be associated with complex issues and other forms of marginalisation. Moreover, while some research designs included both urban and rural schools (e.g., [159,175,237]), few detailed disaggregated effects and distinct causal pathways of impact. The importance of separating out effects cannot be emphasised enough. Onguko's [159] study in Kenya involving a needs assessment, for instance, discovered that urban teachers preferred training on assessment, whereas rural teachers wanted TPD for teaching large classes. Tailoring the TPD content across contexts subsequently contributed to longer-term pedagogical improvements.

Studies also detailed TPD initiatives utilising innovative technology solutions to infrastructural challenges faced in rural/remote contexts. This included enabling access to TPD materials and facilitating communities of learning through social messaging applications (see Section 5.1.2), solar-powered devices to combat electricity shortages [159], and using a local Wi-Fi network connecting teachers to a central server [72]. Researchers emphasised the importance of providing support to teachers in rural contexts, for example, in troubleshooting technology issues, enabling reflection and providing motivation [100,111,160,248].

The flexibility provided through remote learning via mobile devices with pre-loaded content was another advantage flagged in multiple studies in rural settings (e.g., [24,197]). Many studies, however, were small-scale and/or based on pilot initiatives. Others lacked detail around the feasible limits for device sharing, rendering it difficult to draw conclusions for sustainability or scalability. TPD programmes that require only one device or a handful per school are commensurate with common resource constraints. However, teachers' buy-in to minimal technology sharing among peers can be limited, precluding experimentation afforded by individual devices [198]. Research also demonstrated how technology can sometimes be *ineffective* in providing TPD in rural settings [28,98]. Rana et al., [181], for instance, detailed how bringing technology into rural Nepali primary schools already experiencing infrastructural difficulties (from earthquake damage) created further organisational complications that compromised TPD effectiveness. These studies highlight the importance of ensuring constructive and contextualised application of technology to support teachers in rural settings.

5.2.2. *Using tech to improve language of instruction*

Teachers' knowledge and skills in their language of instruction can impact teaching quality, and technology can be used to improve this. EAL/SLL was a focus in 45 studies reviewed. While studies noted language benefits of technology use, few measured actual improvements in teachers' language development or teaching practices relating to languages. There was also no literature relating to the use of technology to assist TPD for sign language, which is concerning, considering 34 million children globally have a hearing disability [227].

A number of studies detailed how technology enabled greater language practice opportunities, including delivering TPD in a target language [81,190,198]. Participants across studies were found to have increased their language confidence and competency through wider language exposure. This included providing second/additional language TPD content on mobile devices as in the English in Action initiative in Bangladesh [198]. Further examples were participation in social media groups (Bett & Makewa, 2020), using language applications [20] and reading and writing practice via the creation of e-portfolios by pre-service teachers in Malaysia [81]. E-portfolio applications – online platforms where teachers can access elements such as lesson plans and feedback, peer forums, and exemplar lesson videos – were also found to meet the planning needs of pre-service English teachers in Turkey, but they were perceived as less effective in supporting teaching and reflection [88]. Further, research rarely documents teachers' initial language levels or any disaggregated initiative effects; these measures could inform adaptation or tailoring of language content.

Using video reflection to self-assess language competency was a feature of three studies [59,123,218]. All noted that teachers used the videos of themselves to identify language errors, such as grammar and pronunciation mistakes, hence improving their language skills. However, none of the studies explored the impact of sustained video reflection to improve language competency over time. Virtual coaching (see Section 5.1.1) for language learning offers further potential benefits: in Kotze et al.'s [100] large-scale study cited earlier, it presented significant cost advantages, which is particularly important when providing TPD in multiple languages. Nonetheless, there were indications of potential negative effects from neglecting home language skills after a year, which raises concerns around the trade-off to improve learners' English competency. Furthermore, the positive impact on teachers' English proficiency was an additional, unexplained benefit of the intervention.

5.2.3. *Using tech in TPD to improve learning for the most marginalised*

Technology presents both opportunities and challenges for supporting teachers to adapt practices for diverse learners' needs. Research highlights the importance of working with teachers to understand their priorities and nuances in challenging settings to more effectively tailor support (Anamuah-Mensah et al., 2013 [159,160];). Nonetheless, this review found a significant lack of technology-supported TPD initiatives focusing on the specific needs of either marginalised teachers or learners (see Section 4.2.4.2).

5.2.3.1. Marginalised teachers. Despite the potential reach of technology designed to be inclusive, there was little evidence on tech-based TPD for SEND teachers. Wormnaes & Sellaeg's [253] study in Uganda found that the audio-described educational video material was valued by the 12 visually impaired participating teachers. It led to constructive reflection as teachers considered their involvement and emotional engagement with SEND learners. The research also discovered that when paired with sighted teachers, visually impaired teachers participated less in discussions. It is critical that such dynamics are considered and effectively addressed to ensure TPD is equitable.

Only three studies explored the role of technology in supporting TPD for teachers in refugee/displacement contexts, where language barriers and emotional trauma commonly pose specific needs. Mendenhall et al.'s [133] multifaceted approach is one example (Exemplar 4). Language applications have enabled female Syrian refugee teachers in Lebanon and Sweden to undertake self-directed learning and simultaneously improve new language skills and teaching practices [20]. There was also evidence demonstrating the benefits of co-designing TPD initiatives with marginalised teachers. For instance, Kennedy & Laurillard [89] worked with Syrian and Lebanese teachers to construct a MOOC designed for TPD in education in emergency (EiE) contexts. The logic that developing EdTech initiatives in the most challenging contexts and extending them to more favourable conditions is compelling but rarely implemented.[12]

[12] See https://blogs.worldbank.org/edutech/scaling-up

Exemplar 4
Mobile mentoring in a refugee context [133]

Teachers in the Kakuma refugee camp in Kenya took part in a TPD initiative and were provided with mobile phones, data and airtime. Over one year, they took part in workshops, virtual peer coaching and mobile mentoring. The peer mentoring fostered communities of learning and relationship building in the camp, and the global mentoring enabled two-way knowledge sharing as external mentors were able to understand the context and tailor support. The mentoring provided real-time responses to challenges and enabled feedback loops (both between mentors/mentees as well as project staff). Teachers also reported using the mobile devices to (a) access the internet and engage in self-directed TPD, for example to find content on how to support SEND learners, and (b) share innovative teaching practices through photos or exemplar videos. Further research might investigate the impact on their students.

5.2.3.2. Marginalised learners. Despite the limited literature identified concerning learners with low socio-economic status (11 studies, 7 of which involved rural/remote learners too), evidence is emerging that tech-mediated TPD can be effective in such settings. The use of participatory video-making in South Africa, for example, was a valuable tool in enabling teacher agency and opportunity for group reflection on matters of marginalisation, such as poverty, orphans and HIV/AIDS [137]. Teachers using laptops, video and OER in the *OER4Schools* initiative in Zambia were found to have raised their expectations of what rural and vulnerable students can achieve [72,73]. They developed their awareness of *all* learners' progress. The initiative's holistic approach renders it difficult to separate out the effects of specific technology. However, the programme highlights the importance of a multimodal and blended approach to effectively support and empower teachers to foster inclusion.

There was a near absence of any TPD initiatives focused on girls or learners from SEND or EiE groups. One ineffective DVD-based remote-learning model for teachers of SEND learners in Namibia [98] is discussed previously. In a rare study including both pre- and in-service teachers, MacEntee [118] explored the contributions and challenges for participatory visual methodologies to enhance HIV education in rural schools across South Africa. Results indicated that the photography-based methods covered gender themes and facilitated teachers' reflexive learning and the production of local resources in under-resourced schools. Challenges, however, included limited technology access (the research project supplied all digital tools) and potential to evoke trauma and discomfort among teacher participants. Another study, at the intersection of gender and EiE, sought to demonstrate the peacebuilding potential of positive gender socialisation in a conflict-affected region of Uganda [28]. This study found no clear evidence of positive impact from SMS messaging on teachers' attitudes, knowledge or practice (in contrast with studies in other contexts, reported in Section 5.1.2).

The findings in this section emphasise the importance of TPD to cater for diverse learning needs, yet among the identified literature there was little detail on how TPD targeted this. The evidence suggests that technology has the potential to facilitate TPD designed to support marginalised learner needs; however, the complexity of these needs requires a holistic approach.

5.3. Multi-level factors influencing tech-supported TPD (RQ4)

This section explores the intersecting, multilevel factors influencing tech-supported TPD initiatives within a coherent education system. It builds on Figure 1 and shows how different elements are informed by government, institutional and teacher priorities. In doing so, it answers RQ4: in what ways are TPD initiatives systemic in their approach, considering macro-, meso- and micro-level factors during design and implementation?

5.3.1. Macro-level factors influencing tech-supported TPD

Macro factors manifest at the national and sub-national level. Despite the importance of this level for governing and coordinating effective TPD systems, 25% of studies did not discuss system-level factors. This subsection discusses the main themes emerging across the other 75% of studies.

5.3.1.1. Resourcing TPD in a fractured environment. Infrastructure is a cross-cutting element in the TPD system. At the macro level, infrastructure involves the construction and resourcing of schools with qualified teachers, equipment (including tech devices), teaching and learning materials and more, by government. It also includes the availability of reliable power and connectivity, crucial to successful implementation of most tech-supported TPD interventions. Macro-level infrastructure was the most frequently named code among system-level factors, appearing in 24% of studies *(f=41)*.

In a study investigating the integration of tech for TPD in Nepal, lack of government funding and investment in digital infrastructure meant that schools could not implement educational directives that government policies set out. These included the provision of ICT infrastructure and professional development of university staff to integrate ICT in teacher education [182]. This lack of funding, and so government ownership over the Nepali TPD system, created a gap in service delivery, filled by international organisations. This example demonstrates a fractured picture of TPD implementation that is all too common [228]. Onguko [159] corroborates, highlighting the importance of coherence to ensure a degree of complementarity between implementing parties, funders, governments and those most affected (i.e., teachers and students). To achieve coherence around national priorities, governments must coordinate and manage partners closely. A push to promote a learning culture across the TPD system would "avoid unnecessary duplication and help large-scale initiatives to learn from both mistakes and successes of small-scale pilot projects" ([171], p. 11). This serves to join up a disparate system of initiatives, actors and funding for effective, equitable and sustainable TPD to promote improved learning outcomes.

5.3.1.2. National policies, assessment frameworks, accountability and incentives. The policy or political environment was the third most frequent code among "factors at the system level" (37 or 22% of studies).[13] The role of policy in stimulating widespread change across the TPD system is exemplified through China's "educational informationization" goals. These aimed to connect every school to the internet and integrate ICT into the curriculum by 2010 [109]. Projects set up to achieve these goals included a distinct focus on developing students' and teachers' tech skills. Increased policy attention on EdTech use and tech-supported TPD effectively addressed both teachers' and learners' needs. The TPD improved instructional delivery and more creative uses

[13] Although there are myriad factors at the policy level that shape the effectiveness of tech for TPD models (e.g. teaching standards and qualification frameworks, recruiting and promotion mechanisms, pay, compensation and tenure), this section focuses on those factors most common in the literature reviewed.

of lesson materials, in turn promoting improved learning outcomes. However, teachers' pedagogical beliefs determined *how* the technology was used, for example whether teachers creatively added animations and images to make their lessons more "vivid" (ibid., p. 114). Moreover, teachers were reluctant to use technology when faced with mounting exam pressures, reverting to traditional, non-tech practice (ibid.). A decade on, the policies and projects that made up China's "educational informationizization" led to considerable national achievements, such as: development of substantial digital resources, including MOOCs. Large-scale TPD on

EdTech has also reached tens of thousands of teachers [239].

National assessment frameworks are central sources of accountability; indeed, "teaching to the exam" is arguably an inevitable consequence of high-stakes assessment [109]. Exams need to reflect broader technological shifts for teachers to value and normalise innovative classroom practices using technology (ibid.). Macro-level assessment frameworks and curriculum uptake have clear impacts on in-classroom teaching and learning, particularly in a pressured environment. Kotze et al., [100] found that inadequate curriculum implementation in South Africa triggered teachers' avoidance of more complex (often learner-centred) activities. Comprehensive and sustainable TPD systems are a key method of breaking the cycle and ensuring policy change stimulates classroom-level change [181]. In sum, high-quality TPD is a crucial link between policy and practice, potentially enabling teachers to maximise the capacity of technology to improve classroom pedagogy [171].

The essential underpinning to a coherent TPD (and wider education) system, is the effective collection, use and interpretation of data. Timely and accurate data allows decision-makers to make informed decisions [11]. Data span levels and topics – from individual teacher attendance or student assessment data to school-level data on performance or infrastructure, through to national school system data. However, data are generally managed, used and interpreted at the macro level.

Data are used less frequently at the micro- or meso-levels to support teachers or institutional leaders. An exception is the work of McKenney and Mor [130], who provide design guidelines to create a valid, practical software tool that could support teachers in collecting, annotating, interpreting and analysing data in their classrooms. These include encouraging teachers to test their own conjectures about effects of their learning material designs on student progress, and to reflect with peers on the data and its implications for their conjectures.

Exemplar 5 also exemplifies how data can be used to enhance the coherence of a TPD system, connecting different actors: reciprocal accountability affords micro-level actors the space to make their voices heard.

Awareness of these contextual realities, including incentives (e.g., [177]), time constraints and teachers' working conditions, can help ascertain the reasons why teachers do (or do not) engage in TPD.

5.3.2. *Meso-level factors influencing TPD*

The meso level involves schools/colleges and communities, coaches and facilitators, TPD initiatives and tech support, and more. It plays a vital role in linking the micro and macro levels. This section discusses meso-level constraints, collective culture and teacher agency, and the role of school leadership (most research focused on schools rather than pre-service education settings; however, messages may apply there too).

5.3.2.1. Meso-level infrastructure and institutional constraints. Meso-level infrastructure can comprise school equipment, a school's technological resources, localised power/energy supply (e.g., solar mini-grids, [255]). This infrastructure is often provided by the state or other macro-level actors, however equipment, management, maintenance and use typically sit with schools and individuals.

Dlamini & Mbatha [40] note that uptake and usage of the extensive school-level ICT infrastructure in South Africa is low. This is due to a lack of school-based TPD equipping teachers with the necessary skills to use technology effectively. As such, the authors advocate for TPD opportunities supporting teachers' use of tech to foster the skills, knowledge and enthusiasm to integrate technology into everyday teaching practice. Hence, coherence between provision of technology *to* schools and TPD concerning how to use these technologies *in* schools is vital [181,182].

Institutional constraints can mean meso-level physical constraints, such as a school's lack of access to technological hardware and/or devices, or large class sizes affecting students' instructional time. Institutional constraints can also denote more 'human' factors, for example, triggering an "unenthusiastic school culture" ([1], p. 102). Such constraints can limit the creativity of teachers, even those enthusiastic about using technology. Where teachers must share limited technological devices, for example, between colleagues or students, the potential added value of the technology has a ceiling as even enthusiastic teachers have limited access. These constraints, whether 'physical' or 'human' can create perpetuating cycles of despondence concerning engagement in TPD activities, ultimately negatively impacting learners' educational experiences.

5.3.2.2. Collective culture and teacher agency. Teachers' collective culture can take the form of a national teaching workforce (macro), or the embedded culture within a given school or cluster of schools (meso). Collective culture is a further significant factor in determining teachers'

Exemplar 5
Tusome's National Tablets Programme in Kenya

A dashboard compiling data on the numbers of observations (recorded on tablets) that coaches undertook was developed to enhance the accountability structures within the ministry of education. This was targeted at establishing greater links between the sub-national (county) and national levels [172]. In addition to heightened accountability structures between coaches, country programme directors and government, coaches' increased use of tablets improved the quality of their instructional support to teachers. However, 'modest relationships' between increased coach visits and overall improved learning outcomes demonstrated the complexity of making system adjustments to improve learning outcomes. The research findings were used to adapt the TPD offering. It highlights the need for further research exploring the relationship between TPD, accountability and learning.

Finally, macro-level working conditions can impact teacher motivation [111]. In particular, consistent salary payments and career progression opportunities are basic elements of a teacher's social contract that affect attitudes towards the profession and engagement in TPD.

attitudes towards, and participation in, TPD programmes and their overall perceptions towards teaching as a whole. Yet a mere 12% *(f= 20)* of studies discussed cultural dynamics.

Lindenberg et al. [111] found that teachers who distrusted the Nicaraguan education system due to previous state failings were less motivated to engage in the TPD. That said, those teachers who did engage in the TPD demonstrated a degree of change in their teaching practices. Yet, even the most effective, equitable and sustainable evidence-based, tech-supported TPD offerings – with all the 'essential ingredients' that would generally denote success – may not work in a given context if teachers' attitudes are negative towards their education system as a whole, or even towards their mentors, coaches or teacher educators. Mutual trust and confidence are essential for success.

School culture – defined as "the basic assumptions, norms and values, and cultural artifacts that are shared by school members" ([126], pp. 8–9) – has the potential to both enable and constrain teachers [1]. School cultures can afford teachers with the requisite experience, safe space and confidence to be creative in the design, delivery and assessment of learning. Yet, school cultures can also often pose significant constraints on a teacher's creativity, inhibiting their inherent urges to "go off script" in order to really engage students [45]. As such, providing teachers with new analytic and design tools to overcome institutional constraints by taking on diverse and changing roles during TPD activities can shed light on the embedded institutional (often 'naturalised', or deep-rooted) behaviours that may constrain teachers in the pedagogical process ([12], p. 41). Technology can play a significant role in drawing in remote, external peers' perspectives. It removes teachers from their school echo chambers, injecting the perspective of the 'other' to learn and grow from and to avoid reinforcing only local traditions.

5.3.2.3. School leadership. School leaders play a large role in 'culture setting' at schools and in wider communities; yet just 20 (12%) studies discussed the role of leadership support in TPD. A school leader who can properly manage and maintain tech resources and provide teachers with the adequate support to integrate technology into classroom practice can act as a lynchpin for the school [22]. Teachers who are hesitant about or resistant to change need role models to show them how they can progress their practice [40]. Agyei & Voogt [1] go further, stating that enabling and supporting school leaders to provide proper "pedagogical leadership in ICT integration [...] will inspire new teachers to push the boundaries of using ICT-enhanced activity-based learning innovation" (p. 103).

Dlamini & Mbatha [40] assert that inspiring school leaders can positively impact learning outcomes. In their study on South African teachers' tech readiness, the high-performing schools had involved school leaders working on school ICT strategies alongside "champion teachers on the ground" who were confident modelling their practice to others ([40], p. 28). School systems must establish mechanisms for identifying high-performing teachers to act as these champions; 19% of the studies cited the benefits of peer support.

5.3.3. Micro-level factors influencing TPD

Whether in the classroom, or through distance means, education decision-makers must prioritise the micro level – where learning happens – when planning, designing and implementing TPD activities.

5.3.3.1. Co-design, experimentation, and teacher voice and agency. Kalogiannakis [84] argues that most "ICT training lacks attention to the context in which teachers work" (p. 14). An effective method of ensuring decision-makers are mindful of micro-level factors is through co-design, where teachers are decision-makers, themselves involved in the planning and design process.

Customisation by, with and for teachers can be supported through design-based research (DBR)[14] that is contextually responsive to participant teachers' needs [131] and sustains teacher learning [103]. An online TPD programme for STEM (science, technology and engineering) subjects in Pakistan in participants' schools allowed the researcher and teachers to collaboratively evolve the programme implementation and evaluation ([7], also discussed in Section 5.2.1.) The resulting accessible online learning environment provided teachers with opportunities to explore STEM integration "by building a community of practice that integrated both asynchronous and synchronous technology-mediated environments" (ibid., p. 204). Such DBR models can also have positive multiplier effects on teachers acting as role models and creating positive collective cultures, elements which can traverse into the meso level and increase potential for scalability.

Teachers are a heterogeneous group, thus the concept of affording teachers agency must be tailored to teachers' backgrounds, experience, beliefs, knowledge, attitudes and motivation (appearing in 99, or 58% of, studies). One-size-fits-all TPD designs can be problematic. As Celestin & Yunfei's [26] findings reveal, teachers' pre-training characteristics (e.g., learning readiness and personal capacity) are significant predictors of post-training performance. Therefore, initiatives must embody the common characteristics of effective TPD (as per Section 2.1) and treat teachers as individuals (just as learners should be treated in the classroom). De Clercq & Shalem (2014) propose a differentiated form of TPD, whereby professional development differs in its organisation, pace, location and modality, according to teachers' needs.

Several studies demonstrate the complexity of teacher agency versus appropriate scaffolding for teachers and show why these features must be treated as fluid concepts. In Bangladesh, pre-loaded iPods increased teachers' classroom use of audio and video materials, but teachers rarely created their own resources [198]. A reliance on ready-made resources such as scripted lesson plans may therefore inhibit teachers' creativity, potentially damaging long-term teacher motivation in the process (ibid.).

(Semi-)scripted lesson plans can set common expectations around student learning and provide less experienced teachers with an appropriate amount of scaffolding, yet more experienced or confident teachers might find them demotivating; responsively fading support is important. While Piper, Zuilkowski et al., [174] found that (semi-)structured pedagogy offered a cost-effective approach to TPD in Kenya, another study exploring teachers' guides across 13 countries and 19 projects offered a salutary lesson. Overly scripted guides produced poorer teacher learning outcomes than simplified ones [173]. Teachers did not adhere to the scripts, often reducing group work for more teacher-oriented activities. Moreover, Kotze et al., [100] suggested, "without teacher learning and teacher agency, these elements of the instructional infrastructure [structured pedagogy, scripted lesson plans on tablets, teacher guides etc.] have little chance of transforming the everyday learning activities and tasks in the classroom" (pp. 5–6). Exploiting technology to share lesson videos or offer opportunities for pedagogy-related discussions (e.g. on social media) can be fruitful though (see 5.1.2).

5.3.3.3. Motivation, time constraints, teacher needs, skills and attitudes towards tech. Motivation can manifest across the system and implicate a range of educational stakeholders. As discussed in Section 5.3.2.2, Lindenberg et al., [111] speak to the high turnover of teachers in Nicaragua, where passion for education is often second place to a teacher's need for a steady salary to support their family. As such, the positioning of the teaching profession in certain LMICs can mean that there are more 'push' than 'pull' factors. Continual teacher turnover has implications for sustainability and scalability of TPD programmes, reliant on continuous feedback loops and the transfer of knowledge, experience and learning, enabled through retention and progression of teachers.

The mode of TPD can also impact a teacher's willingness to engage in professional learning. While blended or distance-based models may be seen as flexible forms of participation, micro-level factors such as teachers' digital literacy or lack of access to personal devices can obstruct participation. This was observed in the previously discussed

[14] DBR involves iterative cycles of design, evaluation and re-design, in collaboration with local stakeholders. DBR studies build theory and generate design principles as well as impacting on practice.

Widodo et al., [243] study (Section 5.2.1) on blended TPD in Indonesia which saw very low online participation compared to the in-person approach. Rapidly increased mobile phone permeation in LMICs may offer more accessible opportunities, yet these are vastly under-used to date (see Figure 9). Unsurprisingly, another key (dis)incentive of teachers' engagement in TPD is time constraints, appearing in 19% *(f=32)* of studies. An online collaborative learning initiative proved ineffective for science teachers in Botswana, with work pressures stated as a core concern [19]. Schools can play a key role in alleviating work pressures by supporting and creating a culture of ongoing teacher learning in the workplace. However, schools are of course part of the broader system that may heighten the pressures placed on schools, in turn pressurising teachers.

It is uncommon for technology-mediated TPD programme designers to assess the learning needs of teachers [26]; although 28% of the studies discussed teachers' prior ICT skills, this figure seems low given the significance of determining teachers' existing skills before implementing a TPD initiative. Nevertheless, one study in rural Kenya found that creating locally-relevant content following a needs assessment ensured teaching practices were developed with support from local TPD experts ([158], see Exemplar 3). This was implemented in a blended learning approach based on reflective practice. Moreover, if teachers have developed skills and positive perceptions in relation to technology, students themselves may feel more confident to engage in the subject content [26]. Conversely, negative perceptions can lead to reluctance. Therefore, tech readiness and adoption sit firmly within a teacher's willingness, skill level and pedagogical belief system [43], along with TPACK [66] proving crucial to the degree of creative classroom technology use [1].

5.3.4. Cross-cutting elements in a coherent system: cost effectiveness, sustainability and scalability

All elements of the TPD system are co-dependent. This section highlights tech-supported TPD studies through this multilevel lens. These designs are generally cost-effective, scalable and/or sustainable (Exemplar 6 provides the first example).

Exemplar 6
TESSA

The TESSA OER project in sub-Saharan Africa has merged educational theory, digital technologies and teaching practice [65]. The project reached 300,000 teachers, holding promise for scaling TPD across SSA. The critical indicators of success include project 'take-up' in diverse settings and the significant impact on the practices and identities of teacher educators and teacher-learners. The programme altered teachers' perceptions of their role from using 'chalk-and-talk' methods to becoming creative "facilitators of learning'' [247].

Students' learning experiences grew through the programme. There was also some degree of impact on ministries of education, through policy reforms and changes in practice. For example, faculties began to work more closely with schools, and materials were used to upskill school leaders. Notably, impact was achieved despite limited ICT infrastructure and expertise.

5.3.4.1. Cost-effectiveness. The cost-effectiveness of a TPD initiative and its related potential to scale is integral to building and expanding TPD initiatives. It is particularly important to understand the costs involved given the scarcity of resources that constrains TPD in LMICs [24]. However, cost analysis is complex, particularly when considering broader costs beyond monetary value. Though this complexity must be recognised, only 11% of studies reported any detail of cost. This reflects the wider issue discussed by Bruns et al., [22] of "a huge publication bias; programs with negative or negligible impacts are almost never reported, and among programs with positive impacts, cost data are not always reported" (p. 226).

Handheld devices can be more versatile than personal desktop computers and are favoured by teachers, as seen in the Primary Mathematics and Reading (PRIMR) Initiative [171]. Not only do portable devices enable more flexible access, but they are also less costly per unit and provide greater opportunities to be shared among colleagues. This positive move away from the "locked, gatekeeper-controlled [computer] lab" (ibid., p. 11) denotes a shift towards technological integration within classroom settings. However, data from Figure 9 show that the TPD landscape does not tend to follow this shift, with 42% of all mentions of devices focusing on computers (although laptops are included within this category). That said, regional data analysis as illustrated in Appendix F (Figure 12) shows that mentions of smart devices and computers for TPD are equal in SSA and South Asia. A further analytical lens (time) shows that computers made up a slightly higher share of devices in studies published between 2008–2013 (48%) compared to studies published between 2014–2020 (40%).

The PRIMR study elucidated cost implications across different levels of the education system. For example, providing tablets at the meso level (to tutors) as opposed to the micro level (to teachers or students) keeps costs manageable. In terms of learning outcomes, all (tech and non-tech) treatment groups performed better than control groups [171]. However, it was unclear whether PRIMR's instructional approach was the more significant factor versus the presence of technology.

Technology cost analyses must be transparent, comparable and considered alongside the learning benefits of any given technology [24]. Use of low-cost MP3 players for teacher learning in rural settings has improved classroom instruction (ibid). The *shared* use of media players within a school proved the most cost-effective option. Although no learning outcome data were provided, per-lesson costs would be even less at scale than printing paper-based materials (ibid).

5.3.4.2. Scalability and sustainability. 'Scalability' denotes the potential of a tech-supported TPD intervention to expand and be implemented beyond the initial location(s), reaching more teachers and learners.[15] 'Sustainability' refers to the durability of a TPD initiative beyond its initial time frame. Both are core to establishing coherence and improving learning outcomes.

If a TPD initiative were to reach national scale – and sustain this – it would support the development of a coherent TPD system with the leverage to engage myriad teachers at once across different contexts, ensuring teachers are connected in a lasting way. The national-scale PRIMR study in Kenya (discussed in Section 5.3.4.1) is one example of a country-wide operation which can build on the learning from previous years [172]. However, cautionary lessons concerning simplistic assumptions about scaling are learned from studies like that of Kraft et al.,

[15] 'Scalability' usually refers to at least district-level expansion, although there is no agreed definition.

[102] on teacher coaching. This showed that effects from effectiveness trials of larger programmes can be far smaller than the effects of smaller programmes.

Claims that programmes are sustainable are not often validated internally or externally [82,90]. Furthermore, a minority (18%) of studies were longitudinal (i.e., containing more than two data-collection time points). Moreover, follow-up after programme completion is rare; evaluations usually take place immediately post-TPD, with little evidence on the long-term effects and changes in teaching practice in these instances. Factors such as implementation delays or unstable political contexts (e.g., [28]; School-to-School International [[189], 2017] may contribute to sustainability issues in LMICs.

Studies[16] that have considered sustainability in-depth include Cilliers et al., [29], who found that the virtual coaching mode initially appearing successful [100] became less cost-effective than in-person coaching after 3 years; the on-site mode was costlier but had significantly greater impacts on learning outcomes. Moreover, home language literacy of the virtual coaching group was again crowded out and actually declined. Additionally, a year-long OER4Schools programme (Exemplar 2) in one Zambian school was followed up through teacher interviews after 18 months [69]. The programme became self-sustaining; previous participants became peer facilitators and teachers had further developed their interactive teaching strategies. Key sustainability mechanisms included culturally sensitive and participatory programme development, semi-structured multimedia materials, and supportive institutional and national structures for professional learning.

Exemplar 7 presents a final example, revisiting the HALI programme highlighted in Exemplar 1. An earlier study undertook detailed cost analysis and was designed to be both scalable and sustainable. These core considerations were noted as proving key to thinking systematically about TPD and engaging with actors, elements and processes at the micro, meso and macro levels.

coding and quality assessment, which can support many further research inquiries.

Seven key conclusions emerge from the findings, as follows. These relate to our first three RQs; conclusions regarding RQ4 are embodied in the Recommendations below.

1 **TPD for technology use is generally under-researched in LMICs (RQ1 – characteristics of studies).** Most countries produced no research studies at all over the 12-year period. Indeed, only 5 countries had 10 or more studies – China, India, Kenya, South Africa and Turkey. These were all MICs, reflecting the inequitable distribution of research. This is a significant influencing factor, given that what is effective in MICs may not be effective in LICs, particularly for marginalised groups whose needs are largely ignored in the literature (RQ3). More support for research conducted in LICs is called for.
2 **Methodological issues abound: sustainability, sampling, access to evidence (RQ1).** The absence of follow-up studies makes it very difficult to judge sustainability, and future research must consider the long-term impacts of TPD interventions leveraging digital technologies. The majority of studies included in this review involved small sample sizes across a limited geographical area (e.g., one school, teacher college, or region), rendering it difficult to make inferences around scalability. Several larger-scale programme reports/evaluations were identified that did provide valuable insights. Nonetheless, the lack of grey literature made publicly available implies that there is a significant amount of (potentially available) evidence from TPD initiatives that is not informing research and decision-making processes.
3 **EdTech can be successfully leveraged to overcome constraints operating in LMICs (RQ2 – effective tech-mediated TPD).** The literature suggests that technology can be harnessed not only to support peer learning, but to build bridges across cultures and geographies, and support the cognitive and attitudinal development of teachers in LMICs. Moreover, social media, including Facebook and WhatsApp, have supported teachers within and across countries to form remote communities of practice, share resources and build knowledge. Preloaded devices that supply teachers with multimedia resources to learn from are promising forms of support. Computers remain the prevalent form of EdTech despite the influx and potential value of smart devices in increasing reach in LMICs. EdTech has the potential to provide flexible learning methods and modalities through online, blended learning or self-study opportunities. Self-study, however, requires that individual teachers have the drive, professional autonomy and technological skills to engage in professional learning activities [243].
4 **The role of TPD facilitators/coaches emerges as paramount, although research on how tech can support these pedagogical leaders is sparse (RQ2).** It can provide (semi-)structured observation tools and prescriptive feedback for use with teachers, for

Exemplar 7
The HALI programme, Kenya

HALI is a health education and literacy intervention that was integrated into teachers' everyday responsibilities [48]. Simplicity was intended in order to be replicable, using locally sourced and accessed semi-scripted lesson plans and instructional materials along with weekly SMS support. Teacher engagement remained steady throughout the project. In addition to quantifiable gains in knowledge, teachers identified changes in their responsiveness to student needs (p. 93). A 'micro-costing' or ingredients-based approach was taken, costing each element of TPD support (e.g., [46]). The three main contributors to cost were: (a) initial training (32%); (b) teacher materials (29%); and (c) SMS support (20%). After one year of the intervention, teachers' knowledge related to early literacy instruction was significantly higher than that of newcomers to the intervention. While student learning outcomes were not reported (as the authors acknowledged), they were measured in the subsequent study by Jukes et al., [80] (Exemplar 1).

6. Conclusions

The increase in numbers of studies published over the past decade, compared to the few from the preceding years, indicates that pioneering research is currently taking place in this exciting field. This review is thus timely. It contributes to the field by offering a wealth of examples – drawn from an unusually large corpus of 170 studies – that evidence and illustrate how we can exploit the significant potential that EdTech offers for TPD in LMICs. This includes how EdTech interacts with contextual influences and how initiative outcomes can be effectively evaluated and better understood. It is accompanied by a truly unique resource for the field: an open, substantial database including fine-grained thematic

[16] Both have been published since the review search period.

instance [185]. Video-recorded observations allow expert coaches or mentors to connect to the physical classroom quickly and cheaply; however, they are under-utilised in virtual coaching. Importantly, despite the common focus on digital technologies in the literature reviewed, the importance of human relationships was frequently emphasised. Without relationship building, virtual coaching in particular can lose efficacy [29].

5 **TPD outcomes are mixed (RQ2).** Tech-mediated TPD outcomes include pedagogical and subject content knowledge, support for teachers' material resource creation in low-resource settings, and increased motivation of both teachers and learners. However, many challenges arise. The evidence often draws on self-reported data or fails to identify changes in classroom practices and/or student learning. Likewise, few studies detailed negative effects of EdTech within TPD initiatives. While research is often understandably directed toward measuring its added value to teaching and learning processes, it is fundamental that any detrimental impact is reported. This enables the field to collectively learn and develop understanding of how EdTech can be effectively applied to improve teaching and learning for all.

6 The findings reinforce conclusions from previous research that **successful TPD is designed with and for teachers rather than being imposed (RQ2)**. Critical reflection through iterative testing in classroom practice can highlight exactly what contextual adaptations need to be made to address specific needs [109]. Future research should examine how using EdTech can more effectively (and efficiently) facilitate the desired deep, critical, 'structured' reflection [166]. This means building in particular on the emerging implications for the types and levels of support (both theoretical and practical) needed to accompany use of videos as stimuli for discussion.

7 **Technology-mediated TPD can be used to narrow inequalities (RQ3)**, especially through providing greater access to teacher learning in remote/rural areas, enabling marginalised voices and enhancing agency. This requires sufficient investment and strategic planning, though, to avoid inequalities in practice being exacerbated – as observed during the Covid-19 pandemic [44,234]. This review's findings contribute to a more nuanced understanding of the emerging opportunities and challenges related to equity; nonetheless, a large volume of research data were not disaggregated to understand how initiatives impact certain groups. It is thus difficult to assess how technology-supported TPD affects different teachers and learners, and how their needs can be more effectively addressed. For instance, given the well-documented gender disparities relating to access and use of technology [240], the tiny number of studies focusing on TPD to support girls' learning is concerning.

While this review was being conducted, the Covid-19 pandemic led to an increased use of technology by teachers and learners. However, support for teachers to adjust to virtual and blended modes of teaching has been patchy, reinforcing existing inequities: "there has not been a global transformation of how teachers use technology" (blog: Wilchowski & Cobo, 2021). The needs identified and recommendations made by this review thus remain highly pertinent.

Recommendations

1 We encourage future TPD programme designers, policymakers, researchers, evaluators, teachers and teacher educators to **take account of multi-level factors across the whole system that influence the success of TPD (RQ4)**; for example, by:
 a taking account of teachers' professional learning needs, motivation and agency, in order to increase appropriateness and efficacy of programmes (micro level);
 b working with teachers to co-create TPD models through, for example, design-based research (micro level);
 c ensuring study of the impact of TPD both on teachers' knowledge and skills but most importantly on the subsequent impact on students' knowledge and skills (micro level);
 d ensuring schools and communities are equipped with the physical and human resources to support technology-mediated TPD (meso level);
 e developing a deeper understanding of the structural and cultural factors that can support or constrain technology-mediated TPD (macro level).

Finally, researchers and stakeholders in this space should also enable and advocate for greater open access to the evidence, both journal articles and grey literature, to inform decision-making.

2 From the 170 studies reviewed on tech for TPD in LMICs, these **high-potential evidence gaps emerge**:
 a more research on larger-scale and longer-term technology-mediated TPD programmes;
 b more studies in under-represented countries, particularly by researchers from LMICs;
 c strategies for using technology to reach and include marginalised groups of both teachers and learners, and to cater for diverse (learning) needs;
 d more research on tech-supported TPD in rural settings often associated with additional challenges (e.g., infrastructure, socio-economic status, conflict/emergency, attendance of girls);
 e how the measures undertaken by some researchers to successfully mitigate the potential detrimental effects of using technology on social relationships between teachers and coaches/TPD providers might be applied more widely, including investigating the use of social media and the feasibility and benefits of video-recorded observations in virtual coaching;
 f more research on how tech can be used to support TPD facilitators and teacher educators (e.g. through scripted coaching software or virtual learning environments);
 g more research on the relationship between technology use and the levels of structure in pedagogy and lesson scripting that are appropriate to sustain pedagogical change across contexts – this includes how much structure is necessary in TPD using social media, and how the effectiveness of informal social media initiatives can be maximised.

3 **These methodological gaps arise:**
 a investigating the added value of technology compared to in-person TPD models;
 b measuring cost-effectiveness of initiatives consistently and comprehensively using experimental methodologies to understand 'hidden costs';
 c undertaking more assessment of impacts on student learning outcomes;
 d conducting follow-up studies to assess sustainability;
 e including more stratification by characteristics of teacher participants (and learners) as well as the disaggregated impact of TPD, e.g., between teacher groups or across geographical regions;
 f strengthening the rigour of reports featuring qualitative data analysis and validating self-reports;
 g conducting reviews of literature published in other languages such as Spanish, Arabic, French and Chinese.

Author contributions

Sara Hennessy led the team, the conceptualisation and review writing. Three team members, Sophia D'Angelo, Saalim Koomar and Adam Kreimeia undertook screening, thematic coding and quality scoring along with writing the conceptual framework and synthesising findings. Another core team member, Nora McIntyre, led on database generation and management, including conducting all of the searches

and developing the analytic schemes. Lydia Cao undertook coding and conducted all of the data extraction, preparing Section 4 and Technical Appendix F. Meaghan Brugha contributed to coding and quality scoring. Asma Zubairi analysed and summarised the quantitative data for Section 4.2.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.caeo.2022.100080.

Appendix A. Historical overview of publications on technology and teacher professional development

1995 – Technology and teacher professional development – US department of education's office of educational technology [67]

1999 – Technology professional development for teachers [191]

2000 – The open learning environment: a new paradigm for international developments in teacher education [142]

2003 – Technology and classroom practices [101]

2005 – Using technology to train teachers: appropriate uses of ICT for teacher professional development in developing countries [53]

2005 – Towards a framework for the use of ICT in teacher training in Africa [228]

2006 – DEEP IMPACT: An investigation of the use of information and communication technologies for teacher education in the global south [107]

2006 – Technological pedagogical content knowledge: a framework for teacher knowledge [136]

2008 – UNESCO ICT competency framework for teachers (version 1) [223]

2008 – International handbook of information technology in primary and secondary education (Kirschner, P., Wubbels, T., & Brekelmans, M. Benchmarks for teacher education programs in the pedagogical use of ICT (pp. 435–447).

2010 – Creating new forms of teacher education: Open educational resources (OERs) and the Teacher Education In Sub-Saharan Africa (TESSA) programme [144]

2010 – Reexamining technology's role in learner-centred professional development [176]

2011 – UNESCO ICT competency framework for teachers (version 2) [224]

2013 – New modes of teacher pre-service training and professional development (Moon et al., 2013)

2013 – Moving education into the digital age: the contribution of teachers' professional development [220]

2015 – Where it's needed most: quality professional development for all teachers. Recommendation 7: use ICT to provide access to content, professional development and professional learning communities [106]

2015 – Towards design-based approaches for ICT integration in African education [235]

2016 – Responding to challenges in teacher professional development for ICT integration in education [216]

2017 – Can new modes of digital learning help resolve the teacher crisis in Sub-Saharan Africa? [145]

2018 – Technology-supported professional development for teachers: Lessons from developing countries [127]

2018 – UNESCO ICT competency framework for teachers (version 3) [226]

Appendix B. Low- and middle-income countries included in searches

Countries searched for were as follows:

Afghanistan; Albania; Algeria; American Samoa; Angola; Argentina; Armenia; Azerbaijan; Bangladesh; Belarus; Belize; Benin; Bhutan; Bolivia; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; Burkina Faso; Burundi; Cabo Verde; Cambodia; Cameroon; Central African Republic; Chad; China; Colombia; Comoros; Congo, Dem. Rep.; Congo, Rep.; Costa Rica; Côte d'Ivoire; ; Cuba; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt, Arab Rep.; El Salvador; Equatorial Guinea; Eritrea; Eswatini; Ethiopia; Fiji; Gabon; Gambia, The; Georgia; Ghana; Grenada; Guatemala; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; India; Indonesia; Iran, Islamic Rep.; Iraq; Jamaica; Jordan; Kazakhstan; Kenya; Kiribati; Korea, Dem. People's Rep.; Kosovo; Kyrgyz Republic; Lao PDR; Lebanon; Lesotho; Liberia; Libya; Madagascar; Malawi; Malaysia; Maldives; Mali; Marshall Islands; Mauritania; Mexico; Micronesia, Fed. Sts.; Moldova; Mongolia; Montenegro; Morocco; Mozambique; Myanmar; Namibia; Nepal; Nicaragua; Niger; Nigeria; North Macedonia; Pakistan; Papua New Guinea; Paraguay; Peru; Philippines; Russian Federation; Rwanda; Samoa; Sao Tome and Principe; Senegal; Serbia; Sierra Leone; Solomon Islands; Somalia; South Africa; South Sudan; Sri Lanka; St. Lucia; St. Vincent and the Grenadines; Sudan; Suriname; Syrian Arab Republic; Tajikistan; Tanzania; Thailand; Timor-Leste; Togo; Tonga; Tunisia; Turkey; Turkmenistan; Tuvalu; Uganda; Ukraine; Uzbekistan; Vanuatu; Venezuela, RB; Vietnam; West Bank and Gaza; Yemen, Rep.; Zambia; Zimbabwe

This list of 136 countries derives from the World Bank's [252] country inventory.

Appendix C

https://docs.google.com/spreadsheets/d/1Zi9lOZvmfvJMESPtvjQv5mJg2ZmVfPPXKa8g2vsLRfM/edit#gid=0.

Appendix D

https://docs.google.com/spreadsheets/d/1ZVxW4-GgvaU-JHF35tjeKT1wzyoJypqle2ppWrnucLE/edit?usp=sharing.

Appendix E

https://docs.google.com/document/d/1kDuBE1BwFtkd9_02LhO81n7vISk7-rGCwjb5jD6fPoE/edit#heading=h.qafxpil7ckt9.

Appendix F

https://docs.google.com/document/d/1-FeZ86XD4ctRQEKeN2gBA7Uvi8YHu3U3oXn-_nH_jhY/edit.

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