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Technology in education

TECHNOLOGY USE IN TEACHER PREPARATION AND PROFESSIONAL DEVELOPMENT IN LOW-AND MIDDLE-INCOME COUNTRIES

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ABSTRACT

This background paper for the Global Education Monitoring Report (GEMR) critically engages with evidence on technology-mediated pre-service teacher education and in-service teacher professional development (collectively termed 'TPD') in low- and middle-income countries (LMICs). Educational technologies offer significant potential to enhance TPD opportunities, which in LMICs are often limited, unsustained, and not evidence-based. Our report is based on the first systematic literature review characterising contextually appropriate, culturally relevant and effective uses of technology in TPD in LMICs. An in-depth synthesis of 170 studies (published between 2008–2020) spanning 40 countries considered macro-, meso- and micro-level system factors in TPD design and implementation. The analysis additionally includes global teacher survey data, ongoing initiatives in LMICs, and 46 other sources (mostly recently published works: 2020–2022). The particular focus is on those tech-mediated TPD models that are sustainable, scalable, cost-effective, supporting the most marginalised teachers and/or learners, and concerned with changing teacher learning practices or improving student learning outcomes. Results showed benefits for teachers, particularly in relation to using tech to provide flexible teacher learning environments; foster remote communities of practice; support coaching and mentoring; cultivate teacher reflection; and improve teachers' knowledge of the language of instruction, subject content knowledge or pedagogical content knowledge. Evidence for sustainability, cost-effectiveness or tangible impacts on classroom practice and student outcomes remains thin, alongside limited attention to marginalised groups. However, promising large-scale initiatives have been identified that may serve to fill some of the persistent evidence gaps. Recommendations are made for researchers, policymakers, teachers and teacher educators.

Keywords

Teacher professional development, teacher training, technology, ICT, low- and middle-income countries (LMICs), marginalised groups, e-learning, pedagogy, communities of learning, coaching, reflective practice

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1.Introduction

The Covid-19 pandemic has sharply increased 'learning poverty' and exacerbated low levels of attainment by children and young people all over the world (⇡Azevedo et al., 2021;⇡UNESCO & UIS, 2017). In many low- and middle-income countries (LMICs), an estimated 70% (up from 57%) of learners now cannot read a simple text with comprehension by age 10 (⇡World Bank et al., 2022). Within-country socio-economic disparities (especially between urban/rural areas) exacerbate inequities in how countries responded to the pandemic (⇡Vegas, 2020). Students marginalised for geopolitical and other reasons are particularly vulnerable to learning losses (⇡UNESCO, 2020a). When used effectively, educational technology (EdTech) can help address these learning losses; it can also, however, widen learning inequalities (⇡Vegas, 2020). Technological innovations are rapidly changing the educational landscape, increasing the need for societies to consider how to leverage EdTech for improved learning outcomes.

The importance of considering EdTech has also become increasingly evident with the recent pandemic, mass school closures, and the need for teachers and schools to turn quickly to remote and hybrid teaching and learning modalities to prevent and then address the learning losses detailed above. Indeed, a global survey of 20,679 teachers across 165 countries emphasised the rapid adaptation demanded of teachers. Forty-two per cent of respondents spent more than 10 days participating in (mostly technology-related) professional development during the preceding year (⇡Pota et al., 2021). Assuming a 7-hour day, this equates to more time spent on TPD than the usual average in OECD (Organisation for Economic Co-operation and Development) countries of 62 hours annually (⇡Henshaw, 2021); one would expect the average to be lower when including LMICs. So, teachers were, on the whole, provided with more development opportunities in reaction to the pandemic. The survey also confirmed that, in LMICs, many teachers (and their students) still do not have access to reliable internet connectivity or digital devices. Beyond infrastructural constraints, digital skills are often limited, which can hinder the use of EdTech for remote learning.

The potential for technology to support teaching and learning is multifaceted: EdTech can be used by students to improve learning outcomes, it can be used by teachers in the classroom to support pedagogical practices and it can be used by teachers and teacher educators to develop their knowledge and skills. This background paper is concerned with the latter: the use of technology as a medium for teacher professional development (TPD) related to school-level education.

Clarifying terms:

In this paper, we use the term 'teacher professional development,' or TPD, to refer to both continuing ('in-service') and initial ('pre-service') teacher education and training opportunities, as well as informal professional development opportunities that teachers may engage with on their own.

We also generally refer to technology-mediated TPD (tech4TPD) throughout this report. We have chosen the word 'mediated' (rather than 'tech-supported', 'tech-enabled' or 'tech-enhanced', and simply referring only to TPD that involves a technology medium, regardless of its efficacy). This is because we hold a critical stance towards technology – recognising that EdTech may not always 'enhance,' 'enable' or positively impact TPD. At times, the effect of introducing hardware or software into a TPD programme may be minimal, and in certain cases, there may even be unintended negative effects. Occasional exceptions are made (the term 'tech-supported' is used) when referring to contexts where technology is known to be supportive.

The authors are positioned within EdTech Hub. This long-term programme equips decision-makers to make informed decisions by increasing the quality and availability of evidence on the role that EdTech plays in raising learning outcomes in LMICs at scale, especially for marginalised learners. Hence, our report brings in research on marginalised teacher and student groups – often glossed over in the literature – where applicable. The specific focus is on LMICs, where teachers are often under-qualified with limited TPD opportunities to develop their pedagogical and subject knowledge (⇡McAleavy et al., 2018). Improving TPD is one pivotal strategy in raising outcomes for poor and marginalised learners in particular.

This paper is heavily based on our recent systematic literature review (⇡Hennessy et al., 2022) that collated and critically evaluated the breadth and strength of evidence on relevant technology-mediated TPD initiatives, across all LMICs. It investigated how EdTech can be used to support effective, scalable, sustained development of teachers in LMICs, including improving subject knowledge and/or classroom pedagogy. We took a critical perspective concerning contextual appropriateness, the added value of technology, and the scope and rigour of the research. Results of the in-depth synthesis of 170 studies indicated that the field is rapidly developing, but that tech4TPD outcomes are mixed. While they largely showed benefits for teachers, the research studies were rarely designed to measure: 1) sustainability across the long term, 2) detailed costs of programmes, or 3) outcomes in the classroom. Limited attention was paid to marginalised groups: only a small number of papers focused on marginalised teachers, including teachers working in emergency settings (f=3) and teachers of learners with special educational needs or disabilities (SEND) (f=1) or marginalised learners from low socio-economic status (f=11, 7 of which involved rural/remote learners too), learners with SEND or from education in emergency (EiE) contexts (f=3). The geographical spread of the research was somewhat limited: only 40/136 LMICs (see Appendix A for a full list of LMICs) had any studies. Additional information and illustrations concerning the promising and problematic initiatives emerging since the initial review are shared throughout this report.

1.1 Effective TPD in LMICs

Teachers are the most significant drivers of student learning at the school level. A breadth of evidence suggests that interventions focusing on teacher development are associated with positive effects (albeit small ones) on primary school learning outcomes in LMICs (⇡Angrist et al., 2020; ⇡Evans & Popova, 2015; ⇡McEwan, 2015). Given the learning losses caused by the Covid-19 pandemic (⤒Patrinos et al., 2022; ⤒Wolfenden, Cross & Henry, 2017), there is an urgent need to support teachers to develop their practices in ways that ultimately serve to improve student achievement.

There is a strong consensus about what makes TPD interventions effective. Table 1 below summarises some of the evidence-informed characteristics of effective TPD. While they tend to apply across countries (e.g.,⤒Hardman et al., 2011; ⤒Moon, 2013; ⤒Sims & Fletcher-Wood, 2020), they also require certain considerations and adaptations to attend to the diverse socio-cultural and economic contexts of LMICs. Teachers working in LMICs face unique challenges, and their political, cultural, and economic realities shape how they engage with TPD, their classroom practice, and their students (⤒Vavrus & Bartlett, 2012; ⤒Power et al., 2019). The core characteristics below, therefore, must not be considered prescriptive, nor universal, but rather adaptive and flexible.

Table 1. Key characteristics of effective TPD

Characteristic	Article sources
Programme content and relevance to teachers' needs	
Informed by research evidence concerning effective pedagogy	⤒Hennessy et al., 2021a; ⤒Osborne et al., 2013
Builds on teachers' existing knowledge, expertise and practices	⤒Darling-Hammond et al., 2017;⤒Timperley et al., 2007
Integrates subject knowledge and pedagogy	⤒Garet et al., 2001; ⤒Orr et al., 2013
Addresses teachers' needs, constraints, interests and agendas in a participatory manner	⤒Barnes et al. (2019); ⤒Power et al., 2019
Engages with difference and ensures linguistic, socio-cultural and other context-specificity	⤒Twining et al., 2013; ⤒Vavrus & Bartlett, 2012
Recognises that students have diverse learning needs	⤒Khvilon & Patru, 2002;⤒UNESCO, 2018
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	⤒DeLuca et al., 2015; ⤒Polly & Hannafin, 2010
Ensures programme design models the pedagogic approaches being promoted, taking a learner-centred approach	⤒Hennessy et al., 2016; ⤒OECD 2005
Emphasises peer dialogue and collaboration within a community of practice (including coaching)	⤒Khvilon & Patru, 2002; ⤒Voogt & Tondeur, 2015
Provides opportunities for discussion and critique of alternative approaches	⤒Marsh & Mitchell, 2014; ⤒Westbrook et al., 2013
Led by teachers and school-based	⤒Cordingley et al., 2015; ⤒Anamuah-Mensah et al., 2012

Institutional and external support for participation	
Aligns with national policy, curriculum standards and assessment frameworks	⭱Lawrie et al., 2015; ⭱Unwin, 2005
Aligns with institutional strategic goals and support from school leaders, striving for school-wide participation and impact	⭱Leach et al., 2006; ⭱McAleavy et al., 2018
Fosters a conducive culture for professional learning, reflection and feedback based on trust and support	⭱Leu & Price-Rom, 2006
Dedicates time for professional development and collaborative inquiry	⭱Desimone, 2009; ⭱Robinson et al., 2010
Sustains over time through regular sessions and ongoing scaffolding	⭱Hill, Papay & Schwartz, (2022);⭱Sims & Fletcher-Wood, 2020; ⭱Twining et al., 2011[1]

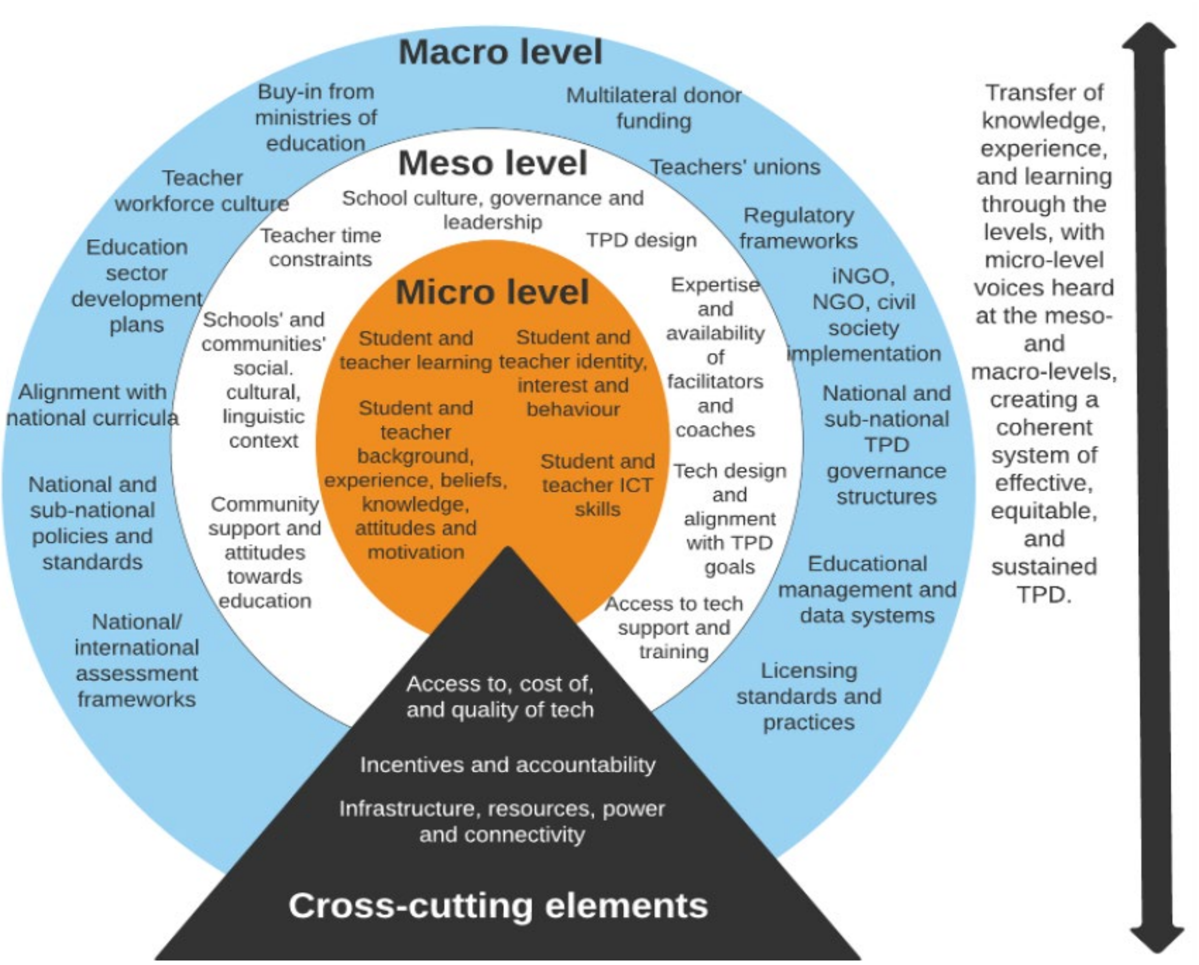
Source: Systematic review by ⭱Hennessy et al. (2022)

1.2 Technology-mediated TPD: A systems approach

Like teaching and learning, TPD does not happen in a vacuum. It is thus necessary to approach TPD holistically, from a 'systems' perspective. This paper draws on ⭱Opfer & Pedder's (2011) framework for interacting professional learning systems and ⭱Lindvall & Ryve's (2019) typology of 'coherence', which suggests the need for alignment of TPD with goals at each level of an education system. We expand this narrative to integrate the role of technology within the TPD ecosystem (a framework for policy and practice, itself nested within the wider education system and sharing its macro, meso and micro levels). The resulting tech4TPD ecosystem is centred on factors influencing design, implementation and uptake). Figure 1 below presents our own conceptualisation, illustrating the importance of considering tech4TPD programmes as existing within a broader TPD ecosystem. Teachers' individual backgrounds, experiences, attitudes and knowledge (micro level) form part of a school or community culture (meso level), which has its own norms and practices. This culture in turn is situated more broadly within the policy environment or teacher workforce, as well as the overall national and regional cultural context (macro level). Each level interacts with and shapes the others.

[1] This source synthesised findings from⭱Cordingley et al. (2007);⭱Hall (2009); ⭱McCormick et al. (2008); ⭱Murchan et al. (2009);⭱Ofsted (2006); ⭱Opfer. Pedder & Lavicza (2008); and ⭱Williamson & Morgan (2009).

Figure 1. A coherent tech-mediated TPD ecosystem



We argue that it is essential to engage teachers in the design of TPD interventions to ensure their relevance and ultimately to maximise their effectiveness. Through co-design, teachers' voices can be heard and listened to at both the school and wider policy levels (e.g., ⇡Kafyulilo et al., 2015). TPD goals and implementation methods are hence not predetermined but negotiated with teachers, who have agency to make decisions regarding their own professional development ('coherence creation': ⇡Lindvall & Ryve, 2019). This helps create a reciprocal transfer of knowledge, experience and teacher learning. It also fosters coherence between the different levels of education systems, resulting in effective, scalable and equitable tech4TPD.

1.3. Aims, content and structure of paper

While there is general consensus regarding what makes TPD interventions effective in LMICs, there is less evidence on how technology can be used to further enhance and support teacher development and learning sustainably and at scale within and across diverse contexts. This background paper contributes to filling those gaps. It reports on how technology can potentially be used to support effective, scalable and sustained development of pre- and in-service teachers in LMICs, including through an analysis of the systemic (micro-, meso- and macro-level) factors supporting and constraining the use of technology for teacher professional learning itself. This paper complements other GEMR 2023 papers, notably the summary of the intrinsic and external barriers to teachers' use of technology in the foundational think piece by ⇡Burns (2021) and the background paper by ⇡Burns (forthcoming) on teachers' integration of technology into classroom-based teaching and learning, that is, teaching with technology in the classroom. Our own focus here is on supporting teachers and their professional development mediated through technology.

This paper explores some of the advantages, drawbacks and logistical considerations of various models of tech-mediated TPD. This includes identifying some key evidence gaps, for example, concerning sustainability, cost-effectiveness and tangible impacts on classroom practice and student outcomes. Findings of very recent follow-up searches, conducted in order to keep pace with the ongoing rapid developments in technology and to see whether evidence gaps identified earlier in our systematic review (⇡Hennessy et al., 2022) have been addressed, are included. In sum, synthesising and updating prior work offers clear, up-to-date evidence on effective practices within tech-mediated TPD. This report takes into account not only academic literature but also teacher perspectives and experiences of working with governments and other stakeholders in LMICs, contributing to further bridging the gaps between research, policy, and practice. It offers accessible and practical recommendations for the use of technology for TPD for policymakers, researchers, teacher educators, and EdTech implementers.

Section 2 of this paper elaborates upon our methodology. Section 3 then summarises the findings that emerged from the literature. In particular, it focuses on five key uses of tech4TPD: tech to offer flexible teacher learning environments (3.1), tech to foster teacher communities of practice (3.2); tech for coaching and mentoring (3.3); tech to cultivate teacher reflection (3.4); and tech to support teachers' knowledge of the language of instruction, pedagogical knowledge or content knowledge (3.5). Throughout the section, 'spotlight examples' are provided to illustrate how each modality can be effectively implemented across diverse geographies. Section 3.6 then links the previous subsections together, discussing system factors in relation to the five key uses of tech4TPD outlined in the paper. In Section 4, we provide examples of ongoing and promising tech4TPD intervention projects in LMICs – this time focusing on those that do not (yet) appear in the literature. Section 5 offers policy recommendations emerging from these collective findings, and Section 6 provides a brief conclusion.

2. Methods

This report triangulates messages across a body of evidence, drawing on:

(a) A rigorous synthesis of evidence via our comprehensive systematic review of 170 publications (spanning January 2008–July 2020) of empirical research on uses of technology in TPD in LMICs, including formal / non-formal learning by pre-service and in-service teachers of students aged 3–18. The outcomes are reported in a journal article (⇡Hennessy et al., 2022), an accompanying policy brief (⇡D'Angelo et al., 2022), a technical report (⇡Hennessy et al., 2021a) and an open, thematically coded and quality-scored bibliographic database.

(b) Updated literature searches spanning July 2020–July 2022, yielding 27 directly relevant papers, plus 19 further relevant sources that the team came across through their professional networks. Searches were targeted at key research evidence gaps emerging from the systematic review (see Appendix A for search terms and evidence gaps addressed).

(c) Collation of recent and current tech4TPD initiatives in LMICs, including research and technical assistance work by EdTech Hub teams collaborating with (and indeed embedded within) Ministries of Education, plus other key research and development of tech4TPD initiatives, sourced through our professional networks and via online searches.

Further details of the data sources and information about the analysis carried out appear in Appendix C.

3. Technology-mediated TPD in LMICs

The following sections synthesise evidence around five key themes that emerged from the tech4TPD review: the use of technology to

1. offer flexible teacher learning environments;
2. foster teacher communities of practice;
3. support coaching and mentoring;
4. cultivate teacher reflection;
5. develop teachers' language skills or content or pedagogical knowledge.

Many studies address more than one of these themes (for example, teacher reflection is often part of a community of practice) and so they are discussed in the section considered most relevant. Each section provides illustrative examples from the literature and examines the types of tech tools and resources that are used, alongside associated TPD programme activities and outcomes. In order to maintain the systems perspective to tech4TPD, Section 3.6 covers discussion of each thematic area or tech 'use' in relation to macro-, meso-, and micro-level enabling and constraining factors impacting programming efficacy, sustainability and scalability.

3.1. Technology to offer flexible teacher learning environments

Flexible teacher learning environments are both formal and informal, physical and virtual spaces where teachers can engage in TPD. When properly designed, they are adaptive to teachers' infrastructural and temporal needs, allowing them to participate in TPD wherever and whenever they want. Three examples of flexible tech4TPD that emerged from the literature review include: independent or self-study (f=22), distance learning (f=20), including Massive Open Online Courses (MOOCs; f=10), and blended learning (f=32). These flexible tech4TPD models often integrate virtual learning environments (VLEs, also known as learning management systems, or LMS; f=33). Due to their flexible and/or hybrid nature, they are commonly used in rural and remote settings (f=23). Examples of flexible tech4TPD environments have also emerged in the updated 2020–2022 literature searches, particularly in the context of the Covid-19 pandemic, which has prompted pre-service and in-service teacher education models to shift to online and remote modalities.

Flexible teacher learning environments can use technology as a tool to enhance the accessibility of TPD opportunities – by transcending physical barriers (e.g., place, including rurality and remoteness), as well as time. Overall, flexibility is critical to providing autonomy for teachers to choose how to learn. For example, teachers may now have the option to choose the pace, location and/or modality of their learning, which they did not previously have (⇡de Clercq & Shalem, 2014). Increased flexibility could also be afforded to teachers with regard to the content and pedagogical approaches they wish to engage in (e.g., self-study versus collaborative group work) (⇡Jonker, März & Voogt, 2020).

3.1.1. Distance learning and/or self-study

Distance learning and/or self-study models of tech4TPD can be particularly important for teachers working in remote and rural communities, or emergency settings, where access to TPD is often limited. For example, a global survey of teachers working in emergency settings found that these educators often organically turn to tech4TPD opportunities offered through open-source websites and social media to support their occupational and psychosocial well-being (⇡Inter-Agency Network for Education in Emergencies, 2021). Additional open course websites include EdX,[2] Edraak[3] (in Arabic), EduCaixa[4] (in English, Spanish, or Catalan), Coursera[5], FutureLearn[6], Alison[7] and Udemy,[8] many of which have mobile applications. MOOCs can provide continuous lifelong learning opportunities throughout teachers' careers (⇡Oyo et al., 2017; ⇡Wang et al., 2018; ⇡Wolfenden, Cross & Henry, 2017), especially in contexts of crisis including mass displacement (⇡Kennedy & Laurillard, 2019); or the Covid-19 pandemic (⇡Mays et al., 2021). When made accessible (e.g., through captions, text-to-speech software or editable font size and formatting), digital learning content can also support the professional development of teachers with disabilities. For example, an eLearning approach during Covid-19 improved the participation of most pre-service teachers with hearing and seeing disabilities, and fostered their autonomy, since they no longer had to depend on their colleagues to read lesson materials for them (⇡Ananga et al., 2021). A recent large online course that was sustained during the Covid-19 pandemic is the Distance Learning and Teacher Training Strategies in the Caribbean Small Island Development States project (Box 1).

[2] https://www.edx.org/ Retrieved 20 October 2022
[3] https://www.edraak.org/en/ Retrieved 20 October 2022
[4] https://educaixa.org/es/home Retrieved 20 October 2022
[5] https://www.coursera.org/ Retrieved 14 November 2022
[6] https://www.futurelearn.com/ Retrieved 14 November 2022
[7] https://alison.com/ Retreived 14 November 2022
[8] https://www.udemy.com/ Retrieved 20 October 2022

Box 1. Large online course in small island states of the Caribbean

Key information: The Distance Learning and Teacher Training Strategies in the Caribbean Small Island Development States project was piloted in 2020 and scaled up in 2021 with the support of the UNESCO International Taskforce on Teachers.

TPD model: The four-week hybrid training was designed to take a holistic and contextualised approach, addressing the needs of teachers in the Caribbean during the Covid-19 pandemic, such as, how to maintain engagement and interaction for learning online during school closures; convert content into appropriate online learning formats; handle school management issues; and how to work with students with diverse educational needs (⇡UNESCO, 2020b; ⇡Conover, 2022).

Technology used: Participating teachers identified various aspects of the online portion of the MOOC that they found useful for their professional development: the use of polls, surveys and self-study reading materials offered opportunities for further self-reflection; and live worksheets supported teachers in preparing their own worksheets for students (⇡Teacher Task Force & UNESCO, 2022).

Outcomes: While the project included teachers from Dutch- and English-speaking countries, the online platform allowed for the formation of language-specific breakout groups where participants could express themselves more comfortably. On the other hand, various challenges were also identified, including lack of access to devices or reliable connectivity for some teachers; the course was more demanding and did not afford flexibility for teachers to progress at their own pace; and there was a need to update the course to meet evolving teachers' needs.

While evidence suggests that distance education programmes can promote teacher learning (e.g., in South Africa: ⇡Amevor et al., 2021) and in some cases, even equal in-person TPD in terms of impact (e.g., in Ghana: ⇡Henaku & Pobbi, 2017), purely remote TPD runs the risk that teachers are not provided with the chance to (promptly) apply learning in practice. Teachers need time and opportunity to apply their skills and knowledge, to trial new instructional strategies and to reflect on their teaching. Various studies have pointed to how distance education for teachers of certain subjects, particularly in the sciences, may be inadequate, given the lack of opportunities for teachers to apply their skills and manipulate necessary equipment such as that found in science laboratories (⇡YeşiLoğlu et al., 2021; ⇡Arslan, 2021). Moreover, research indicates that MOOCs and other forms of technology for remote learning are disproportionately accessed by the more socio-economically advantaged teacher learners within each LMIC (⇡Castillo et al., 2015; ⇡Liyanagunawardena et al., 2013). For many teachers in low-income regions, accessing a VLE can be problematic, while other approaches, such as use of WhatsApp, can be more successful (e.g., recent, government-generated evidence from Zimbabwe (⇡Centre for Research and Integrated Development, Ministry of Primary and Secondary Education et al., 2022). What's more, MOOC materials are often developed within one cultural / geopolitical / curricular context; thus it is important to empower teachers to recontextualise the MOOC materials to adapt them to their own teaching context and needs of their students.

3.1.2. Blended learning models

Blended learning models are designed to minimise the challenges of face-to-face and fully online models of TPD and to exploit the benefits of both. Several studies on blended TPD initiatives (e.g., classroom application coupled with virtual peer reflection) demonstrated gains in teaching practices for teachers of remote/rural communities across India (⇡Wolfenden, Adolfini, Cross et al., 2017; ⇡Wolfenden, Cross & Henry, 2017), Bangladesh (⇡Shohel & Banks, 2010), Pakistan (⇡Anwar, 2017) and Kenya (⇡Onguko, 2014). The jiFUNzeni approach in Kenya stands out as a particularly promising model that has proven to be impactful and sustainable in rural and resource-constrained environments (see Box 2).

Box 2. Sustainable blended tech4TPD through JiFUNzeni in rural Kenya

Key information: The JiFUNzeni approach was developed through a design-based research intervention conducted in rural western Kenya. The field test included designing, developing and implementing a blended learning course for teacher professional development (⇡Onguko, 2014).

TPD model: Leveraging design-based research and local needs assessments, the JiFUNzeni TPD model highlights the importance of considering teachers' cultural and contextual realities when designing tech4TPD (⇡Onguko, 2012a). In the initial phases of implementation, teachers were trained in person on how to use the tablets and were then provided structured time to engage with self-study content either independently or with one another. Teachers could call teacher trainers for additional support using the mobile phones provided. Further, the programme allowed for fortnightly, follow-up, face-to-face meetings, which provided valuable spaces for teachers to share classroom experiences, develop their reflective practice, and give or receive feedback (⇡Onguko et al., 2013).

Technology used: The JiFUNzeni model utilises solar-powered tablets, Open Educational Resources (OER) and open-source software so that both teachers and teacher trainers can create multimedia resources (PDFs, video clips, podcasts and images), ultimately building instructional capacity across subjects through the thoughtful development and delivery of relevant content. These resources are then embedded in HTML content or published electronically so that teachers can access them for self-study (⇡Onguko, 2012a; ⇡Onguko, 2012b).

Outcomes: One year after the intervention, a small-scale study (n=10) found that teachers still used cooperative learning and activity-based learning strategies in their classrooms and that TPD leaders had not only maintained programming fidelity but also had created new innovative ways of supporting teachers through blended approaches (⇡Onguko, 2014). The approach continued in 2015–2019 through setting up an innovative school, Tujufunzeni Junior School,[9] based on experiential learning including EdTech use and regular TPD.[10]

Various blended learning models have also shown promise in emergency settings. In Lebanon, for example, the RELIEF (Refugees, Education, Learning, Information Technology and Entrepreneurship for the Future) project uses a blended model embedding online MOOCs into a campus-based teacher education course (⇡Inter-Agency Network for Education in Emergencies, 2022). The MOOC provides videos of model teaching in crisis contexts, with digital tools for content creation and an online discussion board. This was paired with in-person support from teacher educators, who accelerated the learning process by clarifying theoretical concepts (⇡Inter-Agency Network for Education in Emergencies, 2022).

[9] https://www.facebook.com/Tujifunzeni/ Retrieved 23 October 2022

[10] The school ultimately closed as parents were unable to pay the fees.

3.1.3. Flipped learning models

One form of blended learning, flipped learning models, is increasingly popular in high-income countries, including in teacher education (⇡Han & Røkenes, 2020), though less common in LMICs (f=7). Flipped learning allows teachers to watch video-recorded lectures or access other content independently and thus engage with theory or new pedagogical strategies before entering in-person TPD sessions. In doing so, it can help foster interactive approaches by creating more time to use participatory and experiential teaching and learning methods in sessions (if and when TPD leaders or pre-service teacher education lecturers know how to use these methods: e.g., Pakistan, ⇡Minaz et al., 2017, see Box 3). Flipped learning models enable TPD leaders to select the combination of virtual and in-person activities that maximises student engagement and learning in their contexts (e.g., Turkey: ⇡Kurt, 2017). They allow teachers to engage in learning content at their own pace (e.g., Turkey: ⇡Ipek et al., 2021) and follow content and assignments and access additional study materials outside of in-person or synchronous sessions (e.g., Turkey: ⇡Basal, 2015; Pakistan: ⇡Farooq et al., 2012), maximising opportunities for professional learning and development. However, losing the interactive component of flipped learning may negatively impact teacher satisfaction with these tech4TPD models (e.g., Turkey: ⇡Ilic, 2021). Further, there is a lack of evidence for the positive impact of flipped learning on teachers' practices or student learning, or of its application to synchronous online sessions rather than in-person ones. Only 4 of the 14 studies measuring student learning in the scoping review by ⇡Han & Røkenes (2020) showed significant positive effects.

Box 3. Flipped learning models for pre-service teachers in Pakistan

Key information: A small-scale (n=48) experimental study in Pakistan (⇡Minaz et al., 2017) drew on teachers' pre- and post-tests to evaluate the impact of a flipped learning model on the pedagogies of pre-service teachers.

TPD model: Teachers were able to watch (and re-watch) videos of lecturers in their free time. Clear instructions and post-viewing exercises prompted teachers to summarise key lessons learnt, brainstorm ideas, or identify parts of the video that were unclear or challenging to understand. During in-person follow-up lectures, teachers were able to explore these challenging topics further, and engage more in collaborative learning activities, including group and partner work. The role of the instructor in these lectures was pivotal, as they provided immediate feedback and guidance, and facilitated pre-service teachers' discussion and collaboration. At the end of the lecture, the instructor provided follow-up activities (i.e., homework) and the pedagogical progress of all pre-service teachers was assessed using post-tests.

Technology used: Teachers who participated in the flipped model received a DVD preloaded with various five–ten-minute videos explaining key topics, and accompanying PowerPoint presentations.

Successes and challenges: The study found that pre-service teachers participating in a flipped learning model learnt more than those participating in a traditional model. However, both groups improved their learning outcomes significantly, pointing to the importance of the quality of lectures/lessons and their facilitators, regardless of the use of technology.

3.2. Technology to foster virtual teacher communities of practice

The importance of communities of practice (CoPs) to connect teachers with their peers (and with their TPD leaders, mentors and coaches) cannot be overstated. The benefits of peer support were recognised in more than one-fifth of studies reviewed (22%), although the provision of remote peer feedback or evaluation (11%) and remote communities of practice (12%) were less common. This section explores the various uses of tech to foster remote CoPs between teachers in LMICs, given the growth of such CoPs since the initial systematic review during the Covid-19 pandemic (⇡Ghamrawi, 2022).

We define 'teacher communities of practice' broadly as any informal or formal structure or system in which teachers have the opportunity to communicate with each other, share ideas, resources or effective practices, and brainstorm solutions to common challenges. Importantly, teacher CoPs can be in-person, virtual or hybrid – and technology can play an important yet distinct role in any modality. For example, technology may be used as a communication tool, to connect teachers in virtual CoPs, or as a tool that teachers engage with during in-person CoPs (for example, using a tablet to watch videos of lessons and reflect on or discuss these together). Evidence also indicates spillover effects, whereby a virtual CoP among teachers in the same school or community, can also lead to further in-person collaboration (e.g., in Indonesia: ⇡Mardapi & Herawan, 2019). In this section, however, we focus specifically on how technology can be used to foster virtual CoPs.

Myriad EdTech resources have been used to foster CoPs in LMICs. In particular, the systematic literature review identified a range of social media and messaging tools (f=38), such as WhatsApp and Telegram (⇡Habibi et al., 2018), Facebook (⇡Bett & Makewa, 2020) or microblogs, such as wikis and forums (⇡Stewart, 2015). Additional EdTech resources identified in the updated 2020–2022 searches also include other social media websites such as Twitter (⇡Sunday, 2021) and Instagram (⇡Ramazanoğlu & Toytok, 2021).

3.2.1. Formal vs. informal remote CoPs

Importantly, we differentiate between two types of remote CoPs: those that are formal or integrated into structured tech4TPD models, and those that are informal, teacher-led or that organically arise through independent or self-study. Each has its own benefits and drawbacks. On the one hand, the nature of informal, teacher-led CoPs, likely results in content that is applicable and relevant to the needs of teachers (⇡Khalid et al., 2014; ⇡Stewart, 2015). These CoPs provide spaces for teachers' voices to be at the centre of TPD efforts, for teachers to have agency and decision-making power, and for all teachers involved to have opportunities to share their knowledge and experiences with their peers. On the other hand, a review of social media for TPD found that in the absence of experts or formal moderators, teacher-led CoPs may run the risk of spreading misinformation or inaccurate content (⇡Manca & Ranieri, 2013). Formal and informal remote CoPs need not be mutually exclusive, however. At times, formal CoPs may motivate teachers to continue to engage in informal or teacher-led CoPs beyond structured TPD time (e.g., in Ghana: ⇡Taner, 2018). In Indonesia, when social media was monitored by a teacher educator and paired with in-person TPD support, teachers felt more incentivised to engage with online learning (⇡Widodo & Riandi, 2013). In a systematic review of knowledge-sharing behaviour in virtual CoPs, ⇡Soto et al. (2021) assert a greater influence of internal motivations such as altruism or the need for affiliation in informal CoPs, whereas external factors such as anticipated rewards or reputation tend to have greater import in formal CoPs. Thus, teacher motivations differ based on the type of spaces in which they interact.

3.2.2. CoPs for rural/remote communities

Given the variety of low-, medium- and high-tech devices and resources that can be used in remote CoPs, CoPs constitute an important opportunity for teachers from marginalised communities, where access to infrastructure and connectivity may be limited (e.g., ⇡Bett & Makewa, 2020; ⇡Sari, 2012) and where access to expert pedagogical leaders may be scarce (e.g., ⇡Osmanoglu, 2015). Like VLEs or flipped learning models of tech4TPD (see Section 3.1), social media websites and apps connect pre-service teachers with lecturers outside of normal classroom hours, extending their opportunity for support and supervision (e.g., in Indonesia: ⇡Habibi et al., 2018). Remote CoPs have been used in blended learning models, for example, to monitor post-training activities and provide follow-up support to rural teachers (e.g., in South Africa: ⇡Moodley, 2019; or to monitor and promote teacher attendance (e.g., in India: ⇡Nedungadi et al., 2018). Though small-scale (n=26), a study in rural India examined the AmritaRITE

(Rural India Tablet Education) model which uses WhatsApp and other apps to effectively monitor and promote teacher and student attendance (⇡Nedungadi et al., 2018). While the study found that teacher attendance increased, an unintended positive effect was that the WhatsApp groups encouraged teachers and coordinators to share resources and pedagogical strategies, impacting teacher practices and student achievement in a cost-effective way (⇡Nedungadi et al., 2018).

3.2.3. International/transnational remote CoPs

At an international level, seven studies explored transnational or transregional CoPs, connecting teachers from LMICs to those in high-income countries (e.g., Egypt-Italy: ⇡Biasutti & El-Deghaidy, 2012; US-Dominican Republic: ⇡Carpenter & Munshower, 2019; US-Ecuador: ⇡McPherson, 2010; US-Sri Lanka: ⇡Schreiber & Jansz, 2020; US-Chile: ⇡Barahona & Davin, 2021; US-Turkey: ⇡Üzüm et al., 2020; Sino-Africa cooperation: ⇡Zhu & Chikwa, 2021; and globally:⇡Spiro, 2011). Such transnational remote learning communities allow teachers to identify shared concerns and values about their profession, and deconstruct their assumptions or unexamined beliefs, leading to more profound self-knowledge (⇡Spiro, 2011).

3.2.4. CoPs in Education in Emergency settings

Remote CoPs have also proven to be particularly beneficial for teachers working in emergency contexts, especially those affected by conflict or violence (Box 4; see also: ⇡Burns & Lawrie, 2015; ⇡Inter-Agency Network for Education in Emergencies, 2022; ⇡Mendenhall et al., 2018). In Education in Emergency (EiE) settings, teachers often lack opportunities for formal TPD (⇡Burns & Lawrie, 2015), or may face safeguarding issues when travelling to available TPD opportunities (⇡El-Serafy et al., 2022). ⇡Kennedy & Laurillard (2019) argue that MOOCs (as a form of CoP) can support teachers in contexts of mass displacement, because the ‘online peer community could be a safe place for teachers to discuss and develop a shared understanding of their own experiences as refugees and as teachers in a challenging context’ (p. 144).

Box 4. Remote CoPs to support teachers working in emergency contexts

Key information: In a rare, global study, ⇡El-Serafy et al. (2022) surveyed 280 practitioners of remote CoPs who work in emergency settings across 11 countries in the Middle East, Africa and Asia.

TPD model: Professional learning communities (PLCs) can be autonomous, structured or scripted. The different levels of structure then necessitate different materials to support teacher learning.

Technology used: The study focuses on two core functions in PLCs that technology supports: communication and collaboration (e.g., via social networks like WhatsApp) and resource sharing (e.g., via video conferencing software like Zoom).

Outcomes: Despite the diversity of EiE contexts – some refugee settings, fragile contexts, post-conflict settings, and those affected by natural disasters or forced displacement – the authors argue that technology can play a vital role in enhancing teachers' access to CoPs by improving the effectiveness of existing in-person CoPs and addressing some of the challenges common in emergency settings, including distance from TPD opportunities and lack of security, costs, time and limited access to teaching and learning material or qualified coaches. In particular, practitioners who were interviewed emphasised the sustainable benefits of CoPs, "seeing them as a form of continuous professional development that is resilient in the face of tumultuous, conflict-affected circumstances" (p. 148). The most commonly cited benefits of CoPs included sharing experiences and effective practices, improving skills and knowledge, brainstorming solutions to challenges or tracking teachers' progress. Over half of all teacher respondents believed their participation in CoPs fostered a sense of community, improving both their confidence and well-being.

3.2.5. CoPs during the Covid-19 pandemic

The proliferation of remote CoPs during school closures caused by Covid-19 exemplifies the promising potential for technology to connect and support teachers working in emergency settings. Teacher-led initiatives – or the sorts of *informal* CoPs described in Section 3.2.1 – have emerged on social media such as Facebook, WhatsApp or Instagram where teachers share resources and ideas for remote teaching, brainstorm solutions to the challenges they encounter, and provide socio-emotional support to one another, even in resource-constrained environments and contexts affected by overlapping crises (⇡Inter-Agency Network for Education in Emergencies, 2021). More than one quarter (27%) of teacher respondents from the T4 global survey reported participating in professional online CoPs 'every day or almost every day' during the pandemic, and this figure rises to more than half (54%) of teachers who participated when combining daily and weekly frequencies (⇡Pota et al., 2021). Moreover, 34% of teachers from the T4 survey indicated that they received TPD that focused on engaging teacher CoPs (⇡Pota et al., 2021). Indeed, ⇡McAleavy et al. (2021, p. 5) note that a key lesson from the pandemic is that "the best external support for teachers comes from other teachers." Teacher educators have also engaged in self-study through informal social and collaborative tech4TPD models during the pandemic (e.g., in Israel: ⇡Donitsa-Schmidt & Ramot, 2022). Moreover, few studies measure change in teaching practices or student learning outcomes; no rigorous review of evidence exists on the impact, effectiveness or sustainability of technology-mediated CoPs in emergencies (⇡El-Serafy et al., 2022; ⇡Richardson, 2018).

3.3. Technology to support coaching and mentoring for teachers

The role of more experienced teachers, qualified coaches or mentors is paramount for the success of all TPD, regardless of the use of technology. As our systematic literature review revealed, tech can be used in innovative ways to connect teachers with coaches and mentors; however, this continues to be an under-researched area. Coaching (4%) and mentoring (3%) were the least common forms of peer support in our review, perhaps due to the fact that they may be time- and resource-intensive. This section explores some uses of tech to facilitate coaching and mentoring or support coaches and mentors themselves. Examples include using tech to provide feedback and support, collecting data on classroom observations and supervision or teachers' professional growth, and/or simply providing 'nudges' (quick reminders for teachers to conduct administrative tasks or follow pedagogical principles).

3.3.1. Virtual coaching

Virtual coaching – especially through video conferencing (f=13) – was relatively common in the literature reviewed, and there is a promising, growing body of evidence regarding the effectiveness of such tech4TPD models. For example, ⇡Kraft et al.'s (2018) meta-analysis found similar teaching and learning outcomes for both virtual and in-person coaching. Similarly, a study in South Africa found that, after one year, a virtual coaching model proved cheaper and as effective as on-site coaching in improving teachers' instructional practices and learners' proficiency in English as an Additional Language (EAL) (⇡Kotze et al., 2018). Participating teachers – across 180 schools in low-income communities – were provided with lesson plans and other resources on tablets to implement in the classroom; coaching included fortnightly individual follow-up phone calls to discuss TPD focus areas, weekly group WhatsApp messages for motivational support, and the use of video clips illustrating teaching principles that teachers found particularly difficult. However, ⇡Cilliers et al. (2020) conducted a follow-up study of this programme and found that its effectiveness was diluted over time, particularly because lesson observations and ultimately trusting relationships between coaches and teachers were more difficult to secure in a purely virtual tech4TPD model. Therefore, blended approaches which integrate some in-person visits and ensure that the social aspect of peer support is not lost may be more effective. In a year-long coaching programme in Indonesia, teachers and coaches who received blended training and support (online plus face-to-face) showed statistically significant higher academic performance levels than teachers and coaches who received either fully online or fully face-to-face training and support (⇡Burns, 2013). The coaches who received blended TPD made more frequent contact, expressed greater confidence in their coaching ability and were rated as more effective coaches by teachers and principals. Attrition was far higher in the online coaching group, mainly due to internet reliability.

3.3.2. Coaching through SMS messages

Given the ubiquity of mobile devices in LMICs, Short Message Service (SMS) text messages (f=9) also emerged as a low-cost and accessible form of EdTech to support, prompt or reinforce new teacher practices (e.g., ⇡Slade et al., 2018). Text messages may be best used to offer regular, timely reminders or 'nudges' concerning instructional strategies during or following TPD (⇡Jukes et al., 2017); or to monitor teacher behaviour. However, while messaging allows two-way multimodal communication, including via emoticons, photographs, videos and files (⇡Tao, 2016), it is only a small part of coaching and facilitates the observational and feedback elements less effectively than in-person coaching. It may also be less effective in addressing complex social issues such as gender norms (e.g., ⇡Chinen & Elmeski, 2016). Research in Rwanda is emerging on the effectiveness of using instant messaging chatbots (e.g., on WhatsApp or Telegram) to strengthen teacher involvement and motivation (⇡VVOB, 2021). The conversational, semi-automated chatbot sends small chunks of educational content as well as activities, helpdesk support, reminders and motivational messages.

3.3.3. Coaching or mentoring in EiE settings

Tech4TPD coaching and mentoring models have also been used to support teachers working in EiE settings. One promising example, the Teachers for Teachers programme, harnesses SMS text messages to support teachers working in Kakuma refugee camp in Kenya (see Box 5). A second, smaller scale example comes from the Norwegian Refugee Council's flagship peer coaching initiative in the West Bank, where 10 teachers, who were selected to be trained as peer coaches, participated in six 3-hour zoom workshops (⇡Inter-Agency Network for Education in Emergencies, 2022). It partially followed a flipped classroom approach; the sessions focused on best coaching practices (especially in the context of Covid-19), the objectives and skills of peer coaching, peer coaching tools, planning and time management. In addition, peer coaches connected on a Facebook page to continue to reflect and share ideas. Both these tech4TPD coaching initiatives adapt the Inter-agency Network of Education in Emergencies' (INEE) Teachers in Crisis Contexts' peer coaching model to fit the needs of participating teachers, pointing to the potential impact of OER coaching/mentoring materials to support both teachers and pedagogical leaders.

Box 5. SMS Support for teachers in Kakuma refugee camp in Kenya

Key information: The Teachers for Teachers initiative in Kakuma Refugee Camp, Kenya, aims to support refugee and Kenyan teachers in their efforts to improve their own teaching practice and student learning in the camp.

TPD model: The programme consists of three components: in-person training workshops, peer coaching and mobile mentoring using WhatsApp.

Technology used: Participating teachers in the Kakuma refugee camp were provided with mobile phones, data and airtime and connected with mentors from Columbia University's Teacher College (⇡Mendenhall et al., 2018).

Outcomes: The mentors provided real-time responses to challenges and enabled feedback loops (both between mentors/mentees as well as project staff). The global mentoring also enabled two-way knowledge sharing and fostered communities of learning and relationship building within the camp. Teachers reported using mobile devices to access the internet and engage in self-directed TPD, for example, to find content on how to support SEND learners, and to share innovative teaching practices through photos or exemplar videos. Drawing on the ⇡Inter-Agency Network for Education in Emergencies'(2022) OER training module for Teachers in Crisis Contexts, this blended tech4TPD model points to the importance of tailoring content and structure to the needs of participating teachers through co-design.

3.3.4 Coaching and mentoring for pre-service teachers

The literature review highlighted an important evidence gap – there is a dearth of literature on how tech-enabled coaching and mentoring can support pre-service teachers. Only one study examined tech-enabled coaching and mentoring for pre-service teachers, and this was in the context of second-language teaching. ⇡Kecik et al. (2012) explored the role of university supervisors and 'cooperating teachers' who acted as models and mentors in the Distance English Language Teacher Education (DELT) programme in Turkey. In addition to in-person practice teaching, pre-service teachers participating in DELT could interact with their university supervisors and cooperating teachers through an e-portfolio application. The e-portfolio served as a central repository to store the course handbook, sample lesson videos, grading rubrics, useful links to additional resources, as well as pre-service teachers' lesson plans and self-reflection reports, and feedback received from their supervisors and cooperating teachers. The e-portfolio app also acted as a forum where all three stakeholders (pre-service teachers, supervisors and cooperating teachers) could discuss course-related content, ask technical questions and provide guidelines. Pre-service teachers designed their practice lesson plans and received various rounds of feedback through the e-portfolio, before trialling it in a classroom as part of their practicum. The use of the e-portfolio app thus established a network among all participants, reducing pre-service teacher isolation, and increasing academic support with a focus particularly on teaching and learning (i.e., through the lesson plan). However, the authors also found that the role of cooperating teachers was more effective than the role of university supervisors in this environment, particularly because cooperating teachers also had opportunities for face-to-face interaction with pre-service teachers (e.g., through in-person classroom observations). Exploring the perceptions of all three types of stakeholders, ⇡Kecik et al. (2012) point to several limitations of the e-portfolio modality: pre-service teachers and university supervisors felt that the e-portfolio did not help them give or receive peer feedback on the actual teaching while cooperating teachers felt pre-service teachers were not very successful at reflecting on students' learning difficulties in the classroom. Given the importance of coaching and mentoring that is centred on teaching and learning practices, more research is needed to understand how an e-portfolio application – and tech-enabled coaching or mentoring in general – can be used to support pre-service teachers.

3.3.5. Support for pedagogical leaders

As noted in the West Bank example above, tech4TPD models can also be designed to support the professional development of coaches and mentors themselves. Virtual coaching has been used to support school leaders and pedagogical coordinators of secondary schools in Brazil (⇡Bruns et al., 2018). School leaders and pedagogical coordinators attended three workshops focused on observing teachers in the classroom and discussing classroom practice during individual sessions. Skype was then used in treatment schools to facilitate communication between each school's pedagogical coordinator and an expert trainer. A randomised evaluation of this programme found that this sort of virtual external expert coaching via Skype costs USD2.40 per student, proving cost-effective in raising teachers' classroom effectiveness and producing significant student learning gains in mathematics and Portuguese (⇡Bruns et al., 2018). However, lecturing from the blackboard remained the dominant teaching mode in both treatment and control schools, although teachers receiving the coaching spent significantly more time on "discussion / debate / Q&A". Given ⇡Cilliers et al.'s (2020) study above, the sustainability of these virtual coaching models should be examined.

Subject-specific software (see more in Section 3.5) has also been used to support pedagogical leaders – a recent study of a blended learning course spanning four countries of East Africa (Kenya, Rwanda, Tanzania and Uganda) found that maths teacher educators particularly enjoyed learning through an open-source maths software product, as they found the software engaging. However, some teacher educators had access issues within their institutional contexts (⇡Golding & Batiibwe, 2021). Given the changing roles of teacher educators during Covid-19, further research is needed on how to improve not only pedagogical leaders' content knowledge or pedagogical content knowledge, but also their capacity to provide teachers with social and emotional support (⇡Donitsa-Schmidt & Ramot, 2022).

Software can also be used to provide structured observation tools or feedback to coaches and mentors, improving the quality of expert support. Boxes 6 and 7 provide two large-scale examples of coaching software, both of which have resulted in enhanced coaching practices, though the link between coaches' instructional support and the overall impact on teacher learning outcomes was less clear. Beyond pedagogical support, the tech tools also collected and stored data on coaching sessions to hold coaches accountable and monitor teacher progress.

Two promising large-scale examples of how software can be used to support coaches and mentors in LMICs were identified in the literature: Tangerine:Tutor (now 'Coach') in Uganda and Tusome's National Tablets Programme in Kenya (see Box 6 and Box 7, respectively). Evidence suggests that both these examples improved the quality of coaching sessions and established a relationship built upon mutual accountability between coaches and teachers.

Box 6. Tangerine:Tutor (Coach) in Uganda

Key information: Tangerine:Tutor is a model scaled successfully in Kenya that was adapted for the Ugandan context.

TPD model: The Tangerine:Tutor software provides guided observation protocols to coaches in Uganda, improving the quality of in-person coaching by automatically generating feedback that coaches can read to teachers in post-observation discussion sessions (⇡Pouezevara et al., 2019). The software also stores coaching data on a user-friendly, web-accessible dashboard, allowing coaches to follow case management summaries of their teachers.

Technology used: Tablets and software resources.

Outcomes: A drawback of this tech4TPD model, however, was that the new software was more time-intensive than the previous paper-based coaching tools. The new tool was more detailed, meaning coaches had to spend more time at each classroom observation in schools; this resulted in coaches visiting fewer schools. Nevertheless, the tablets and software resources made the work easier (i.e., less cognitively demanding) and increased coaches' commitment and accountability.

Box 7. Tusome National Tablets Programme in Kenya

Key information: In 2013, the Kenyan government implemented Tusome to fast-track improvements using EdTech. This programme used tablets to enhance teacher coaching and oversight (⇡Myers et al., 2021).

TPD model: Tusome's National Tablets Programme in Kenya compiles data on the number of observations (recorded on tablets) that coaches undertake (⇡Piper et al., 2017). It was developed to enhance the accountability structures within the Ministry of Education and was targeted at establishing greater links between the sub-national (county) and national levels. While other models of coaching keep teacher coaching separate from accountability structures (⇡Burns, forthcoming), the authors argue that alongside clear roles and responsibilities for coaches and mentors, such structures are critical to providing the specificity needed for coaches and mentors to thrive in their role.

Technology used: Tablets were used by coaches and mentors.

Outcomes: For Tusome, survey and test data indicated that coaches' increased use of tablets improved the quality of their instructional support to teachers in a cost-effective way (⇡Piper et al., 2015; ⇡Piper et al., 2017).

3.4. Technology to cultivate teacher reflection

Reflective practice is at the heart of professional development. Through critical self-reflection, teachers can analyse the impact of their instructional strategies on student learning, brainstorm solutions to the challenges they encounter, and ultimately tailor and improve their pedagogy (⇡DeLuca et al., 2015; ⇡Schön, 1991). Teacher reflection was a key TPD component of tech4TPD in the literature reviewed (f=45 or 26%).

A range of tech resources that seek to develop teachers' reflective practices has been used in tech4TPD models. While videos – including video lessons or episodes of microteaching – appeared in nearly half (43%) of all 170 publications, and constituted a quarter (25%) of all tech resources mentioned, more active forms of technology may afford a deeper level of critical reflection: these include digital storytelling (⇡Ivala et al., 2014; ⇡MacEntee, 2019), e-portfolios (⇡Kecik et al., 2012) and blogging (⇡Khan, 2017; ⇡Lee et al., 2019; ⇡Pascarella, 2009).

3.4.1. Video-based reflection

The power of video, in particular, is that it allows teachers to see teaching and learning processes first-hand. This is particularly important given that in many LMICs, teachers often lack access to 'model' teachers or pedagogical experts (⇡Osmanoglu, 2015). Tech4TPD models that integrate video provide opportunities for teachers to observe exemplary teachers and/or to watch themselves or their peers teach (e.g., ⇡Lok et al., 2018; ⇡Güngör, 2016) so that they can become reflective practitioners. For pre-service teachers, video-based conversations can support reflection when completing one's practicum; for example, ⇡Tülüce and Çeçen (2016) found that pre-service teachers analysed micro-teaching episodes to discuss pedagogical, psychological and physical aspects of their teaching. Videos can allow teachers to self-evaluate (e.g., in Turkey: ⇡Batman & Saka, 2021), and engage in more collaborative conversations with pedagogical leaders (e.g., in Brazil: ⇡Kaneko-Marques, 2015). Importantly, some teachers may feel less confident or comfortable watching videos of themselves, and/or having peers comment on their practice, and therefore it is important to consider how to create an environment that is conducive to constructive feedback and positive relationships (e.g., as found in a study of pre-service teachers in Turkey: ⇡Güngör, 2016). Videos can also focus on students, so that reflective conversations centre on student learning and needs (e.g., in Vietnam: ⇡Saito & Khong, 2017). In some contexts video vignettes that do not align with 'best practices' have been used to stimulate teacher reflection and discussion (e.g., in Indonesia:⇡Ragatz et al., 2015). Videos of real lessons have allowed pre-service teachers to connect their teaching practices with new theoretical knowledge (⇡Osmanoglu, 2015). The OER4Schools programme in Zambia exemplifies a sustainable and scalable tech4TPD model in which video lessons are integrated into a multimodal and blended approach to effectively support and empower teachers to foster inclusion (Box 8). As usual, it is difficult to isolate the impact of technology, as it was just a small part of a more comprehensive programme.

Box 8. Video-based reflection to support marginalised learners

Key information: The OER4Schools programme is a tech4TPD initiative initially based in Zambia, but which has been taken up in other countries, such as Zimbabwe.

TPD model: Videos of interactive teaching by local teachers offered an external stimulus for school-based, peer-facilitated teacher discussion, reflection with peers and inquiry. Learning was guided by built-in prompts for both teachers and facilitators, and materials explicitly linked theory to practice. Teachers had the chance to collaboratively design and trial new pedagogical strategies, largely stimulated by videoed practices they viewed. A professional learning resource was developed consisting of 25 two-hour sessions, organised into five units, covering interactive teaching principles, group work, questioning, dialogue, Assessment for Learning and inquiry-based student learning.

Technology used: video, OER, laptops, projector.

Outcomes: Teachers raised their expectations of rural and vulnerable students and developed their awareness of all learners' progress (⇡Hennessy et al., 2015; ⇡Hennessy et al., 2016). After one school year, teachers (n=12) adapted to learners' needs and used more practical and group work in classes. In turn, pupils built a deeper understanding of subject matter, collaborated and used digital technologies for problem-solving (⇡Haßler et al., 2018; ⇡Hennessy et al., 2016). The extensive multimedia materials helped the programme become self-sustaining: teacher interviews conducted 18 months after the intervention revealed that previous participants had become peer facilitators and teachers had further developed their interactive teaching strategies (⇡Haßler et al., 2020). Sustainability mechanisms included culturally sensitive and participatory programme development, semi-structured multimedia materials focused on video-based reflection and supportive institutional and national structures for professional learning.

3.4.2 Structured reflection

Support for TPD leaders (Section 3.3) is critical and can contribute to a more 'structured reflection' for teachers (e.g., ⇡O'Sullivan, 2002). Various studies have shown that the expertise of teacher educators (⇡Lee et al., 2019) or the activities used to facilitate reflection (⇡Makarani, 2012) can hinder or enhance the impact of a video-mediated TPD initiative. Built-in educator notes and prompts to facilitate discussion can support teacher reflection both on their own practice and on videotaped lessons of other teachers, as found in the OER4Schools tech4TPD model in Zambia (Box 8: ⇡Haßler et al., 2018; ⇡Hennessy et al., 2016, and Zimbabwe: ⇡Walker, Hennessy & Pimmer, 2022). E-portfolios have also been used as reflective tools for pre-service teachers and lecturers to monitor and continuously evaluate teachers' professional development (e.g., in Malaysia: ⇡Kabilan & Khan, 2012). Videos with reflective questions can also be paired with lesson plans for teachers to practise the modelled instructional strategies, as was done in a maths tech4TPD model in Indonesia (⇡Ragatz et al., 2015).

How to support structured reflection in online or virtual tech4TPD environments is also an important – yet under-researched – area. A small-scale study of five pre-service teachers in Malaysia found that using EDMODO, an LMS, was effective in supporting teacher collaboration and dialogue, but that there was a need for a more systematic and structured approach when fostering critical reflection in the virtual environment (⇡Suppiah et al., 2019). In particular, the authors explain how, despite numerous attempts made by the teacher educator to encourage pre-service teachers to think more deeply about the problems they face and to articulate and justify their decisions from a theoretical perspective, this was not successfully translated into subsequent online reflective entries or interactions. Instead, the comments and responses made by pre-service teachers in the EDMODO platform were more social and/or informational in nature. The authors suggest there is a need to explore further the nature and level of expertise for online facilitation of structured reflection. It is also important to note that this study only took place over the span of 4 weeks – and therefore more time may be needed to reach a deeper level of reflection (⇡Desimone, 2009; ⇡Tülüce & Çeçen, 2016).

3.4.3. Impacts of reflection

When followed by questioning and discussion, videos can develop not only teachers' reflective skills (⇡Liang, 2015; ⇡Osmanoglu, 2015) but also their content knowledge (e.g., as perceived by students in Indonesia: ⇡Ragatz et al., 2015) or pedagogical content knowledge (e.g., as perceived by teachers in Nicaragua: ⇡Lindenberg et al., 2016 and Indonesia: ⇡Susantini et al., 2018). For language teachers, watching videos of themselves or their peers will allow them to scrutinise their communication skills more closely, pronunciation and fluency (e.g., as in the case of pre-service teachers in Turkey: ⇡Güngör, 2016; ⇡Tülüce & Çeçen, 2016). In a rare study on disaster prevention and response education in Turkey, ⇡Gökmenoğlu et al. (2021) used live and animated videos to train teachers. However, only three studies using video report observable changes in teachers' practice: JiFUNzeni in Kenya (see Box 2), English in Action (EiA) in Bangladesh (see Section 3.5), and OER4Schools in Zambia (Box 8). The latter also documents teacher-reported impacts on student learning (⇡Hennessy et al., 2016).

3.4.4. Reflection-to-practice for marginalised teachers and learners

Without opportunities for teachers to apply what they learn after viewing and reflecting on videos, the likelihood of catalysing pedagogical change is limited. This was demonstrated in studies that worked with marginalised teachers and learners. In Namibia (n=15), a tech4TPD model using DVDs and follow-up activities to prepare teachers better to support SEND students found that, without opportunities to apply their knowledge and reflect on practice, the model proved ineffective because teachers were unable to transfer new pedagogical knowledge to classroom use (⇡Kok & Blignaut, 2014). Likewise, in Saudi Arabia, pre-service SEND teachers (n=24) identified various challenges when learning sign language through videos, especially the lack of opportunities to practise sign language with each other and reflect, ultimately limiting their confidence (⇡Alawajee, 2021); thus reflection with peers is a critical building block to improved confidence. On the other hand, a second study of teachers of SEND students found that using videos of autistic students enabled pedagogical leaders to scaffold teacher thinking around student behaviour, further enabling them to better respond to and accommodate these learners (⇡Lam et al., 2022). Again, impacts on student learning outcomes were not reported.

3.5. Technology to develop teachers' language teaching skills, subject knowledge or pedagogical knowledge

A substantial number (f=45) of the publications reviewed examined how tech4TPD models could improve teachers' skills in developing literacy and oral competence in the language of instruction, including second language teaching – often this was English as an additional language (EAL) within the reviewed articles. Multilingual skills are critical for teachers working in LMICs in general, where the language of instruction is often not the teachers' first language (⇡Zhao et al., forthcoming). Likewise, various studies explored outcomes related to teachers' subject or content knowledge (f=28), or pedagogical knowledge (including TPACK: f=40). Subject, content, and/or pedagogical knowledge are particularly important outcomes for marginalised teachers from rural/remote areas who may have more limited access to quality training opportunities, as well as ethnic minorities or speakers of minoritised languages. Tech uses include specialist language learning applications, audio-visual materials, lesson plans on preloaded devices, virtual coaching and more.

3.5.1 Preloaded devices

Preloaded devices (f=17) are also often used in the literature to support teachers' language learning or to provide resources for teachers to teach languages or use student-centred pedagogies in general in the classroom. A promising example of a tech4TPD model that uses preloaded TPD resources to develop teachers' second language learning / English as an Academic Language (SLL)/EAL is the EiA programme in Bangladesh. As a blended tech4TPD model, EiA combines school-based support systems with the provision of mobile phone memory cards, or Apple iPods preloaded with innovative audio-visual materials including videos of Bangladeshi teachers or audio files aligned to the Bangladeshi textbooks for teachers to use in their classrooms (⇡Shohel et al., 2012a; ⇡Power et al., 2012; ⇡Shohel & Kirkwood, 2012). Teachers can use these materials on their own through self-study or more structured support at the school level, including by participating in workshops or bi-monthly 'cluster meetings' (⇡Power et al., 2012).

Various studies have examined this 'trainer in your pocket' model (⇡Walsh et al., 2013), highlighting the benefits of hand-held technologies for in-service training in resource-constrained environments (⇡Shohel & Banks, 2010) and for classrooms supporting disadvantaged children (⇡Mahruf et al., 2012). On the one hand, internal evaluations indicate substantial improvements in teacher classroom practices and student learning outcomes. A quasi-experimental study found a significant shift away from traditional pedagogies to more communicative approaches and significant increases in test scores, especially for boys (⇡Power, McCormick, & Asbeek-Brusser, 2017). On the other hand, various studies have questioned the sustainability of EiA, making claims about its ineffective training materials and use of technology, reduced teacher enrollment and motivation and infrastructural challenges, especially in rural areas (⇡Rahman et al., 2019). Nevertheless, the EiA model has been scaled up and institutionalised by the Bangladeshi government (⇡Power, McCormick, & Asbeek-Brusser, 2017); as part of the institutionalisation process, the model was iteratively adapted to maximise effectiveness (⇡Power et al., 2019);[11] see more updates in Section 4.2.3.

Devices preloaded with scripted or semi-scripted lesson plans have proved promising, particularly in changing teacher learning practices and increasing student learning outcomes in a cost-effective way, as seen from the Health and Literacy Intervention (HALI) project in Kenya (Box 9) or the Funda Wande course in South Africa (Box 10).

[11] For example, the number of training sessions was reduced, and school-based support was strengthened by school leaders, teacher facilitators and local education officers playing a more active role (⇡Power et al., 2019).

Box 9. Improving literacy at scale with semi-scripted lessons in Kenya

Key information: The Health and Literacy Intervention (HALI) focused on TPD to improve first-grade teachers' literacy instruction in coastal Kenyan government schools.

TPD model: The model paired semi-scripted lesson plans (in Swahili and English) with training workshops and weekly text messages to provide brief instructional tips and motivation for teachers to implement lesson plans (⇡Jukes et al., 2017).

Technology used: Intentionally designed to be replicable, the HALI model leverages low-tech modalities such as SMS and locally sourced and accessed semi-scripted lesson plans and instructional materials (⇡Dubeck et al., 2015).

Outcomes: While the effect of the technology itself cannot be isolated, teachers found the lessons and training materials useful, and the weekly text messages a good source of new teaching ideas, while the bidirectional SMS model created a supportive community (⇡Dubeck et al., 2015). A 'micro-costing' or ingredients-based approach was taken, costing each element of TPD support and found that the three main cost contributors were initial training (32%), teacher materials (29%) and SMS support (20%) (⇡Drummond et al., 2005). Engagement of teachers remained steady throughout the project and after one year of the intervention, teachers' knowledge related to early literacy instruction was significantly higher than that of newcomers to the intervention (⇡Dubeck et al., 2015), ultimately resulting in improved literacy outcomes and reduced dropout rates for students (⇡Jukes et al., 2017). The programme was scaled at a national level (⇡Jukes et al., 2017; ⇡Piper et al., 2018).

Box 10. Improving literacy in African languages with scripted lessons in South Africa

Key information: Funda Wande is an open-access online course that trains teachers in South Africa how to teach literacy and numeracy in African languages such as isiXhosa.

TPD model: The training materials were iteratively designed over three years by local experts to ensure their relevance, quality and alignment with the national curriculum. In addition to the online course, teachers receive in-person support through weekly school-based coaching visits and occasional off-site workshops where they can collaboratively reflect and create their own lesson plans or teaching resources.

Technology used: Teachers receive both printed materials and a preloaded flash drive with a full set of videos (⇡Funda Wande, 2019) and multimedia resources, including structured lesson plans, professionally filmed classroom videos, handwriting and reading booklets and infographics (⇡Ardington & Meiring, 2020).

Outcomes: Midline findings from a randomised control trial (RCT) of Funda Wande over three years of implementation (2019–2022), found that the programme resulted in changes in teachers' classroom practices and a statistically significant 0.17 standard deviation impact on learners' reading proficiency after the first year (⇡Ardington & Meiring, 2020). This translates to approximately 20–27% of a year's worth of learning (equating approximately to one term) for Grade 2 learners. The impact on Grade 1 learners was even greater: literacy outcomes improved between 33–58% of a year's worth of learning when compared to the control group. The intervention had a consistently positive impact on all learners, regardless of their baseline proficiency levels, indicating that even the most vulnerable students benefited from it. Due to the pandemic, midline findings after the second year showed that no further improvements were found for intervention group learners over control group learners (⇡Ardington, 2021).

3.5.2. Subject-specific software

Subject-specific software includes anything from offline or low-tech options, especially educational apps, to higher-tech options including online computer programmes, gamification (⇡Alyaz et al., 2017) or virtual reality (⇡Chinen & Oviedo, 2022). In Ghana, interactive voice recognition (IVR) was used to support teachers' foundational literacy (⇡Afoakwah et al., 2021). This unique tech4TPD model used phone calls to provide teachers with a series of 10-minute audio-recorded lessons along with two interactive quiz questions to assess their understanding. Each week, a new IVR lesson was made available for teachers, who also received SMS reminders to ensure their participation. The model was designed to be both flexible and blended: teachers could call back and participate in the 10-minute IVR lesson whenever they had time, and they met weekly in person, in groups to discuss that week's session. Results indicated improved teachers' self-confidence and knowledge of foundational literacy concepts; however, the impact on student learning was not measured.

Software applications have been commonly used to improve teachers' pedagogical content knowledge (⤒Shulman, 1986), especially in mathematics (f=19) or science subjects (f=15) (e.g.,⤒Çoban et al., 2016; ⤒Kocakaya & Gonen, 2010). In comparison, all six other subjects mentioned (literacy, EAL/SLL, social studies, religious studies, computer technology, 'other'[12]) appeared in only 35 publications combined. When used in conjunction with certain pedagogies and support structures, Geogebra[13] appears to be particularly effective in improving teachers' and teacher educators' (⤒Golding & Batiibwe, 2021) understanding of a range of mathematical concepts (⤒Aytekin & Kiymaz, 2019; ⤒Koparan, 2019; ⤒Tatar & Zengin, 2016; ⤒Zengin, 2018; ⤒Zengin & Tatar, 2015). Despite the breadth of research, controlled studies are rare. Additional software studied in the literature includes Mathemagic,[14] CopyCat[15] (⤒Smith et al., 2009), MATLAB[16] (⤒Amevor et al., 2021) or Google Sketch Up[17] (⤒Uygan & Kurtuluş, 2016) to learn geometry, or the mobile game UFractions[18] and an intelligent tutoring system called ActiveMath[19] to learn fractions (⤒Nygren et al., 2019). 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.

3.5.3. Teacher creation of digital teaching and learning materials

TPD models are more likely to effectively facilitate changes in both subject knowledge and pedagogy when teachers have opportunities to 'create digital teaching and learning materials' (theme extracted from the literature review). Studies specifically referenced the use of 'OER' (f=20) and 'editable web pages' (e.g., blogs and wikis: f=14) to create or adapt teaching and learning materials. In a recent study in Indonesia, English teachers were trained to use Prezi, Google Classroom and PowerPoint to teach communication skills (⤒Syafryadin et al., 2021), while in a study in Ghana, teachers and students collaboratively used their mobile phones to create an online course drawing on diverse multimedia (e.g., powerpoints and eBooks) (⤒Grimus & Ebner, 2014). TPD models using collaborative design teams (⤒Akayuure & Apawu, 2015; ⤒Kafyulilo et al., 2015; ⤒Kafyulilo et al., 2016) or tech-mediated problem-based learning (Karami et al., 2013) have proved effective in improving teachers' technological pedagogical content knowledge (TPACK) and digital skills. During the Covid-19 pandemic, the use of online and blended learning models to support teachers in the design of remote teaching tools and pedagogies was of paramount importance (⤒Raina et

[12] Note the code for "Other" subjects included all subjects that were mentioned in studies fewer than three times (e.g., sexual and reproductive health, art, physical education, etc.).
[13] Geogebra is an open-source, dynamic mathematics software for all levels of education that combines geometry, algebra, spreadsheets, graphing, statistics and calculus. It offers an online platform with over 1 million free classroom resources created by the multilingual community numbering millions of users across the globe. https://www.geogebra.org/ Retrieved 21 October 2022.
[14] https://www.transum.org/Software/Fun_Maths/Mathemagic.asp Retrieved 21 October 2022
[15] http://www.sunsite.ubc.ca/LivingMathematics/Packages/CopyCat/ Retrieved 21 October 2022
[16] https://uk.mathworks.com/products/matlab.html Retrieved 21 October 2022
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[19] https://activemath.com/ Retrieved 21 October 2022

al., 2022; ⇡Teacher Task Force & UNESCO, 2022). However, in these studies, the role of the teacher educator or TPD facilitator remained largely unexamined.

3.5.4. Supporting marginalised teachers' language skills

Technology – and in particular its diverse communicative functions – has the potential to provide teachers with greater opportunities to develop language skills. Examples of tech4TPD efforts to support SLL include refugee teachers using mobile devices and language applications in Lebanon (⇡Bradley et al., 2019), computer-assisted language learning in Iran (⇡Meihami & Esfandiari, 2021), social media groups in Kenya (⇡Bett & Makewa, 2020), transnational CoPs between teachers in Chile and the US (⇡Barahona & Davin, 2021), the creation of 'pronunciation podcasts' in Turkey (⇡Kafes & Caner, 2020) and e-portfolios in Malaysia (⇡Kabilan & Khan, 2012). Other uses of technology for promoting teacher language skills involve using video reflection to self-assess language competency (⇡Güngör, 2016; ⇡Makarani, 2012; ⇡Tülüce & Çeçen, 2016) or virtual coaching (⇡Kotze et al., 2018). However, negative effects were discovered on learners' home language skills (⇡Kotze et al., 2018), indicating that spillover effects must be considered when planning initiatives to promote teachers' and learners' language development. Moreover, research on the whole rarely documented teachers' initial language levels or any disaggregated initiative effects, which are factors that could inform the adaptation of language content to improve outcomes.

3.5.5. Adapting to needs of marginalised learners

Initiatives focusing on TPD for marginalised learners were rare, but findings indicate that tech4TPD can be effective in developing teachers' skills in inclusive and student-centred pedagogies and curricula. Examples include the EiA programme in Bangladesh mentioned above, and OER4Schools in Zambia (Box 8), which resulted in teachers' enhanced instructional practices and increased expectations of vulnerable students (⇡Hennessy et al., 2015; ⇡Hennessy et al., 2016). Various online repositories provide open-access videos that teachers (and students) can use to learn about diverse topics, including ⇡EENET's (no date) catalogue of videos on inclusive education in emergency settings,⇡Ekitabu's (2016) sign language videos and, in Colombia, ⇡Coschool's (2021) videos on social and emotional skills. While a pilot teacher training programme for eKitabu has promising outcomes (e.g., on teacher knowledge and attitudes: ⇡Kibet et al., 2021), to our knowledge none of these OERs have been rigorously evaluated. One study from India exemplifies that although teachers had positive attitudes towards using assistive technology with SEND learners, they were in need of both training and infrastructural support (⇡Kundu & Bej, 2020). Teachers of SEND students often feel reluctant to employ digital technologies in the classroom when they lack an understanding of how to best use those technologies to attend to learner needs (⇡Lynch et al., 2020). The use of assistive technologies to support SEND learners is fundamental to educational equity and inclusion, yet continues to be an under-researched area (⇡World Bank, 2022). Some initiatives have also demonstrated the value of technology as a tool for creative projects focusing on causes of marginalisation, such as poverty, orphaning and HIV/AIDS, for instance, through video-making software (⇡Mitchell et al., 2008) and photography (⇡MacEntee, 2019). Virtual reality has been used to enhance perspective-taking and promote conflict resolution in refugee settings, although impact on student learning was not measured (⇡Chinen & Oviedo, 2022).

3.6. A systems approach to tech4TPD

In Section 1.2 we described our approach to considering the TPD ecosystem within the broader education system. This section follows this conceptualisation, using it to analyse the five key themes discussed in Sections 3.1–3.5 through a systems lens. As per Figure 1, we use the levels of the system to separate macro-, meso-, and micro-level factors, with the understanding that these levels do — and indeed, must — interact in order to achieve coherence across the TPD ecosystem.

3.6.1. Macro-level enabling and constraining factors: Policy and practice

Policy or the political environment was identified as an enabling or constraining factor to tech4TPD models in more than a fifth (22%) of the 170 original publications collected. An example of this is observed in China, where the 'educational informationisation' goals aimed to connect every school to the internet and integrate ICT into the curriculum by 2010 (⇡Li, 2014). Beyond this infrastructural target, the project also included a distinct focus on developing students' and teachers' tech skills alongside access provision. Increased policy attention on EdTech use and tech-supported TPD effectively improved instructional delivery and more creative uses of lesson materials, in turn promoting improved student learning outcomes. A decade later, the policies and projects that made up China's 'educational informationisation' have led to considerable national achievements, such as the development of substantial digital resources, including MOOCs, reaching tens of thousands of teachers (⇡Li, 2014). This shows the potential of policy reforms when macro-level educational infrastructure projects are linked to upskilling students and teachers in tandem. However, when policy reforms do not align with TPD design and the relevant needs of teachers and learners in the classroom, this can create a confused, incoherent teaching and learning environment. In the same article, ⇡Li (2014) shows the complexities of misalignment at play. Teachers did not see the value of integrating technology into their practice when they did not perceive it as a useful means for students to pass their examinations. So, heavy examination pressures led to teachers "teaching to the test", instead of attempting innovations in the classroom, such as using technology. Thus, for policies and plans to be understood, embraced and implemented effectively, macro-level policy development needs to be coupled with ground-up micro- and meso-level approaches such as teacher needs assessments, local government engagement processes and change management (⇡Rogan & Grayson, 2003;⇡Haßler & Khalayleh, 2019).

Similar to ensuring that national policy meets local practice, foreign policies that are sometimes asserted through bilateral and multilateral aid organisations need to be critically reviewed to ensure they are indeed what is needed for the country at that point in time. A study reviewing the rationale for policy adoption in Rwanda found that the suitability of the learner-centred pedagogy policy for Rwanda was not questioned and little contextual evidence was provided, yet the policy was still adopted and put into practice because of foreign aid availability and donor influence (⇡van de Kuilen et al., 2019). Thus, it is important for national policymakers to ensure that foreign policies being implemented are relevant to the country's needs and contexts.

3.6.2. Macro-level enabling and constraining factors: Infrastructure

In Figure 1, infrastructure is noted as a 'cross-cutting element'; however, we report on it here in this macro section, acknowledging the ways in which infrastructure impacts across levels and influences the impact of TPD initiatives. Indeed, infrastructural challenges (and/or innovations) offecting tech4TPD models in nearly a quarter (24%) of all 170 articles initially collected. While digital learning is quite possible offline, ensuring that teachers have access to connectivity and devices to engage with digital learning in hard-to-reach and disconnected settings can support greater participation in TPD initiatives. Results from the global T4 Education survey shine a light on the most marginalised groups throughout the Covid-19 pandemic. Almost a quarter of all teachers who responded to the global survey reported that their school did not have access to the internet at all (⇡Pota et al., 2021). A separate survey of teaching unions throughout the pandemic found that approximately 38% of teachers globally, the majority of whom are based in LMICs, had no access to the internet (⇡Colclough, 2020). Access to tech was a particularly constraining or enabling factor in 22% of the articles reviewed. Additionally, more than half of teachers in the T4 survey reported that shortages of technological hardware for instruction were a hindrance; these figures are starker for teachers working in rural locations and also for those working in low-cost private schools (⇡Pota et al., 2021). While lack of access to tech can be constraining, this needs to be balanced with evidence of teachers being reluctant to utilise tech provided and devices being left unused in storerooms, as experienced in rural schools in Nepal (⇡Rana, Greenwood & Henderson, 2022). Generally, ⇡Pota et al. (2021) found concerning results for teachers working in low-cost private schools as they reported teachers having less access to technology, making less use of it, and having fewer TPD opportunities. Improving opportunities for this particular group is critical given that they often receive lower, sometimes exploitative, salaries than government school teachers (e.g., India: ⇡Kingdon, 2019; and globally: ⇡Mcloughlin, 2013). Onguko's various studies of the JiFUNzeni blended learning model in rural Kenya (Box 2) emphasise the need to find appropriate tech resources and infrastructure for remote and resource-constrained environments; for instance, video-based materials cannot always be easily accessed.

Our literature review discovered studies in which innovative technology solutions were utilised to address infrastructural challenges. This includes using a local Wi-Fi network to connect teachers to a server located on the intranet (documented, e.g., in ⇡Hennessy et al., 2015 and very widely used in various programmes, such as Kolibri (⇡Kolibri, no date) and (⇡Adam et al., 2020). Installing solar-powered devices to combat electricity shortages (⇡Onguko, 2014), sharing TPD materials and facilitating communities of learning through social messaging applications (⇡Taner, 2018) have also been shown to be effective means of overcoming large-scale infrastructure inadequacies. A study from the Covid-19 pandemic in South Africa explored the transition to online learning for pre-service teachers in rural communities and with limited internet access. Findings suggest that to overcome connectivity issues, pre-service teachers and teacher educators preferred using asynchronous modalities and a combination of low-tech educational resources, including the university LMS, emails and social media (⇡Tsakeni, 2021).

3.6.3. Macro-level enabling and constraining factors: Scalability and sustainability

Scaling educational interventions involves expanding beyond existing settings; however, it also refers to the depth of change, as "scaling up" must "effect deep and consequential change in classroom practice" (⇡Coburn, 2003, p. 4). The work on coaching offers a key example of the challenges faced here. ⇡Kraft et al. (2018) conducted a meta-analysis of 60 studies on teacher coaching at pre-primary and primary levels in the US. They found that larger programmes produced a fraction of the effects of smaller-scale programmes; although the study focused on the US education system, issues of scale may well be relevant for LMICs too. Where scale and cost-effectiveness intersect is also intriguing. As stated above, ⇡Cilliers et al. (2020) compared on-site and virtual coaching modalities and found that the virtual coaching modality – which initially proved more successful – became less cost-effective in the long run, after 3 years. Though the on-site mode was costlier, it ultimately produced far more significant student learning gains (⇡Cilliers et al., 2020). The authors suggest this is in part due to the fact that the coach–teacher relationship dwindled over time in the virtual coaching model. An important consideration therefore for tech4TPD coaching and mentoring models beyond infrastructure and connectivity concerns sustaining human relationships in the long run.

⇡Golding & Batiibwe's (2021) recent study of a blended model for maths educators across four African countries points to important lessons on designing scalable tech4TPD models for pedagogical leaders. Designed on the basis of an analysis of effective low-tech delivery, the training was initiated with an intensive 10-day face-to-face programme in which new pedagogical practices were modelled and trainers then actively sought out participants' accounts of their contextual constraints to tailor the model over time iteratively. Next, teacher educators received three months of distance learning support via 'action research related activity' so that they could further trial, reflect upon, evaluate and develop materials and pedagogical approaches for their local contexts. Mathematics teacher educators used their own mobile devices and computers with downloadable apps – including Geogebra and WhatsApp – rather than online synchronous activities requiring frequent web access. A free app by the African Institute for Mathematical Sciences Schools Enrichment Centre (AIMSSEC) also offered self-help plans for collaborative workshops with maths teachers. The model had a positive and sustained impact (1 year later) both on teacher educators' mathematical and pedagogical capability and on that of the teachers they trained, also resulting in improved primary pupil learning – as reported by teachers.

3.6.4. Meso-level enabling and constraining factors: TPD design, co-creation and needs assessment

The nature of addressing thorny issues in inequitable contexts predicates the need for technology-mediated TPD to be contextually designed. This was fundamental in research on flexible tech4TPD models. Studies of MOOCs in Uganda and India, for example, highlighted the need for initiatives to ensure local stakeholder input and to be adaptive to contextual needs, such as language and cultural factors (⇡Oyo et al., 2017; ⇡Wolfenden, Cross & Henry, 2017). The design of coaching and mentoring software is also important to consider. While free and low-tech apps have proved promising (⇡Golding & Batiibwe, 2021), those supporting observations and feedback sessions should align with pedagogical leaders' and teachers' digital literacy levels, and not be too time-consuming or too cognitively demanding to navigate (e.g., as in the case of the Tangerine:Tutor or COACH software in Uganda: ⇡Pouezevara et al., 2019).

Contextualised design is also crucial. Local adaptation appeared as an enabling or constraining factor in more than a fifth (21%) of the 170 articles initially reviewed. Several studies identified the importance of locally-developed OER, including video resources used in reflective tech4TPD activities (e.g., ⇡Hennessy et al., 2016; ⇡Onguko, 2012a; ⇡Onguko et al., 2013). It is important that teachers have opportunities to see models of teaching in classrooms that look similar to their own. Likewise, video content should not be too theoretical. Videos that are too theory-laden or do not provide practical examples of teaching may be less effective in stimulating change in practice, as found in a case study in Namibia (⇡Kok & Blignaut, 2014). In this study, teachers also found the videos to be time-consuming to watch, or unclear, with no visual examples (⇡Kok & Blignaut, 2014). For teachers who have difficulty seeing, videos made accessible with audio descriptions have proved promising in increasing engagement and participation in reflective activities (⇡Wormnæs & Sellæg, 2013).

A valuable way of ensuring that technology-supported TPD is contextually appropriate is to obtain information on teachers' profiles and their individual needs. This is particularly important when working with marginalised teachers. In addition to intentionally designing to fit teachers' qualifications, three EiE studies identified in our literature review each highlight the importance of co-design and incorporating teachers' language and emotional needs (⇡Bradley et al., 2019; ⇡Kennedy & Laurillard, 2019; ⇡Mendenhall et al., 2018; see also ⇡Inter-Agency Network for Education in Emergencies, 2022). Likewise, a recent study across 13 countries in sub-Saharan Africa provides a model for engaging teachers in the co-creation of tech4TPD models during the Covid-19 pandemic. The model includes a needs assessment, mentorship and iterative monitoring and adaptation (⇡Negeze & Iyer, 2022). Likewise, ⇡Onguko's (2014) study in Kenya highlights the benefits of co-creation. Needs assessments for teachers working in urban and rural settings meant that varied approaches to tech4TPD were applied and contributed to longer-term pedagogical improvements. While some research designs included differentiated teacher groups – e.g., urban and rural schools in ⇡Piper et al., 2016; ⇡Onguko, 2014; ⇡Wang et al., 2018 – few have detailed disaggregated effects or distinct causal pathways of impact. The importance of separating out effects and catering to different teacher and learner audiences cannot be emphasised enough to enable tech-supported TPD to meet marginalised teacher and learner needs and alleviate inequity.

Listening to teachers' voices is central to any needs assessment. The T4 global teacher survey provides data on over 20,000 teachers' views around teaching with technology across 165 countries during the Covid-19 pandemic (disaggregated by urban/rural locations, school type, gender, teaching experience, student age, and subject area). Our analysis of this data (reported in a joint publication with T4 Education: ⇡Pota et al., 2021) found that the most common foci of TPD experienced over the preceding (peak pandemic) year centred on online/remote teaching and learning, specifically on technologies (53%) and pedagogical techniques (43%). However, high proportions of teachers expressed their need for (further) TPD focused on developing skills and confidence in using digital technologies in teaching (54%) and help with remote teaching (41%). The next ranked needs were caring for teachers' mental health and well-being (39%) and support in developing pedagogy and teaching methods (38%). All of the above were higher priorities than support in developing teachers' curriculum subject knowledge (32%), although the latter was still an issue for almost one-third of teachers. The disaggregated T4 survey data are available upon request to T4 Education. TPD designers and providers could benefit from interrogating them for specific countries and settings to effectively design TPD models that address teachers' acute needs.

3.6.5. Meso-level enabling and constraining factors: Teacher communities

EdTech can be used in a range of ways to develop or enhance teacher communities within or across schools. As Section 3.2 explored, remote CoPs may be integrated into flexible tech4TPD models or serve as standalone support structures for teachers' distance or self-study learning. However, various factors shape the effectiveness of such approaches. Notably, ⇡Soto et al. (2021) discuss the importance of technical factors such as the quality of the platform housing a virtual CoP and its overall user experience. In addition to infrastructural and connectivity considerations (e.g., ⇡Wickramanayake & Muhammad Jika, 2018; ⇡Widodo & Riandi, 2013), different social media platforms may have different affordances for CoPs. In China, for example, ⇡Sun et al. (2017) found that instant messaging apps resulted in more social interactions between teachers, while online discussion forums resulted in dialogue aimed at knowledge construction. In South Africa, ⇡Mabaso & Meda (2019) found that using WhatsApp met pre-service teachers' needs and supported them in collaboration, but did not adequately develop their digital literacy skills. On the other hand, ⇡Allela et al. (2020) point to several challenges with WhatsApp, including the limited number of group members (256 maximum) and the fact that new members cannot access any messages sent before they join the group, placing them at a disadvantage.

Teacher communities, in particular those involving marginalised groups, can be subject to power dynamics. A rare small-scale study with visually impaired teachers (n=12) in Uganda used videos with audio descriptions to encourage participation from teachers with visual disabilities (⇡Wormnæs & Sellæg, 2013). While the initiative permitted the participation and engagement of teachers with disabilities alongside their non-disabled colleagues, it also highlighted how power dynamics existed when non-disabled teachers outnumbered those with disabilities and participated more in group discussions following the video viewing. This points to critical considerations when designing tech4TPD involving teacher communities that aim to develop the reflective practices of marginalised teachers, and reiterates the need to co-design tech4TPD models with teachers to understand their learning preferences. Indeed, a second study in Cambodia found that teachers preferred working in small groups rather than pairs (⇡Lok et al., 2018). These seemingly small details can help inform the design of more equitable and effective tech4TPD.

3.6.6. Meso-level enabling and constraining factors: School culture

School cultures are defined as "the basic assumptions, norms and values, and cultural artefacts that are shared by school members" (⇡Maslowski, 2001 pp. 8–9); they have the potential to both enable and constrain teachers (⇡Agyei & Voogt, 2014). Given the importance of school culture, it is surprising that more studies did not identify school-level factors as enabling and constraining tech4TPD. Key factors identified in the 170 publications collected include school leadership (12%), cultural dynamics (12%), school socio-economic status (8%), classroom level factors such as student behaviour or access to resources (<5%) and support from the wider school community (<5%).

School cultures can afford teachers with the requisite experience, safe space and confidence to be creative in the design, delivery and/or assessment of student learning. Yet, school cultures can also impose constraints on a teacher's creativity, inhibiting their inherent urges to 'go off script' in order to really engage students (⇡Dresser, 2012). 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 (⇡Barquero et al., 2018: 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 avoids reinforcing only local traditions. As such, the culture a teacher finds themself in can play a pivotal role in the way they develop their language, subject, content and/or pedagogical knowledge.

Developing an institutional culture of reflective practice is crucial within schools. It takes time to develop critical reflective skills that can lead to changes in teacher perceptions (⇡Tülüce & Çeçen, 2016). Teachers require tools and approaches to give and receive feedback effectively, and promoting a reflective culture within schools can ensure that feedback is appreciated and encouraged. School culture setting starts with school leaders, and from here must filter through the school system (⇡Bruns et al., 2018). This culture setting can help in relation to reflective practice, and also more broadly in relation to teachers' attitudes towards TPD, tech, and overall teaching practice (⇡Agyei & Voogt, 2014; ⇡Barquero et al., 2018). Other factors that shape the effectiveness of videos in school-based TPD models include an institutional culture and leadership supportive of peer learning, and the costs of tech infrastructure and maintenance (⇡Liang, 2015; ⇡Saito & Khong, 2017). In China, ⇡Liang (2015) found that a school culture of reflection was established by setting up cameras in teachers' classrooms so that they could later observe themselves with their colleagues. The authors argue that without observers' physical classroom presence, teachers' authentic pedagogical skills were better exposed and the information gathered, and feedback provided to teachers was more credible (⇡Liang, 2015). Nevertheless, major ethical and technical considerations arise with teacher surveillance of this kind. Further, teachers may have certain preferences when it comes to watching videos of themselves or of others. In Cambodia, a comparative study found that teachers preferred watching videos of expert teachers modelling effective pedagogy, rather than watching themselves (⇡Lok et al., 2018), while a study in India found that teachers who were initially reluctant to watch their own practice later learnt to enjoy it (⇡Makarani, 2012). So, understanding what works within a particular school, and establishing routines together in schools can aid culture setting that is responsive to teachers' preferences while also challenging teachers, at times, to sit outside of their comfort level.

School leaders play a crucial role in setting the institutional culture and expectations. A 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 (⇡Bruns et al., 2018). Some teachers may need close support and guidance when integrating ICT, whereas others might be more confident to adopt technology in their classroom practice; school leaders must understand the needs of different teachers in their school context. Teachers who are hesitant about or resistant to change need role models to show them how they can further develop their practice (⇡Dlamini & Mbatha, 2018). ⇡Agyei & Voogt (2014) 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 (2018) assert that inspiring school leaders can positively impact student learning outcomes. In their study on South African teachers' tech readiness, high-performing schools had involved school leaders working on school ICT strategies alongside 'champion teachers on the ground' who were confident in modelling their practice to others (⇡Dlamini & Mbatha, 2018, p. 28). School systems must establish mechanisms for identifying high-performing teachers to act as these champions who can work to set the overall culture of teacher learning in the school.

3.6.7. Micro-level enabling and constraining factors: Teachers' skills, preferences, attitudes

Individual factors such as teachers' digital skills, preferences and attitudes towards tech shape their engagement with remote CoPs, and wider tech4TPD models (e.g., ⇡Ata & Cevik, 2019; ⇡Stewart, 2015; ⇡Soto et al., 2021; ⇡Wang & Lu, 2012; ⇡Widodo & Riandi, 2013). Teachers' prior tech skills, in particular, was the most common enabling/constraining factor influencing this engagement identified in the literature (in 48 of 170 articles, or 28%). In South Africa, ⇡Moodley (2019) found that teachers' attitudes towards using WhatsApp for a virtual CoP were dependent upon their awareness of the context within which the community exists and the willingness of the participants to accept differing views and opinions. Studies in Nigeria and Zimbabwe found that teachers were intrinsically motivated to access social media via personal or shared devices for educational purposes in contexts where they lacked access to government-provided technology resources (⇡Mushayikwa, 2013; ⇡Wickramanayake & Muhammad Jika, 2018), while a study in Sierra Leone found that teachers preferred using WhatsApp over discussion forums in an LMS Moodle App when engaging in remote communities of practice (⇡Allela et al., 2020). Teachers' low level of technology skills or lack of access to personal devices can hinder their participation in distance learning or online portions of blended tech4TPD models (e.g., in South Africa: ⇡Dlamini & Mbatha, 2018 and Indonesia: ⇡Widodo & Riandi, 2013). In Bangladesh, older teachers were less likely to access online professional development opportunities due to their lack of technology skills (⇡Prime Minister's Office: Bangladesh, no date). More experienced or motivated peers – and in some cases, even adolescent students who may have more advanced ICT skills than their teachers (⇡Onguko, 2014) – can serve as an important support to increase teacher engagement and facilitate teacher learning with technology (⇡Mukama, 2009). Interestingly, there is limited evidence of older or more experienced teachers' resistance to technology, contrary to popular belief (⇡Burns, forthcoming; ⇡Pota et al., 2021). For subject-specific software, initial weaknesses in subject content knowledge may preclude more than superficial uses, inhibiting impact on teacher learning (e.g., in Turkey: ⇡Kocakaya & Gonen, 2010). The effectiveness of computer-mediated TPD models is also often shaped by teachers ' prior training in computer use, and the time they spend using computers (⇡Gokdas & Torun, 2017). Our literature review did not, however, identify any examples of personalised learning software that adapts to teachers' competency levels (e.g., as in adaptive technologies for students).

Various studies have examined teachers' preferences for learning with EdTech. Teachers in Ghana, for example, preferred using the messaging app Telegram because it accommodates a larger number of participants, and they could use it to easily access content from previous live training sessions that they had missed (⇡Ananga et al., 2021). In Indonesia, science teachers had positive attitudes towards learning with WhatsApp and LMSs (⇡Khaleyla et al., 2021). Using technology to connect teachers with their peers, coaches and mentors is an emerging trend in the literature (see Sections 3.2 and 3.3). Blended learning models that provide limited opportunities for teachers to engage with one another can result in teachers feeling isolated (e.g., in Turkey: ⇡Yılmaz & Malone, 2020).

3.6.8. Micro-level enabling and constraining factors: Human relationships and well-being

Several studies have also pointed to the importance of maintaining human relationships and social connections in tech4TPD efforts (e.g., ⇡Cilliers et al., 2020: see more in Section 3.3 on the use of technology to support coaching and mentoring). Indeed, the shift to online learning during the Covid-19 pandemic has prompted various researchers to examine impacts on teacher well-being (especially pre-service teachers: e.g., ⇡Güldal Kan et al., 2021; ⇡Kirkiç & Yahsi, 2021; ⇡Özkul et al., 2021). ⇡Widodo & Riandi (2013) found that in a blended learning tech4TPD model incorporating lesson study, Indonesian teachers preferred face-to-face communities of practice over social media, again highlighting the importance of human relationships. ⇡Soto et al. (2021) also elevate the significance of human relationships; they point out that principles such as trust are integral to a well-functioning virtual CoP.

Only one study mentioned how threats of cyber security hindered teacher engagement in tech4TPD (Nigeria: ⇡Wickramanayake & Muhammad Jika, 2018). None of the studies identified in the literature review sought to actively train teachers in online safeguarding. Indeed, in the T4 survey, teachers rated safeguarding as a low priority for their own professional development (⇡Pota et al., 2021). Thus this evidence gap takes new precedence, given the risks concerning online safety, which have become increasingly evident during the Covid-19 pandemic.

3.6.9. Micro-level enabling and constraining factors: Teacher autonomy, accountability and agency

Evidence suggests that individual preferences and dispositions can shape teacher engagement with online learning. Technology can be a motivating factor for teachers to engage in self-study by looking for teaching and learning resources, creating their own resources, or connecting to other teachers (⇡Mushayikwa, 2013). However, self-study models of tech4TPD require teachers to have a certain level of autonomy. While online TPD programmes nearly doubled in the last decade in Australia, they have also been associated with lower completion rates and poor engagement (⇡Ledger et al., 2021). A study in Turkey found that pre-service teachers who had higher levels of digital literacy or spent more time online were more able to self-regulate their independent study (⇡Özdemir & Önal, 2021), while evidence from China suggests that MOOCs had the greatest impact on 'persistent' teachers, or those more actively engaged in the self-study learning content (⇡Wang et al., 2018). For teachers who are less motivated, incentives or systems of accountability may need to be established; teachers in Indonesia had low attendance for the online components of a blended TPD initiative due to "the absence of formal consequences" (⇡Widodo & Riandi, 2013, p. 388). As such, there is a tension between teachers' autonomy in making decisions about their own learning, when they have the option to do so, and accountability in participating in centralised continuous professional development.

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 the Bangladesh EiA project, pre-loaded iPods increased teachers' classroom use of audio and video materials, but teachers rarely created their own resources (⇡Shohel & Kirkwood, 2012b). A reliance on ready-made resources such as scripted lesson plans may therefore inhibit teachers' creativity, potentially damaging long-term teacher agency and motivation in the process (⇡Shohel & Kirkwood, 2012b). Indeed, a study exploring teachers' guides across 13 countries and 19 projects found that scripted guides improved student learning outcomes; however, when the guides were overly scripted, especially as teachers' confidence increased, teacher learning outcomes dropped (⇡Piper et al., 2018). Teachers did not adhere to the scripts, often reducing group work for more teacher-oriented activities. ⇡Kotze et al. (2018) noted that "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). Thus, while (semi-)scripted lesson plans can set common expectations for student learning or provide less-experienced teachers with an appropriate amount of scaffolding, more-experienced or confident teachers might find them demotivating. So, fading support in line with a teacher's confidence and ability to teach the subject is important (⇡Piper et al., 2018). This important finding may also be relevant for teacher educators – a recent study in India suggests that tech4TPD models should provide resources at a variety of levels to account for lecturers' diverse skills and competencies (⇡Raina et al., 2022).

3.6.10. Micro-level enabling and constraining factors: Time

Time constraints may be an additional hindrance for teachers hoping to engage in self-study (⇡Boitshwarelo, 2009). Time constraints appeared as a challenge in nearly a fifth (19%) of all 170 publications initially collected, suggesting that time expands beyond impacting teachers' self-study, to affecting teachers' engagement with wider tech4TPD models. Certain activities within blended learning models may also be more time-consuming, for example, developing lesson plans with new learner-centred pedagogies (⇡Jukes et al., 2017). Some teachers may also have less time to engage in tech4TPD than others, which is often the case for women, as described below. It is also worth noting that in-person off-site TPD can require travel time and incur transport and per diem costs.

3.6.11. Micro-level enabling and constraining factors: Marginalisation

The main areas of marginalisation emerging from the research are gender, SEND, EiE and rural location. (The numerous initiatives for rural teachers are discussed throughout Section 3. While a few studies addressing the other three areas of marginalisation are mentioned there too, as relevant, here we focus on and elaborate on those three areas explicitly). While the *gender* digital divide has been well documented (e.g.,⇡Laurillard et al., 2018; ⇡USAID, 2020), the differentiating impacts of tech4TPD on women are thin. On the one hand, a study in Turkey found that female teachers were more likely than male teachers to self-regulate their online learning (⇡Özdemir & Önal, 2021). Indeed, a study in Zimbabwe recounts how a young female teacher was motivated to use ICT to "prove that [she] was capable" and overcome gender biases (⇡Mushayikwa, 2013, p. 284). A study in Pakistan found that female higher education teachers believed that digital platforms countered negative, gendered attitudes by giving them more of a voice than was afforded by face-to-face peer discussion (⇡Khan, 2017). On the other hand, however, a study in Uganda found that SMS text messaging was less effective than in-person training in changing gender norms that shaped teachers' attitudes or behaviours (e.g., ⇡Chinen & Elmeski, 2016). Given the unique challenges that women face, the limited number of studies that seek to address gender dynamics and/or explicitly support female teachers is noteworthy. Few studies interpreted their findings in relation to teachers' sex or gender. For example, a study in Cambodia found that one of the barriers teachers faced to accessing tech4TPD was "large families to take care of" (⇡Lok et al., 2018, p. 287) but the authors did not note whether these barriers were faced more by female or male teachers. Due to traditional gender norms, women may be expected to shoulder childrearing and other domestic responsibilities, creating time constraints and hindering their access to professional development opportunities, a pattern which has become even more evident during the Covid-19 pandemic (e.g., in Ghana: ⇡Ananga et al., 2021).

Despite the potential reach of technology designed to be inclusive, there is little evidence on tech-based TPD for *SEND teachers*. The aforementioned study by ⇡Wormnaes & Sellaeg (2013) in Uganda found that the 12 visually impaired participating teachers valued the audio-described educational video material and reflected constructively on their involvement and emotional engagement with SEND learners. 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. One example is ⇡Mendenhall et al.'s (2018) multifaceted approach (Box 5). ⇡Kennedy & Laurillard (2019) worked with Syrian and Lebanese teachers to construct a MOOC designed for TPD in EiE contexts. In the study of female Syrian refugee teachers in Lebanon and Sweden by ⇡Bradley et al. (2019), language applications facilitated self-directed learning and development of new language skills and teaching practices.The ⇡Inter-Agency Network for Education in Emergencies' (2022) recently launched report on promising practices in TPD highlights the myriad ways technology can support teachers working in contexts of fragility, conflict and violence. Examples of tech4TPD include technology-based remote training modalities, self-paced online exercises, communication platforms such as Microsoft Teams, and the use of interactive pedagogies and resource platforms in bilingual (Arabic and English) MOOCs. In an example of a tech4TPD model in Rohingya refugee camps in Bangladesh, the authors note the need for blending 'no-tech' and 'low-tech' modalities with more advanced technologies. This can be done, for example, by distributing digital content and videos through hard drives. To conclude, it seems that the logic of developing EdTech initiatives in the most challenging contexts and extending them to more favourable conditions is compelling but rarely implemented.[20]

3.6.12. Micro-level enabling and constraining factors: Devices

Beyond large-scale infrastructure considerations such as connectivity, different types of devices offer different levels of flexibility for teachers. For example, ⇡Ilic (2021) found that pre-service teachers in Turkey found it easier to use computers than tablets when participating in a flipped classroom. On the other hand, given the proliferation of mobile phones in LMICs, these may serve as important tools for flexible tech4TPD models (e.g., ⇡Mushayikwa, 2013; ⇡Taner, 2018). Portability is one such device characteristic which can offer teachers flexibility in that teachers are not constrained to — often problematic – computer labs to complete teacher learning; rather, they can learn at a location of their choice (⇡Piper et al., 2015). Despite the advantages of mobile devices such as cell phones and tablets, our systematic review found that 42% of all devices mentioned in the literature related to computers (desktops/laptops). Finally, we note that it is curious that KaiOS 4G-enabled devices (⇡James, 2020) are entirely absent both in the research literature and in the intergovernmental/non-governmental organisation discourse around the internet, despite significant deployments across sub-Saharan Africa (⇡KaiOS, no date).

4. Insights and evidence from practice

While the previous section focuses on evidence from our literature searches, there are a number of further national/large-scale tech-mediated TPD programmes that contribute to the current and emerging evidence base. The following interventions (and accompanying research studies) have been selected on the basis of the following criteria:

- National or large-scale initiatives that design for sustainability, scalability and/or cost-effectiveness;
- Combining and integrating various technology uses within the TPD programme design that are appropriate for LMIC contexts;
- Seeking to address identified high-potential evidence gaps and the methodological gaps on tech-mediated TPD, arising from our recent literature review (Appendix B).

4.1. Mature, large-scale, tech-supported TPD programmes

Recently completed large-scale TPD programmes in Senegal and Nigeria offer emerging evidence on effective uses of technology in TPD, including some challenges experienced.

4.1.1. Senegal's blended CPD in the 'Lecture Pour Tous' programme

[20] See https://blogs.worldbank.org/edutech/scaling-up Retrieved 21 October 2022.

Intervention – Senegal's 'Lecture Pour Tous' ('Reading for All') programme targeted over 14,000 teachers using a CPD model that included in-person workshops and follow-up support via other modalities such as coaching, teacher learning circles and SMS. To scale cost-effectively and adapt to Covid-19-related school closures, the programme evolved in 2022 to incorporate a blended model. Technology-mediated TPD aspects include: digitised, interactive, self-directed learning modules alongside hard copies; WhatsApp groups plus in-person, school-based and cluster-based learning circles; SMS push-messaging for reminders, tips and motivation; and digital tools to support coaches.

Research findings – Regarding teacher learning, teachers preferred in-person to distance learning, although WhatsApp was found to be useful for timely, relevant information and reminders, and distance learning showed initial increases in teacher knowledge (⇡Proudfoot et al., 2022). Only 53% of teachers surveyed used the digitised, self-guided learning modules, citing difficulty accessing the modules as the barrier. Lecture Pour Tous also introduced new coaching models to address previous issues where 1:1 coaching sessions were typically "sporadic, supervisory, and rarely based on classroom observation", school leaders struggled to find the time to support teachers alongside their other responsibilities, and they were generally untrained in constructive coaching techniques (⇡Bagby et al., 2022, p. 2). An RCT, qualitative research and cost analysis were conducted on the new coaching models to compare:

1. the base coaching model (in-school directors coach teachers monthly; external inspector coaches school director quarterly), against
2. a tele-coaching model (head district inspector tele-coaches teachers fortnightly and in-school director monthly; quarterly in-person school cluster meetings), and
3. a supplemental in-person coaching model (nearby experienced director coaches teachers and in-school director monthly in person; quarterly in-person school cluster meetings) (⇡Bagby et al., 2022).

Findings resonated with those of ⇡Burns (2013) mentioned above, and included:

- Teachers receiving supplemental in-person coaching or tele-coaching were 23% more likely to give constructive feedback and critical guidance while students read than teachers in the base model;
- Supplemental in-person coaching led to better instructional practices and was thought to be more useful by teachers, tele-coaches and directors;
- Tele-coaching was more cost-effective, costing almost 83% less than in-person coaching to achieve 0.1 standard deviations of improvement in how teachers guided individual student reading practice.

Alongside the findings, lessons learnt from the implementation included the need for more financial support and capacity building of system personnel and improved coaching of coaches, to achieve the full effectiveness of models being evaluated.

4.1.2. Nigeria's national Teacher Development Programme

Intervention – The 6-year ⇡Teacher Development Programme (2019), commencing in 2013, worked with the government of Nigeria to support 62,000 primary and junior secondary teachers and achieve better learning outcomes for over 2.3 million students. Teachers used their own or state-provided devices to access digital content. Facilitators were also provided with amplifiers to connect phones to, so that teachers could, for example, play rhymes to help with phonics. In Phase 1, teachers were given phones and SD cards; as this would not be replicable by the government, it is notable that the programme subsequently revised its strategy for technology use to capitalise on tech already available in the context. By Phase 2, teachers were using their own phones for audiovisual materials and participants were trained on how to transfer materials from tablet to phone or phone to phone.

Research findings – Overall, the endline findings indicate that the actual use of devices by teachers (about 60%) fell short of the target (about 90%) (⇡Teacher Development Programme, 2019). In the years when face-to-face training was at its peak, the use of devices was higher; the report states that usage between training sessions decreased because teachers felt that they had already seen the videos and did not need to watch them again. This raises the need for blended approaches, nudging to motivate teachers and the updating and replenishing of digital resources.

4.2. Emerging large-scale tech-mediated TPD research: 'Watch this space'

Ongoing large-scale TPD research studies in Tanzania, Sierra Leone and Bangladesh are generating early insights on potentially beneficial uses of technology in TPD.

4.2.1. Tanzania's national tech-mediated, school-based TPD programme

The intervention – The Government of Tanzania is incrementally rolling out a national, decentralised, school-based teacher continuous professional development (TCPD) programme. School-level 'Communities of Learning' (CoL) are at the core of the model, along with supplementary workshops, coaching and mentoring and self-learning modules. A Moodle-based LMS for teachers, coaches and government officials will house interactive digital TCPD material, data collection tools and teacher needs assessments.

The research – EdTech Hub, the Aga Khan University and the Tanzania Institute of Education are conducting research on the cost-effectiveness and sustainability of the TCPD model, to improve student learning outcomes in rural Tanzanian primary schools (⇡Aga Khan University, 2022). The evidence gaps (see Appendix B) that this study addresses include:

1. research on the added value of technology mediation of longer-term TPD programmes in LMICs;
2. strategies for using tech to reach and include marginalised teachers and learners, catering for diverse needs, particularly in rural areas; and
3. research on how tech can be integrated into sustainable national TPD implementation models and used to support facilitators and teacher educators without compromising social relationships.

Learning from the first iteration of roll-out in 2022 included the need for more interactive, pedagogically-grounded, peer facilitator training and support, improved peer facilitator guides and CoL modules, orientation on the LMS and accessing digital materials, and improved CoL attendance monitoring. Additionally, better coordination and alignment between regionally-differentiated implementing partners were identified as critical to having a unified national TCPD intervention.

4.2.2. Sierra Leone's national tech-mediated TPD programme

The intervention – To address low student learning outcomes at basic education levels in Sierra Leone, a national TCPD programme is being designed, tested and iteratively scaled over a 5-year period. The model centres around lesson observations and structured coaching, supported by CoPs and tablets containing an LMS and digital content. The programme targets approximately 22,000 teachers at the primary level and seeks to train and support pedagogical leaders – at scale – to undertake lesson observations, conduct coaching and facilitate communities of practice. The evidence gaps (see Appendix B) that this study addresses include more research on larger-scale and longer-term technology-mediated TPD programmes in under-represented countries. While there are tech-based challenges – including connectivity, data capacity and content updating – the use of tablets and structured digital content on specific pedagogical foci are critical components to support facilitators and teacher participants at scale.

The research

EdTech Hub is leading a sandbox in partnership with the World Bank and the Sierra Leone Teaching Service Commission (TSC), conducting a series of experiments testing individual components of the model as well as a holistic prototype in preparation for programme piloting. Early research (e.g., ⇡Sengeh et al., 2021) has revealed that teachers value the advantages that a tablet, LMS and digital content can provide to support teaching practices and facilitate engagement in a community of practice. For instance, one experiment on tablet maintenance found that teachers – without prompting – utilised the tablets to self-record and later reviewed their teaching with peers. It is now necessary to learn how such video-based review and reflection processes can be promoted – and how tech-based barriers can be addressed – within the holistic TCPD package at scale to enhance teaching and learning outcomes. Alongside this, the Tich Mi Ar Tich Dem larger-scale research study investigates the impact and sustainability of the government's scalable, TCPD programme. Early findings show the need to support teachers in better understanding the reflective nature and structure of CoPs, provide clearer guidance on the purpose and content of workshops to teachers and district officials, and consider incentive structures for teachers (⇡Walker, Tegha et al., 2022).

4.2.3. Bangladesh's Muktopaath mobile learning platform for teachers

The intervention – Building on the groundwork provided by the English in Action programme in Bangladesh (discussed in Section 3.5.1; ⇡Power, McCormick & Asbeek-Brusse, 2017), the Prime Minister's Office is supporting the continued use of Muktopaath, a Bangla-language mobile learning platform used by 400,000+ teachers. The courses are free or low-cost (~USD4), although as in many contexts, additional costs affecting affordability include data. The Anonde Gonit Shikhi ('Let's learn Maths with fun') course, which over 130,000 have completed, is the most popular course and uses a gamified approach to learning numeracy. The evidence gaps (see Appendix B) this study addresses include undertaking more assessment of impacts on student learning outcomes.

The research – The Open University and Dhaka University – funded by EdTech Hub – are conducting a study in Bangladesh on Mobile Learning for Empowerment of Marginalised Mathematics Educators (3Mpower) (⇡Grimette, 2022). 3Mpower researches at-scale TPD courses on numeracy provided via Muktopaath, specifically their use by teachers from rural areas, female teachers and ethnic minorities. The research aims to generate new evidence on equitable mobile learning in TPD, learning design for TPD on numeracy, effective pedagogies for TPD with technology and cost-effectiveness of TPD through mobile learning. The generated evidence on numeracy outcomes and cost-effectiveness will support decision-makers on how technology can be used to improve teacher quality and students' numeracy learning outcomes.

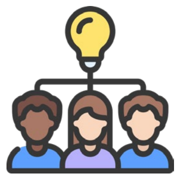
4.2.4 TCPD implementation – research – policy nexus

Emerging evidence from the aforementioned national, tech-mediated TPD programmes shows the importance of researching at scale with governments, where the effectiveness of tech4TPD designs and models is impacted by the quality of the implementation. Factoring real-world elements – such as hard-to-reach schools, uneven device access, stakeholder coordination, budget constraints, and political economy issues – into tech4TPD design and implementation plans is key to the sustainability and (cost-)effectiveness of programmes. As such, our policy recommendations draw on the evidence in light of the complex real-world contexts where tech4TPD implementations will occur.

5. Policy recommendations

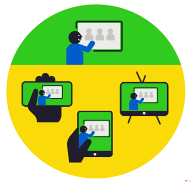
These 12 recommendations are updated and somewhat expanded versions of those in the policy brief by ⇡D'Angelo et al., 2022), stemming from the original systematic review.

5.1. Work with teachers to design TPD interventions



All (pre- and in-service) teachers are professionals capable of reflecting on, critiquing and developing their own practice and recognising their own agency to effect change. TPD initiatives must therefore support teachers as individuals rather than being imposed without sufficient teacher input. Designers and implementers should work with teachers and other stakeholders to co-create TPD models that are relevant to their needs and that leverage their skills and capacities to improve teaching and learning, including using design-based research approaches (e.g.,⇡Anwar, 2017: Pakistan). For example, consider establishing a teacher advisory group or forum, using focus groups or surveys to assess teachers' needs and interests, or using more participatory approaches like co-creation workshops. Teacher learning content and tech4TPD environments need to be flexible and adapted to available infrastructure as well as to teachers' pedagogical, curricular and cultural needs.

5.2. Leverage EdTech to enhance teaching practices



EdTech should be used to complement, not supplement or replace, the skills and capabilities of teachers and practitioners (⇡Major & Francis, 2020). Preloaded devices that provide teachers with easily accessible, innovative teaching and learning resources to use in the classroom, SMS messages with lesson plans, or guides for (semi-)structured pedagogy, are all examples of how EdTech can be used to enhance teachers' classroom practices. However, it is critical that this content is culturally appropriate, teacher-centred and speaks to teachers' lived realities, and aligned to curriculum or qualification frameworks and other policies. While structured lesson plans can support teachers in utilising new teaching techniques, overly scripted ones may be inappropriate for sustaining pedagogical change across contexts (⇡Piper et al., 2015: Kenya). This important finding aligns with other work that construes scalability in terms of enacting and developing deep understanding of pedagogical principles and norms of interaction rather than spreading activities or materials (⇡Coburn, 2003) and designs TPD accordingly using semi-structured approaches (e.g., ⇡Haßler et al., 2018).

Thus, tech4TPD must be designed to scaffold teacher learning across diverse levels of skills and pedagogical competencies to ensure practices are, in fact, enhanced, and not hindered. Indeed, lesson planning and the use of dynamic, curriculum-aligned teaching and learning materials (such as the PRIMR reading textbooks and stories related to the Kenyan curriculum provided on Kindle e-readers by ⇡Piper et al., 2015) are two practices that can improve student learning.

5.3. Systematically monitor and evaluate how TPD impacts student learning

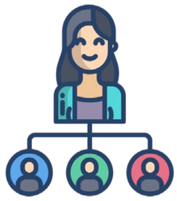
Professional learning mediated through technology use can contribute to improving teaching quality and student learning outcomes. While several studies measured the impact of TPD programmes on teachers' pedagogical/subject knowledge (17%), skills (10%) or classroom practice (12%), very few examined the subsequent impact on students' knowledge and skills (5%). Impact on student learning must remain central to all technology-supported TPD programmes and evaluations. Pre/post-student evaluations or more rigorous experimental trials are two ways of doing this; while more small-scale and iterative research methods (e.g., design-based implementation research, sandboxes) can also help in improving and adapting small-scale programmes. The added value of the tech above and beyond 'business as usual' also needs to be measured and related to how it is used by teachers.

5.4. Explore how tech4TPD can improve student literacy

Literacy was examined in only 13 (<8%) of the 170 publications reviewed, while nearly twice as many studies (25) examined maths. This makes literacy one of the less-frequently studied subjects, despite pre-Covid-19 statistics estimating that the majority of 10-year-old children in LMICs cannot read a simple text (⇡UNESCO Institute for Statistics & Statistics, 2017). TPD's potential impact on student literacy is an important evidence gap that must be prioritised.

5.5. Use EdTech to support teacher trainers and educators

While there is a need for more evidence in this area, EdTech can support the work of teacher trainers and educators. Structured coaching software and observation tools can prompt feedback provided to teachers (⇡Bruns et al., 2018: Brazil). VLEs can allow teacher trainers and educators to share content with teachers or provide support outside of normal class / training time (e.g., ⇡Basal, 2015, Turkey). These are important uses of EdTech to help teacher trainers or educators do their jobs more effectively, in turn supporting teachers to reflect on their own practices and progress regarding personal and educational reform priorities. However, for success, teacher educators need more than technology tools and content; they need practical teaching experience themselves, and pedagogical expertise reaching at least the level it is hoped that the teachers will develop.



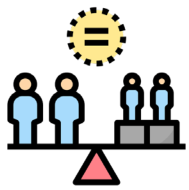
5.6. Foster trust and positive relationships

TPD is most effective in an environment of mutual respect for teachers, trainers, coaches, district officials and school leaders, alongside trust in the education system, the TPD programme goals, and/or technology in general. ⇡Cilliers et al. (2020: South Africa), for example, found that virtual coaching loses efficacy over time because trusting relationships are harder to secure without face-to-face interaction. Supportive and constructive relationships should be prioritised in technology-supported TPD programmes, integrated into teachers' codes of conduct, teacher qualification frameworks or education sector plans. Providing mental health and psychosocial support – a need reported by almost 40% of teachers surveyed by ⇡Pota et al. (2021) – may be an important first step in humanising the teaching profession and fostering positive relationships among teachers and other education personnel; however, this carries greater difficulties through remote or virtual interactions.

5.7. Explore formal and informal uses of EdTech to facilitate teacher communities of practice

Informal models of TPD include organic and teacher- or facilitator-led online and/or remote communities of practice through, for example, Facebook, WhatsApp or other commonly used social media (e.g., ⇡Taner, 2018: Ghana). Blended models are particularly powerful (e.g., ⇡Wolfenden, Cross & Henry, 2017). Communities of practice are increasingly recognised (featured in 37 publications) as critical for teacher well-being, especially during the Covid-19 pandemic and school closures. Effective forms of informal social media use should be explicitly encouraged, while simultaneously ensuring the pedagogical rigour of the ideas being promoted, and alignment of content and TPD objectives. This can happen, for example, by trialling and refining ideas learnt in informal spaces in school-based learning circles or with colleagues.

5.8. Focus on equity and supporting the most marginalised



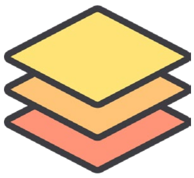
As technology has the potential to create further divisions and even exclude groups, it is critical that more focus is placed on understanding how tech can most effectively support TPD that reaches and includes marginalised groups of both teachers and learners and caters for diverse (learning) needs. This includes women and girls, refugees and those working in emergency settings, and learners and teachers with disabilities, among others. This recommendation from the literature is strongly reinforced by teachers' own perspectives: 37% of teachers in the T4 Education global survey wanted governments to prioritise providing digital support to marginalised learners so as to address learning loss from the Covid-19 pandemic (⇡Pota et al., 2021), demonstrating demand from teachers to support the most marginalised.

Although 40 LMICs were represented in the reviewed publications, 96 further LMICs were not. Only 5 countries (all middle-income) had 10 or more studies. More research is needed in under-represented countries and regions and in remote or rural communities, which often have additional challenges (e.g., infrastructure, socio-economic status, conflict/emergency, attendance of girls, language barriers). Marginalised teachers and learners can benefit hugely from tailored TPD and technology-facilitated connection to others in similar contexts.

5.9. Improve technology infrastructure and upskill teachers

Addressing each of the above recommendations depends on adequate infrastructure since this can strongly affect the impact of tech4TPD initiatives, as outlined in Section 3.6.1. Leveraging EdTech means equipping teachers and schools with sufficient access to appropriate kinds of digital devices and materials. Currently, high proportions of teachers globally have no access to the internet nor to digital devices for professional learning in their schools (⇡Colclough, 2020; ⇡Pota et al., 2021). Yet, online learning can provide access to up-to-date resources, facilitate connections to those in remote settings, and increase participation in TPD initiatives. More financial investment is needed here; however, a range of low- to high-tech devices and modalities need to be considered. In particular, more attention needs to be paid towards developing and sustaining innovative, scalable technology solutions to tackle specific infrastructural challenges. These include solar-powered devices, low-tech technologies and asynchronous modes of communication. It is absolutely crucial that EdTech purchasing is carefully planned to be (a) appropriate for the context, the teacher learning objectives, needs and preferences, and accompanied by (b) long-term maintenance and (c) peer support from ICT champions in schools. Moreover, teachers' digital skills are often limited; if technology is to be used effectively, teachers need TPD support in this area, and EdTech choices need to be suitable for their skill levels.

5.10. Design with the TPD ecosystem in mind



When designing technology-supported TPD programmes, it is imperative to consider the whole, wider ecosystem (see Section 3.6 and Figure 1), including:

- At the macro (or district and national) level: developing a deeper understanding of the structural and cultural factors that can support or constrain technology-mediated TPD.
- At the meso (or school) level: ensuring schools and communities are equipped with the physical and human resources to support technology-mediated TPD.

- At the micro (or teacher and student) level: taking account of teachers' professional learning needs, experience, expertise, motivations and agency, to increase appropriateness and efficacy of programmes. And monitoring impact on student learning outcomes is crucial.

Ongoing initiatives outlined in Section 4.2 offer early indications of how tech can be integrated into sustainable national TPD implementation programmes in ways that not only take perspectives of relevant stakeholders at every level of the education system into account but provide induction and training for them as well as for teachers and pedagogical leaders.

5.11. Strive for scalability, sustainability and cost-effectiveness in TPD programmes

Only 11% of all studies reviewed reported any detail of cost, few were large scale, and only 18% were longitudinal (evaluating impact along multiple points in time). This suggests an urgent need to commission, support or advocate for more research that focuses on larger-scale and longer-term programmes that consider costs and/or cost-effectiveness, as well as scalability and sustainability. Drawing on the Principles for Digital Development, effective scaling practices to move beyond the problem of 'pilotitis' include alignment on the definitions of scale for the initiative, designing for scale from the onset, and securing funders and partners that could expand the initiative to new communities (such as through franchising) (↑Principles for Digital Development, no date). Policymakers and TPD implementers can support this by openly publishing a breakdown of total costs for each TPD programme; however, this itemisation is notoriously challenging owing to hidden/undifferentiated and recurring costs (↑Evans & Popova, 2015). To address inconsistent and non-comprehensive methods of measuring costs, protocols such as the 'Capturing Cost Data' guidance note, can be used which elaborates on effective practices like the need for non-financial information in cost reports, disaggregated and input-specific data and real-time cost capturing (↑World Bank et al., 2019). As the few studies on sustainable tech4TPD interventions have shown, TPD programme implementers, researchers and practitioners must all seek to iteratively monitor and evaluate interventions across the system as well as at classroom and school levels in order to sustain teacher learning (↑Kurt, 2017). Critical reflection on interim messages from research can highlight exactly what contextual adaptations need to be made to tailor programmes to specific needs and in relation to the enabling and constraining factors encountered along the way (↑Li, 2014; ↑McKenney et al., 2013).

1.5.12. Coordinate and manage partners closely

To achieve the necessary coherence around national priorities, close coordination is needed within government and between governments and partners, including implementers, foreign aid and philanthropic organisations, or TPD providers. A push to promote a culture of collaboration, critical reflection and learning across the TPD ecosystem would 'avoid unnecessary duplication and help large-scale initiatives to learn from both mistakes and successes of small-scale pilot projects' (↑Piper et al., 2015, p. 11). This will serve to join up a disparate system of initiatives, actors and funding.

6. Conclusion

This paper offers a substantial overview of research on EdTech use in TPD across LMICs. It identifies the current strengths, linkages and gaps in the field, spanning many diverse contexts and TPD foci. It also provides informative insights into the advancement of teaching quality, which strengthens education systems and can ultimately impact learner outcomes. The unusual step of following up a large-scale review of academic literature by additionally taking into account both teacher perspectives and experiences of working collaboratively with governments and other stakeholders in LMICs contributes to further bridging the gaps between research, policy and practice. Indeed, regularly reviewing the tech4TPD field, and reflecting on updated evidence is crucial to ensuring we remain informed of the latest trends and innovations.

The report offers a set of 12 accessible and practical recommendations that can provide policymakers, educators, academics, sponsors and implementing partners with a stronger foundation for programming decisions regarding sustainable, scalable and inclusive technology-supported TPD in their regions. A key one is the need to focus explicitly on equity, devising strategies for using technology to reach and include marginalised groups of both teachers and learners, and to cater for diverse (learning) needs. More research is needed in under-represented countries and regions, and rural areas. Marginalised teachers and learners can benefit hugely from tailored TPD and technology-facilitated connections to others in similar contexts. While the Covid-19 pandemic led to increased use of technology by teachers and learners, 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: ⇡Wilichowski & Cobo, 2021). The needs identified and recommendations made here thus remain highly pertinent.

The findings demonstrate and illustrate how technology use in TPD initiatives can enhance or hinder teacher learning. They reinforce the ever-present need for researchers to critically evaluate assumptions made about its positive role and added value beyond non-technology initiatives, concerning whether, what and how technology should be applied. The changing educational paradigm renders such scrutiny and rigorous research more pressing.

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Appendices

Appendix A: Filters

- Published from July 2020 to June/July 2022
- Full text ONLY
- Language: English
- Type of resource:
    - Articles
    - Books and Book Chapters
    - Conference papers/proceedings, etc.
    - Dissertations/thesis
    - Government and official documents
    - Literature Reviews

Search 1. Equity – teachers or learners from marginalised groups

Theme no.	Theme name	Search terms
1	LMIC	LMIC OR low middle income countr* OR sub*saharan africa OR latin america OR [Actual LMICs fully listed below]
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
4	Equity	Disabilit* OR disabled OR SEND OR special educational need* OR marginalised learner OR visual impair* OR hearing impair OR deaf OR blind OR rural OR ethnic minorit* OR linguistic minorit* OR refugee* OR displace* OR migrant* OR immigrant* OR girls OR women OR female
Note: The use of an asterisk (*) denotes a wild character used to locate all singular/plural forms of a term.		

Search 2. TPD models that are sustainable, cost-effective, or scalable

Theme no.	Theme name	Search terms
1	LMIC	As in Search 1
2	TPD	As in Search 1
3	Tech	As in Search 1
4	Sustainable and/or scalable	Sustainability OR Sustainable OR cost-effective* OR scalab* OR large-scale OR longitudinal OR follow-up
Note: The use of an asterisk (*) denotes a wild character used to locate all singular/plural forms of a term.		

Search 3. TPD models that have an impact on learning outcomes or teachers' classroom practices

Theme no.	Theme name	Search terms
1	LMIC	As in Search 1
2	TPD	As in Search 1
3	Tech	As in Search 1
4	Outcomes	Learning outcomes OR classroom practices
Note: The use of an asterisk (*) denotes a wild character used to locate all singular/plural forms of a term.		

Search engines: 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

Countries searched for:

LMIC OR low middle income countr* OR sub*saharan africa OR latin america OR Afghan* OR Albania* OR Algeria* OR Samoa* OR Angola* OR Argentin* OR Armenia* OR Azerbaijan OR Bangladesh* OR Belarus* OR Belize* OR Benin* OR Bhutan* OR Bolivia OR Bosnia and Herzegovina OR Botswana* OR Brazil* OR Bulgaria* OR Burkina Faso OR Burkinabe* OR Burundi* OR Cabo Verde* OR Cambodia* OR Cameroon* OR Central African Republic OR Chad* OR China OR Chinese OR Colombia* OR Comoros OR Comorian OR "Democratic Republic of Congo" OR Congo* OR OR Costa Rica* OR Cˆote d'Ivoire OR Ivory Coast OR Cuba* OR Djibouti* OR Dominica* OR "Dominican Republic" OR Ecuador* OR Egypt* OR "El Salvador" OR Salvador* OR "Equatorial Guinea" OR Guinea* OR Eritrea* OR Eswatini OR liSwati OR Ethiopia* OR Fiji OR Fijan* OR Gabon* OR Gambia* OR Georgia* OR Ghana* OR Grenada OR Grenadian* OR Guatemal* OR Guinea* OR Guinea-Bissau OR Guyana* OR Haiti* OR Hondura* OR India* OR Indonesia* OR Iran* OR Iraq* OR Jamaica* OR Jordan* OR Kazakhstan* OR Kenya* OR Kiribati* OR Micronesia* OR Polynesia* OR Korea* OR Kosov* OR Kyrgyz* OR Lao* OR Lebanon OR Lebanese* OR Lesotho* OR Basotho OR Liberia* OR Libya* OR Madagasca* OR Malagasy OR Malawi* OR Malaysia* OR Maldives OR Maldivan* OR Mali* OR "Marshall Islands" OR Marshallese OR Mauritania* OR Mexico OR Mexican OR Micronesia OR Moldova OR Mongolia OR Montenegr* OR Morocc* OR Mozambique OR Mozambican OR Myanmar* OR Namibia* OR Nepal* OR Nicaragua* OR Niger* OR Nigeria* OR Macedonia* OR Pakistan* OR "Papua New Guinea*" OR Paraguay* OR Peru* OR Philippin* OR Russia* OR Rwanda* OR Samoa* OR "Sao Tome and Principe" OR Senegal* OR Serbia* OR Sierra Leone* OR "Solomon Islands" OR Somalia* OR "South Africa*" OR "South Sudan*" OR "Sri Lanka*" OR "St. Lucia*" OR "St. Vincent and the Grenadines" OR Vincentian* OR Sudan* OR Suriname* OR Syria* OR Tajikistan* OR Tanzania* OR Thailand* OR Thai OR Timor-Leste OR "East Timor*" OR Togo* OR Tonga* OR Tunisia* OR Turkey OR Turkish OR Turkmenistan* OR Tuvalu* OR Uganda* OR Ukrain* OR Uzbekistan* OR Vanuatu* OR Venezuela* OR Vietnam* OR West Bank and Gaza OR Palestin* OR Israel* OR Yemen* OR Zambia* OR Zimbabwe*

Note. Individual countries were defined as LMICs in the World Bank's country inventory.

Appendix B: Evidence gaps and methodological gaps (from ↑Hennessy et al., 2022)

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 technology-mediated 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.

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.

Appendix C: Details of methods

C1 Data Sources

This report triangulated messages across a body of evidence collected by our team using different methods, through drawing on:

(a) A rigorous synthesis of evidence via our comprehensive systematic review of publications (academic plus grey literature, spanning January 2008–July 2020) of empirical research on uses of technology in TPD in LMICs, including formal / non-formal learning by pre-service and in-service teachers of students aged 3–18. After screening almost 5,000 papers, 170 studies conducted in 40 LMICs were thematically coded, quality scored and synthesised, and data on publication characteristics were extracted. The review provided deep insights into the systemic factors supporting and constraining use of technology for professional learning and for teaching. The outcomes are reported in a journal article containing a detailed account of the (PRISMA[21]) methods (⇡Moher et al., 2009) and critical review of findings (⇡Hennessy et al., 2022), an accompanying policy brief (⇡D'Angelo et al., 2022), a technical report (⇡Hennessy et al., 2021a) and an open, thematically-coded and quality-scored bibliographic database.[22]

(b) Updated literature searches spanning July 2020–July 2022. The 27 directly relevant papers emerging (after screening the resulting 212 publications), plus 19 further relevant sources that the team came across through their professional networks, were ultimately included. Searches were targeted at four key research evidence gaps emerging from the systematic review (see Appendix A for search terms):

1. Technology supporting TPD focused on marginalised teachers and learners in LMICs;
2. Sustainability, cost-effectiveness or scalability of tech4TPD initiatives in LMICs;
3. Tech4TPD models that have an impact on student learning outcomes or teachers' classroom practices.
4. Inclusion of teachers' voices – via analysis of global teacher survey data (⇡Pota et al., 2021; ⇡Inter-Agency Network for Education in Emergencies, 2021; ⇡Colclough, 2020; ⇡El-Serafy et al., 2022).

(c) Collation of recent and current tech4TPD initiatives in LMICs, including research and technical assistance work by EdTech Hub teams collaborating with (and indeed embedded within) Ministries of Education, plus other key research and development of tech4TPD initiatives, sourced through our professional networks and via online searches.

[21] Preferred Reporting Items for Systematic Reviews and Meta-Analysis (⇡Moher et al., 2009).

[22] The full bibliography for ⇡Hennessy et al. (2022) is available digitally here: https://docs.edtechhub.org/lib/E5J2KHF2.

C2. Analysis

The methodology of this background paper comprises a synthesis involving thematic coding of the messages arising across the data sources listed above, including extraction of relevant data charts on evidence trends already prepared for the systematic review (⇡Hennessy et al., 2022) and its associated technical report (⇡Hennessy et al., 2021b). The resulting themes form the headings in Section 3. The synthesis included identification of illustrative case examples from authentic practice (presented in shaded boxes), drawn from diverse evidence sources, including both published studies and ongoing initiatives. These spotlight examples were each chosen to provide information concerning one of our evidence gaps (see full list of evidence gaps in Appendix B); they either exemplify sustainable, scalable or cost-effective tech4TPD models, or those that have effectively supported marginalised teachers and/or marginalised students, with a focus – where possible – on changing teaching practices and/or improving student learning outcomes. Importantly, many tech4TPD models draw on multiple uses or approaches (e.g., reflective practice and coaching or mentoring); and generally, evidence of impact cannot be isolated to one use of technology alone.

The synthesis highlights promising, locally-contextualised forms of technology-mediated TPD identified in the literature, including virtual coaching, observation and monitoring tools, creating/curating OER, subject-specific software or applications, video-stimulated critical reflection, blended teacher learning, online communities of practice and social messaging through WhatsApp and other social media. The outcomes are described in Section 3.

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