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Conceptualising a data analytics framework to support targeted teacher professional development

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ABSTRACT

This paper proposes a conceptual framework enabling the development and adoption of descriptive, diagnostic, predictive and recommendatory data analytics in teacher professional learning by harnessing some of the affordances of digital technologies to convert data into actionable insights. The paper argues for a technology-enhanced approach that uses data to support teachers in selecting appropriate professional development (PD) options to improve their professional practice. The ultimate goal is to lay the foundations for a robust and adaptable data analytics framework that could offer tailored PD recommendations based on the developmental trajectories of individual teachers. The paper analyses data-supported personalised professional learning as meaning-making and the appropriation of cultural artefacts within the 'mobile complex' - consisting of structures, agency, and the dynamic interplay between cultural and technological tools and practices. This study undertakes a comprehensive literature review to identify key concepts, gaps, and theoretical insights, informing the development of a data analytics framework. The resultant framework integrates personalisation, teacher agency and autonomy, contextual relevance, and ethical safeguards into PD process, aiming to foster a responsive, collaborative, and context-aware data-supported PD.

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The desirability of a data analytics framework

Teacher professional development is a multifaceted and dynamic process that remains integral to fostering pedagogical effectiveness and adapting instructional approaches to suit the dynamic needs inherent within diverse educational contexts (Darling-Hammond *et al.* 2017, Ávalos 2023). In the ever-evolving landscape of education, the pursuit of tailored and effective PD opportunities persists as a continual endeavour, imperative for addressing the multifaceted needs of educators (Nolan and Molla 2019, Fairman *et al.* 2023). Within this context, the integration of data analytics emerges as a potentially innovative opportunity for continuing teacher professional learning (Sampson 2017, Gabbi 2023, Khulbe and Tammets 2023). Defined as an interdisciplinary field leveraging statistical techniques and computational algorithms to derive insights from data, data analytics can potentially inform decision-making with real-time evidence, personalise learning experiences and discern nuanced patterns, thereby enabling effective teacher support (Siemens and Gasevic 2012, Siemens 2013, Berendt *et al.* 2014, Lang *et al.* 2017, Littlejohn 2017, Ruiz-Calleja *et al.* 2017, Hakimi *et al.* 2021).

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A review of the literature reveals a plethora of frameworks and models guiding teacher PD (Kennedy 2005, 2014), yet few of these paradigms incorporate data analytics as a substantive element. Teacher PD (TPD) is recognised as a complex endeavour (Opfer and Pedder 2011, Strom and Viesca 2021), manifesting across multiple dimensions – organisational, systemic, and individual – with each dimension contributing uniquely to the professional growth and evolution of the practices of educators. Organisational TPD typically involves formal training aligned with institutional goals, while systemic TPD reflects broader educational policies at larger scales, ensuring compliance with standards and curricula beyond single institutions as well as impacting on student outcomes measured by international tests and associated league tables. At the individual level, TPD prioritises teachers' personal agency and internal motivation, offering activities like self-directed learning, mentorship and collaborative inquiry, tailored to each educator's unique professional development needs and aspirations. These dimensions often overlap and interact, forming a complex tapestry of professional learning that evolves across different career stages (early-, mid- and late-career) reflecting heterogeneity inherent in teacher profiles (Coppe *et al.* 2024). In this regard, Huberman's research was pioneering in its recognition of the variability (in terms of needs and experiences) in teacher professional lives (Huberman 1989a, 1989b). His work underscored the notion that the professional journey of educators is not monolithic; rather, it is subject to significant variation and evolution at different stages of their work life. This important understanding suggests the need for a nuanced approach to PD, one that is acutely aware of, and responsive to the shifting landscapes of teachers' professional trajectories (Coppe *et al.* 2024).

This perspective is echoed in the personalisation literature, which posits that educators, as lifelong learners, possess distinct professional paths, learning preferences and developmental needs (Goodwin *et al.* 2019); therefore, PD should be responsive to these fluctuations. The efficacy of PD is significantly enhanced when it is customised and tailored to these individual traits, as teacher learning, akin to student learning, is not a one-size-fits-all endeavour (Schifter 2016). Personalised PD, therefore, emerges as a critical approach that challenges the traditional, standardised one-size-fits-all models of professional development. By addressing the diverse and context-specific needs of educators, personalised PD critiques the assumptions of uniformity in teacher learning and professional growth. It shifts the focus from top-down, institutionally-driven programmes to a more responsive, teacher-centred model that prioritises individual agency, contextual relevance, and professional autonomy, thus aligning with critical perspectives that aim to challenge established hierarchies and promote greater equity. This approach not only empowers teachers but also recognises the complexities of their roles within varied educational environments and career phase (Copur-Gencturk *et al.* 2024), making it a transformative alternative to conventional PD frameworks. Moreover, scholars have pointed out personalised PD systems can help augment teachers' competencies (Ma *et al.* 2018, Chaipidech *et al.* 2022).

Notwithstanding, evidence suggests that PD models often default to standardised approaches that are increasingly focused on furthering institutional/school development plans or are even designed in response to agendas at the level of school trusts or mission-led organisations. This can create an environment where PD feels like an exercise in compliance rather than an opportunity for meaningful professional growth. These PD initiatives, as highlighted by (Mifsud 2023, Simmie 2023), frequently grapple with an inherent deficiency in adaptability and customisation, thus impeding their resonance with the intricate array of teachers' needs, unique challenges and goals. Similar, sentiments are echoed by numerous scholars (Hargreaves 2000, Kennedy 2014, Desimone and Garet 2015) that the prevailing uniformity in such PD methodologies not only limits their potential impact but also overlooks the individualised needs that are intrinsic to effective PD. Indeed, a purely top-down, institutionally-driven approach risks alienating educators by reducing TPD to a prescriptive process, one that fails to address the unique challenges teachers face in their specific environments. Consequently, the tension between individual and institutional priorities in TPD warrants critical examination, as there exists a risk of data analytics (in this case) being employed to identify and address perceived

deficits in teachers' adherence to predetermined professional practices, rather than fostering genuine growth and transformation. It is, therefore, crucial to strike a balanced approach between promoting institutional goals versus respecting teacher agency in professional development, ensuring that TPD remains a collaborative process that takes into account the differing needs and contexts of teachers (Darling-Hammond *et al.* 2017).

A data analytics framework, as proposed in this paper, offers the potential to mediate this balance by offering personalised insights that could harmonise institutional priorities with tailored learning pathways for teachers. For instance, by leveraging data-supported insights, institutions can pursue goals, such as enhancing teaching quality and advancing to educational standards by tracking trends, identifying gaps, and tailoring interventions based on evidence rather than assumptions. At the same time, by incorporating teacher input and contextual factors into the data-supported process – the framework empowers teachers to take ownership of their learning and to shape their own professional growth. However, critical to the success of this approach is the ongoing dialogue between institutional priorities and teacher agency. If data is used to impose rigid benchmarks without considering teacher input, the risk of reducing TPD to a bureaucratic exercise increases, potentially stifling innovation and creativity. Therefore, the proposed framework emphasises flexibility and adaptability, enabling teachers to co-construct their professional learning pathways within the broader institutional vision.

The notion of personalisation, i.e. the adaptation of PD interventions to the specific interests, preferences and requirements of individual teachers, is central to this paper, as it advocates the use of data analytics to tailor TPD experiences to individual and/or collective teacher needs and trajectories (Gabbi 2023, Khulbe and Tammets 2023). Yet, it is essential to consider the compatibility and potential tensions between concepts of personalisation as applied in a data analytics context and the concept of personalisation in TPD. While data analytics offers the potential for granular personalisation and visualisation (Bondie and Dede 2024) by examining individual data points and patterns, relying too heavily on these tools and foci may overlook the intricate nuances inherent in TPD (Del Pilar Gonzalez and Chiappe 2024). As TPD is inherently a relational and contextual process, where the pursuit of personalisation through data analytics requires a more nuanced understanding of teachers' professional identities, values and the socio-cultural dynamics of their learning environments. This implies that personalisation within TPD extends beyond mere individualised quantifiable data points, encompassing the intricate interplay of relational dynamics, tacit knowledge exchange and the subjective experiences that shape an educator's professional journey (Saar *et al.* 2018).

Thus, data analytics, while supporting the progression of learning (Kubsch *et al.* 2022), it must also recognise the inherent value of relational learning and consider capturing physical classroom data, complemented by qualitative methods such as classroom observations and reflective practices, to holistically facilitate the translation of learning into meaningful changes in teaching practices. This implies that the conceptualisation of data-supported personalised PD as a complex and multifaceted process must be grounded in three complementary theoretical perspectives: behavioural, critical, and sociocultural. Each perspective offers a unique lens for understanding the complexities of teacher learning and development, and together they provide a holistic view of how data-supported personalised PD can be most effectively implemented. For instance, a behavioural perspective provides the tools and metrics for measuring and adapting teacher practice based on data, while a critical perspective addresses the structural issues – such as power dynamics and hierarchical inequalities inherent in institutional control and teacher agency – as well as ethical concerns, particularly regarding assumptions in the use of data within PD. A sociocultural perspective then enriches this understanding by situating teacher development within the broader social and cultural landscape, ensuring that personalised PD is not only data-supported and equitable but also deeply contextualised and sustainable.

By providing data-supported, personalised insights, data analytics has the potential to empower teachers in their decision making about their professional learning journeys and it can act as

a catalyst for reflective practice (Sergis *et al.* 2019). Its effective use can be gleaned from examples where data-driven insights could lead to targeted PD interventions (Hirsch *et al.* 2018) to accommodate the needs, strengths and growth areas of individual teachers. For instance, data analytics can identify specific areas where a teacher may benefit from further development, such as questioning techniques or differentiated instruction and recommend resources or courses that address these needs. We contend that the process of identifying personalised requirements should involve a balanced approach that combines data-supported insights and teacher agency (Lockton *et al.* 2020). Since data analytics can provide objective recommendations based on historical teaching practices and student outcomes, relying solely on externally determined requirements could undermine teacher autonomy (Buchanan and McPherson 2019). Therefore, personalised recommendations should be based on a collaborative process where teachers self-reflect on their PD needs, complemented by data-supported insights and then contextualise recommendations based on their professional judgement and unique teaching contexts. The goal is to empower teachers by providing data-informed guidance while respecting their autonomy, expertise and professional identity, fostering a co-constructed approach to personalised PD interventions.

The utility of data analytics extends across a spectrum, from being a precursor for personalising learning experiences to pre-emptively identifying and mitigating academic challenges (Ferguson 2012, Mangaroska and Giannakos 2018, Khor 2024). However, the utilisation of data analytics in TPD raises legitimate ethical concerns, potential risks and apprehensions associated with the perception of excessive monitoring or a surveillance mechanism embedded within data-supported educational technologies. In this context, Foucault's (1977) interpretation of the Panopticon becomes particularly relevant, as systems of constant, invisible observation may foster a 'Big Brother' paradigm in which teachers feel perpetually monitored. This form of surveillance, whether direct or indirect, can impose control over teachers' practices, thereby inhibiting innovation and limiting their professional autonomy. When educators perceive these technologies as mechanisms of excessive oversight rather than supportive tools, it can erode trust and diminish the efficacy of TPD initiatives. Consequently, this undermines open reflection, experimentation, and authentic professional growth. It is, therefore, crucial to establish robust ethical frameworks and guidelines that prioritise data privacy, transparency and the autonomy of teachers (Rodríguez-Triana *et al.* 2016, West *et al.* 2016). Moreover, issues such as interpretability of data and the alignment of data-supported recommendations with teachers' professional contexts are crucial for the advancement of data analytics in TPD. Addressing these challenges involves not only refining the algorithms and data models but also ensuring that the insights generated are contextually relevant and respectful of teachers' professional agency and autonomy, thereby facilitating a seamless integration of data-supported recommendations within the multifaceted realities of educational practice.

While data and learning analytics have become powerful tools for making informed decisions supported by data, there has been little research into how it might shape teacher PD (Oliva-Cordova *et al.* 2021, Chiu *et al.* 2022, Salas-Pilco *et al.* 2022). Furthermore, there exist only very few, if any, data analytics frameworks to determine suitable TPD interventions, involving a dual consideration: informed by specific teachers' profiles while simultaneously being adaptable to address the unique requirements of individual teachers. This gap underscores the need for a robust framework that not only can effectively diagnose and identify teachers' unique PD needs – by incorporating multiple data sources and stakeholder inputs – but also identify clusters of teachers facing similar issues, facilitating the formation of collaborative learning communities that reflect shared cultural and professional experiences (Lameras and Arnab 2021). The potential for data analytics to inform and tailor PD initiatives (by synthesising diverse data points), however, presents an untapped opportunity to support each teacher's unique professional journey. Hence, this paper addresses the following fundamental research question:

> *What are the key characteristics and potential impacts of a data analytics framework designed to support targeted teacher professional development across varied educational contexts?*

By explicitly posing this question, the paper acknowledges issues around the feasibility and potential value of such a framework and emphasises the need for drawing upon the existing literature and theoretical perspectives. This approach allows for a systematic exploration of the challenges, opportunities and implications associated with integrating data analytics into TPD, in ways that respect the multifaceted nature of professional learning, the diverse contexts in which teachers operate, and the need to enhance teacher agency. Engaging with the affordances of data analytics for TPD requires navigating a wide literature base from different, if cognate disciplines each with their epistemological, ontological and axiological traditions.

To this end, it seems timely and important to appraise the potential of data analytics to dissect historical data about professional and pedagogical practice with a view to offering personalised recommendations to facilitate targeted and impactful PD interventions. As the emerging capabilities and affordances of AI continue to advance, they are likely to transform data analytics from merely reflecting a static snapshot of past educational interactions to becoming a dynamic, predictive tool capable of offering highly personalised recommendations (Holmes and Tuomi 2022, Salas-Pilco *et al.* 2022). AI technologies can process vast amounts of educational data to identify patterns and trends that may not be immediately or easily apparent to human analysts. This can lead to more nuanced and granular insights into teacher professional practice, approaches to teaching and learning, and learner outcomes (Celik *et al.* 2022). These AI-driven insights have the potential to optimise resources and outcomes for teachers (Kusmawan 2023, Dandachi 2024). The descriptive case study by Tapalova and Zhiyenbayeva (2022), for example, indicates AI's transformative potential and predictive capabilities that can forecast individual teachers' PD requirements, while its adaptive learning environments can personalise the PD experience (Hwang 2014) to accommodate individual teachers' pace, preferences and goals, thereby potentially enhancing the effectiveness of PD and engagement with PD (Hwang *et al.* 2020).

As we navigate this transition, it is imperative to recognise that the future trajectory of data analytics in education sciences will likely be characterised by a shift towards more adaptive, responsive and personalised educational experiences, underpinned by the sophisticated analytical power of AI. In this paper, therefore, we aim to conceptualise a data analytics framework that aims not merely to aggregate data but to translate these insights into actionable and contextually relevant personalised PD interventions. Integrating AI into our proposed framework could make professional development more adaptive and personalised, enhancing its overall impact on teacher growth. In essence, the ability of AI to analyse complex data sets and to provide real-time feedback can facilitate a more dynamic and responsive approach to teacher PD, one that aligns with the evolving educational landscape and the specific needs of educators.

Theoretical foundations and review of literature

Data analytics in education: applications, prospects and challenges

Data analytics in education can be defined as the measurement, collection, analysis and reporting of large sets of data to better understand learners and their learning environments (Siemens and Baker 2012, Siemens 2013, Lang *et al.* 2017). At its core, educational data analytics involves the systematic analysis of data generated from diverse educational processes to improve decision-making and educational practices (Agasisti and Bowers 2017, Ferguson *et al.* 2019, Wise 2019). This multifaceted discipline encompasses a spectrum of applications ranging from personalising learning experiences to optimising institutional resources and learner outcomes (Maseleno *et al.* 2018) and it integrates technical and social/pedagogical dimensions to inform teaching strategies, curriculum development and learner support services (Siemens 2013).

Amidst the contemporary educational landscape, data analytics has emerged from the burgeoning use of digital resources, learning management systems and various online educational platforms, yielding copious data in diverse formats and at various levels of granularity (Romero and

Ventura 2017). The volume and diversity of data generated from these systems cannot be analysed manually, necessitating analytical tools, such as data/learning analytics, to automatically explore, analyse and uncover patterns and insights with the intention of benefiting students, teachers and administrators alike (Siemens and Baker 2012, Dawson *et al.* 2019). Largely, the field of data analytics capitalises on the digital footprints/traces and clickstream data, ranging from log files and online assessments to discussion forum interactions, left by learners as they interact with these various tools (Gašević *et al.* 2016, Littlejohn 2017). These traces, when analysed and interpreted through sophisticated data analytics, can hold real potential to optimise both formal and informal learning processes traceable and visible to support professionals with their learning (Baker and Yacef 2009, Gašević et al. 2015, 2017, Littlejohn 2017).

However, the translation of these digital traces into meaningful educational interventions often remains elusive and frequently encounters obstacles in the way of widespread adoption of data use (Macfadyen and Dawson 2012, Gašević *et al.* 2016, Selwyn 2019). One of the primary challenges is the complexity and purity of data itself; the sheer volume and variety of data points can be overwhelming (Wolpers *et al.* 2007, Jones and McCoy 2018) and without a clear framework or utilisation pathways for analysis, the actionable intelligence or strategies that can be gleaned from this data are diluted (Boyd and Crawford 2012, Ferguson and Clow 2017). In addition, teachers frequently harbour doubts regarding the usefulness of data. Even those who are open to engaging with data may lack the necessary expertise and relevant skills to interpret and apply data analytics effectively (Rienties *et al.* 2018, Khulbe and Tammets 2023). This gap highlights the need for professional development that equips teachers with the necessary skills to harness the power of data and learning analytics (McKenney and Mor 2015).

While analytical tools for examining learning data hold the theoretical promise of assisting teachers in utilising data effectively, they frequently fail to live up to expectations (Kitto *et al.* 2018, Knight *et al.* 2020). This shortfall is largely due to the fact that these tools are often developed without incorporating appropriate theoretical perspectives and without adequately taking into account the requirements and preferences of end-users, in this case the teachers themselves (Knight and Shum 2017). For instance, an increasing number of learning analytics dashboards (LADs), recommender systems and other sophisticated data visualisation mechanisms distils complex datasets into accessible insights for end-users. Nevertheless, scholarly investigations reveal a pattern of underutilisation and intermittent engagement with these tools, alongside an absence of robust evidence substantiating their impact on educational outcomes (Ali *et al.* 2013, Ferguson *et al.* 2016). Moreover, the premise of data visualisation is to offer an intuitive understanding of the information presented. Empirical research by Corrin and De Barba (2015) indicates that while learners are capable of deciphering feedback from LADs, the translation of this feedback into concrete actions remains a challenge (Gray *et al.* 2021). Similarly, Dazo *et al.* (2017) observed that teachers, despite their enthusiasm for LADs, encounter difficulties in correlating the data with pertinent pedagogical issues. This underscores the notion that the mere availability of data analytics does not inherently confer the ability to act upon the insights derived.

In line with this, the current corpus of scholarly discourse presents several focal points on data analytics, with particular emphasis on the pragmatic phases of data engagement (Price-Dennis and Lang 2018, Wise and Jung 2019). This body of work elucidates the critical stages through which educational data must be processed to yield actionable insights. Furthermore, it underscores the imperative of adhering to robust legal and ethical frameworks that govern the use of such data. Paramount among these considerations is the safeguarding of individual privacy, the imperative to mitigate the risks of data misinterpretation (Selwyn 2019). These elements are integral to optimising the utility of data analytics within educational contexts. Thus, the integration of data analytics into existing educational practice not only requires comprehensive technical solutions but also clear utilisation pathways (aligned with educational goals and learning outcomes) that could guide the use of data from collection to application. Equally, a large body of literature (Kovanović *et al.* 2018, McKenna *et al.* 2019) suggests that data analytics tools, if properly integrated, could play a pivotal role

in fostering a culture of reflection and metacognition. Generally, teachers are encouraged to engage in self-regulatory learning (SRL), a critical component of professional learning, as they become more aware of their learning habits, progress and areas in need of improvement (Littlejohn *et al.* 2012). This shift towards empowering learners with data reflects a broader movement in education to position learners as active agents in their learning journeys (Laursen 2020, Ndukwe and Daniel 2020).

By merging the insights gleaned from data analytics with the principles of learner-centred pedagogy, educational institutions can create more responsive and adaptive learning environments that not only support learners in achieving academic success but also equip them with the self-regulatory skills necessary for lifelong learning (Kovanović *et al.* 2018, Marienko *et al.* 2020). Thus, the integration of data analytics into educational practices, while fraught with challenges, offers a potential that extends beyond the optimisation of learning processes. When realised, it can lead to the cultivation of reflective, self-regulated learners who are better prepared to navigate the complexities of an increasingly complex educational landscape.

Navigating professional development in a Data-Supported Educational Landscape

In the post-pandemic era, marked by digital transformation, the educational sector has witnessed an exponential increase in the use of digital tools and the proliferation of online and/or blended learning platforms (Barreiro 2022). This shift has led to the 'datafication' of education, where vast quantities of data are amassed, extending from digitised traditional classroom activities to sophisticated online learning environments. Pangrazio *et al.* (2022) critique this trend, arguing that the growing reliance on data as a panacea for educational challenges masks deeper issues related to control, surveillance, and the reduction of complex educational processes into simplistic metrics. They are particularly sceptical of the belief that data alone can 'fix' educational problems and caution against its uncritical adoption. This critique is especially relevant in today's educational landscape, where teachers in the UK and globally are now immersed in a data-rich context. Their professional performance and classroom dynamics are continually quantified and scrutinised, often through annual evaluations based on student outcomes and other pedagogical metrics. This pervasive datafication – often propelled by New Public Management ideologies and reinforced by international organisations (such as OECD, PISA, UNESCO, and Governments, etc.,) – and quality assurance frameworks necessitate a critical discourse on the 'politics' of metrics.

The overreliance on quantitative metrics, as a panacea for educational quality and accountability, may inadvertently eclipse the qualitative, humanistic dimensions of teaching and learning, leading to a potential 'tyranny' of metrics (Muller 2018). Amidst this backdrop, it is imperative to critically examine the implications of this trend and ensure that the pursuit of data-supported insights does not overshadow the nuanced realities of educational practice and the diverse experiences of learners and educators. Additionally, it is crucial to acknowledge that this shift underpinning the datafication narrative is not inherently beneficial and carries with it significant challenges. For instance, a challenge often lies not in the data collection but in the timely and effective analysis of such vast quantities of data. The implementation of predictive learning analytics, for instance, is fraught with complexities, ranging from ethical considerations around data privacy to the practical difficulties of integrating these systems within existing educational frameworks (Umer *et al.* 2023).

Educational data analytics, while playing a pivotal role in the potential refinement of teaching practices and customisation of instructional strategies, must be approached with a discerning lens and comprehensive metrics, mindful of the socio-political nuances and the ethical challenges it presents (Agasisti and Bowers 2017, Hoppe 2017). To elaborate, the transformative possibilities of data-supported approaches should not be viewed as an end in itself but as a means to enriching our understanding of the pedagogical process, ensuring that it serves the needs of educators and not the other way around. Accordingly, to create a comprehensive set of metrics that can guide data-supported personalised PD recommendations, it is important to consider various dimensions that

capture the individual needs of teachers, the effectiveness of PD interventions, and the socio-cultural context in which these interventions occur.

The metrics (see Table 1) put forward here as a starting point for wider discussion seek to indicate what has been shown to be beneficial for teachers in the literature surveyed and data that can be correlated to point teachers towards personalised interventions that they might engage with. The metrics envisioned here are not exhaustive but indicative and illustrative and seek to provide a starting point for considering various dimensions that could be measured to understand the role of data analytics in fostering personalised PD. They are designed to be sensitive to the socio-cultural context and practices that shape and are shaped by the use of digital technologies and to provide actionable insights that can enhance the quality and relevance of PD initiatives. Each of these metrics is tied to a specific type of PD strategy (supported by empirical evidence from the literature) and possible teacher outcome that is expected to improve through engagement with evidence-based PD strategies.

Teacher professional development: critical insights, current trends and gaps

At the heart of TPD lies the recognition of its role as a continuous, collaborative, context-specific process that is essential for the advancement of teachers' knowledge, competences and values (Desimone *et al.* 2002, Guskey 2002, Borko 2004). Avalos (2011) posits that professional development of teachers transcends mere acquisition of knowledge; it is an intricate endeavour that translates this knowledge into pedagogical practices to foster student development. According to Kazemi and Hubbard 2008 and Opfer and Pedder 2011, teacher professional learning is a complex process (situational, contextual, ecological), involving many processes, actions and mechanics; a process which necessitates both cognitive engagement and emotional investment from teacher both individually and as a collective entity (Tan and Dimmock 2014). This complex PD process often requires teachers to critically reflect on their own beliefs and convictions and to actively seek and apply viable alternatives for enhancement or change in their instructional approaches, however, this is not always the reality. In practice, the extent to which teachers engage in such practice often depends on the design and mechanisms of the PD programme in which they participate as well as the level of support provided.

This reality has prompted the field of TPD to explore various theoretical constructs aimed at elucidating the mechanisms through which teachers acquire new knowledge and adapt their practices (Postholm 2012). These theoretical constructs span from linear paradigms, such as those proposed by Guskey (2002), who suggests a linear trajectory of teacher learning as a result of specific interventions and conditions, to more intricate, meshed notions and/or complexity thinking acknowledging the complex interplay of factors influencing teacher learning (Taylor 2020). This implies that teacher learning is an inherently dynamic and often unpredictable process, shaped by a series of iterative and complex web of learning processes (Desimone 2009, Opfer and Pedder 2011, Basma and Savage 2018, Keay *et al.* 2019).

In terms of the effectiveness of PD, a robust body of knowledge has been established, delineating what works to foster teacher learning and what works less well (Garet *et al.* 2001, Desimone 2009, Van Veen *et al.* 2012, Desimone and Garet 2015, Darling-Hammond *et al.* 2017, Alo *et al.* 2018, Kalinowski *et al.* 2019, Sims and Fletcher-Wood 2021). The literature on teacher professional development consistently emphasises the need for development opportunities that are not only continuous but also deeply rooted in the context of teachers' work environments. Active engagement, collaboration among peers and a focus on both content and pedagogical content knowledge are frequently cited as key components of successful PD programmes. Equally, studies have illuminated the importance of sustained and intensive professional development programmes that go beyond episodic, workshop-based models, advocating instead the embedding of learning opportunities within teachers' professional practice (Bautista et al., 2015, Asterhan and Lefstein 2023). These programmes are more likely to have a lasting impact, as they provide ongoing support

Table 1. Metrics for guiding personalised PD interventions.

Dimension	Sub-Dimension	Metric	Description	Indicative Evidence of Effectiveness	Data Source(s)
Evidence-Based PD Practices	Literature-Supported Strategies	**Collaborative and Social Learning Approaches**	PD strategies that involve teachers working together to solve problems, develop teaching skills, and reflect on their practices through dialogue and reflection.	Supported by literature indicating that collaborative PD leads to changes in teacher practice and student achievement (e.g. Vescio *et al.* 2008).	PD programme records, observation of PD sessions, teacher surveys.
		Inquiry-Based PD Models	PD strategies that encourage teachers to engage in inquiry as a means to improve their teaching, often involving teacher and/or action research.	Research suggests that inquiry-based PD can enhance teacher reflection and instructional practice (e.g. Darling-Hammond *et al.* 2009).	PD programme records, teacher reflective journals, interviews with participants.
		Technology Integration Training	PD strategies focused on effectively integrating technology into teaching and learning processes.	Studies show that targeted technology PD can improve teachers' technological pedagogical content knowledge (TPACK) (e.g. Mishra and Koehler 2006).	PD programme records, pre- and post-technology integration assessments, classroom observations.
		Content-Specific PD	PD strategies that provide deep content knowledge in specific subject areas, such as maths or science.	Literature indicates that content-specific PD is linked to improved teacher content knowledge and teaching methods (e.g. Garet *et al.* 2001).	PD programme records, content knowledge assessments, observation of content-specific teaching practices.
		Formative Assessment Techniques	PD strategies that train teachers in using formative assessments to guide instruction and provide feedback.	Empirical evidence supports the use of formative assessments to improve student learning outcomes (e.g. Black and Wiliam 1998).	PD programme records, teacher surveys on assessment practices, analysis of student work.
		Classroom Management Techniques	PD strategies that focus on establishing and maintaining effective classroom environments.	Research supports the effectiveness of PD in classroom management for improving student behaviour and engagement (e.g. Everston and Weinstein 2006).	PD programme records, classroom observation using behaviour checklists, teacher self-reports.
		Differentiated Instruction Techniques	PD strategies that equip teachers to tailor instruction to meet diverse student needs.	Studies demonstrate that differentiated instruction PD can lead to more inclusive and effective teaching practices (e.g. Tomlinson 2001).	PD programme records, teacher lesson plans, student feedback surveys.

(*Continued*)

Table 1. (Continued).

Dimension	Sub-Dimension	Metric	Description	Indicative Evidence of Effectiveness	Data Source(s)
Teacher Outcomes Based on Good Practice		**Instructional Practice Improvement**	Changes in instructional strategies and techniques that align with best practices.	Literature indicates that PD focused on specific instructional practices can lead to improved teaching methods (e.g. DeSimone 2009).	Classroom observations using standardised rubrics, teacher self-assessment, peer feedback.
		Content Knowledge Enhancement	Increase in teachers' depth of understanding in their subject areas.	Research supports the idea that content-focused PD improves teachers' subject matter knowledge (e.g. Hill *et al.* 2008).	Pre- and post-content knowledge assessments, analysis of lesson plans, student performance data.
		Pedagogical Content Knowledge (PCK) Growth	Development of teachers' ability to teach content in effective and meaningful ways.	Empirical studies show that PD can enhance teachers' PCK, leading to better student understanding (e.g. Shulman 1986).	PCK surveys, video analysis of teaching, student interviews.
		Teacher Self-Efficacy	Improvement in teachers' ability to create and maintain a positive learning environment.	PD that includes classroom management training is linked to better classroom climate and student behaviour (e.g. Oliver *et al.* 2011).	Classroom climate surveys, behaviour incident reports, teacher reflections on classroom management.
		Formative Assessment Proficiency	Enhanced skills in using formative assessments to inform instruction and provide feedback.	Literature suggests that PD on formative assessment techniques can improve student learning (e.g. Wiliam 2011).	Analysis of formative assessment use in the classroom, teacher interviews, student feedback.
		Integration of Technology	Effective use of technology to support teaching and learning.	Studies indicate that PD on technology integration can lead to more innovative and engaging teaching practices (e.g. Ertmer and Ottenbreit-Leftwich 2010).	Technology use logs, student engagement metrics, teacher technology proficiency assessments.
		Reflective Practice and Professional Growth	Teachers' engagement in reflective practice leading to continuous professional development.	Reflective practice as part of PD is associated with ongoing teacher learning and adaptation (e.g. Schön 1983).	Reflective journals, professional growth plans, PD participation logs.

(*Continued*)

Table 1. (Continued).

Dimension	Sub-Dimension	Metric	Description	Indicative Evidence of Effectiveness	Data Source(s)
Teacher Characteristics	Individual Teacher Profile	**Professional Development Needs**	A detailed analysis of each teacher's professional development needs based on their current skills, knowledge gaps, and career goals.	Tailored PD has been shown to be more effective in meeting individual teacher needs (e.g. Darling-Hammond *et al.* 2017).	Surveys, interviews, performance evaluations.
		Demographics	Understanding teacher demographics, including – age, gender, ethnicity/race, years of experience, educational background, subject specialisation, geographical location, school type, full-time /part-time status	Knowing the composition of the teacher workforce can inform strategies that enhance the effectiveness of educational programmes and policies.	Surveys, HR records
	Historical Engagement with PD	**Historical PD Data Analysis**	Review of past PD activities that the teacher has engaged in, including completion rates and feedback provided.	Understanding past PD engagement can inform future PD recommendations (e.g. Desimone 2009).	PD records, learning management systems (LMS) data.
	PD Preferences	**Learning Modality Analysis**	Identification of preferred learning modalities. Also, teacher's PD orientation, i.e. individual and/or collaborative learning	PD that accommodates individual learning preferences can improve learning outcomes (e.g. Pashler et al., 2008).	PD feedback forms.
	Socio-cultural competence	**Cultural Competency Evaluation**	Assessment of the teacher's ability to engage with and teach students from diverse cultural backgrounds.	Cultural competency is crucial for effective teaching in diverse classrooms (e.g. Gay 2002).	Self-assessment tools, student feedback, peer reviews.
Technology proficiency and Engagement with digital technologies	Digital Literacy	**Technology skills assessment**	Evaluation of teachers' proficiency with digital tools and platforms used in PD and teaching.	Technology skills are necessary for effective PD engagement and classroom integration (e.g. Tondeur *et al.* 2017).	Skills assessments, PD platform usage data.
	Online interaction patterns	**Online behaviour analysis**	Analysis of teachers' interactions in online PD platforms, including participation in discussions and resource utilisation.	Online interactions can provide insights into teachers' interests and engagement with PD content (e.g. Krutka *et al.* 2016)).	Analytics from PD platforms, discussion logs.
		Usage Frequency	Number of times digital tools are used by teachers in PD activities.		Log data, self-report surveys
		Usage Duration	Amount of time teacher spent using digital tools in PD activities.		Log data, self-report surveys
		Types of Resources Accessed	Variety of digital resources accessed by teachers for professional learning.		Usage tracking, self-report surveys
	Cultural Practices and Perceptions	**Attitudes Towards Technology Integration**	Teacher beliefs about the value of technology in PD.		Surveys, interviews
		Perceived Value of Tech-Enhanced PD	Teacher perceptions of the relevance and effectiveness of technology-enhanced PD.		Surveys, focus groups
Teacher Agency and Autonomy		**Opportunities for Choice**	Opportunities for teachers to direct their own PD learning paths.	Teacher agency is argued to be instrumental in supporting, conditioning and restricting PD (e.g. Hardman *et al.* 2023).	PD programme analysis, teacher surveys

(*Continued*)

Table 1. (Continued).

Dimension	Sub-Dimension	Metric	Description	Indicative Evidence of Effectiveness	Data Source(s)
		Teacher-Led Initiatives (Self-directedness)	Number and impact of PD initiatives proposed or led by teachers.		Programme records, case studies
Institutional Support and Structures		**Resource Availability**	Availability of human, technological resources and infrastructure for PD.	Content focus and active learning over extended periods of time and within a professional community in situ are shown by research to be important variables (Ingvarson *et al*. 2005)	Inventory checks, institutional reports
		Policy and Leadership Support	Level of institutional support for innovative PD practices.		Policy analysis, leadership surveys
Data-driven decision making		**Responsiveness to PD recommendations**	Measurement of how teachers respond to data-driven PD recommendations and the subsequent actions taken.	Responsiveness to data-driven recommendations can indicate the relevance and personalisation of PD (e.g. Mandinach and Gummer 2016).	PD platform recommendation tracking, teacher feedback
Big Data Analytics		**Data Privacy and Ethics/ Compliance with Data Protection**	Adherence to data privacy laws and regulations in PD data handling.		Compliance audits, policy reviews
		Transparency and Consent	Clarity and consent in the collection and use of PD-related data.		Consent forms, data management reviews
		Identification of Patterns			
		Recommendation of Target Areas and Development of PD Plan			
		Data Visualization			

for teachers to implement new strategies, reflect on their practice and make iterative improvements. However, despite the prevailing consensus on the effective PD characteristics, a number of scholars have raised concerns regarding the empirical foundations of this agreement (Wayne and Youngs 2003, Sims and Fletcher-Wood 2021, Hill *et al.* 2022). These critiques point to a lack of distinctive features in the research outcomes, as evidenced by studies that have not identified clear benefits of PD (Yoon *et al.* 2007). Furthermore, recent empirical investigations that have intentionally crafted PD initiatives based on these purportedly effective characteristics have not yielded the expected improvements when measured against control groups (Garet *et al.* 2016, Yang *et al.* 2020). This suggests that the relationship between PD design and teacher learning outcomes may be more complex and less predictable than previously thought (Desimone 2023, Fairman *et al.* 2023).

Contextual factors are widely acknowledged as being critical in the success of PD initiatives (Sandholtz and Ringstaff 2016, Nawab and Bissaker 2021; Koffeman and Snoek 2019). For instance, the culture of a school, the support provided by leadership and the broader policy environment can either facilitate or hinder the professional growth of teachers (Bautista and Ortega-Ruiz 2015). A school culture, for example, that values continuous learning and provides time for collaboration is more likely to see positive outcomes from PD efforts (Overstreet 2017, Furner and McCulla 2019). Similarly, leadership that actively supports teacher development by allocating resources and encouraging innovation can significantly enhance the effectiveness of PD (King 2011, Tayag and Ayuyao 2020). Despite the clear benefits of context-specific PD, there remains a tendency within the field to adopt generic approaches that do not adequately address the unique needs of individual teachers or the specific challenges of their teaching environments (Opfer and Pedder 2011). This one-size-fits-all approach can lead to a mismatch between the PD offered and the actual needs of teachers, resulting in suboptimal outcomes (Borko 2004).

As such, there is a growing call within the literature for PD that is differentiated, allowing for personalisation that takes into account the diverse backgrounds, experiences and pedagogical challenges faced by teachers (Grierson and Woloshyn 2013, Chaipidech *et al.* 2022). Moreover, contemporary perspectives on PD underscore the importance of a social-constructivist approach, recognising that teachers' learning is inherently social, shaped by context and evolves dynamically within a professional community (Kennedy 2014, Boylan *et al.* 2018). This understanding has led to the development of job- and workplace embedded PD models that integrate practical, collaborative and reflective elements. These models encompass a range of supportive structures such as instructional coaching, peer observation, action research and inquiry as well as individualised and customised professional growth plans. Additionally, they leverage technology through customised online learning platforms and foster collective knowledge-building within communities of practice.

Intersection of data analytics and teacher PD

The intersection of data analytics and teacher PD represents a potentially transformative nexus in education offering a data-supported lens through which to refine and enhance pedagogical practices (Mangaroska *et al.* 2019, Khor 2024). This fusion facilitates the creation of personalised learning pathways – defined as tailored educational experiences that address the individual needs of participants – and the adoption of adaptive teaching strategies, which adjust instructional methods based on real-time data. Furthermore, this approach empowers teachers by providing them with real-time feedback, enabling the identification of learning gaps and allowing for timely interventions (McKenna *et al.* 2019, Khulbe and Tammets 2021, Bondie and Dede 2024, Dandachi 2024, Del Pilar Gonzalez and Chiappe 2024).

Agasisti and Bowers (2017) advocate the emergence of the 'educational data scientist', a role that underscores the imperative of harnessing data in educational decision-making processes. This aligns with the call for data-supported decision-making in education, where teachers are empowered to leverage data to inform instructional practices, identify student needs and personalise learning experiences (Datnow and Hubbard 2016). However, the

mere presence of data is insufficient; the efficacy of data analytics hinges on its alignment with sound pedagogical principles and teacher agency (Wise and Shaffer 2015, Wise 2019, Wise and Jung 2019).

Buckingham Shum *et al.* (2019) emphasise the importance of 'human-centred learning analytics' that prioritises the needs and agency of teachers within the data-driven landscape. This resonates with Knight *et al.* (2014) notion of the 'middle space' where data analytics meets pedagogy, urging for a focus on meaning-making and critical reflection alongside data interpretation. Data analytics, within TPD, reveals its role in identifying gaps in teacher knowledge and pedagogical skills, thereby enabling targeted and effective PD (Sclater *et al.* 2016). Furthermore, it can facilitate the personalisation of TPD through using diagnostic and predictive analytics to prescriptive analytics by aligning learning opportunities with individual teacher profiles and variables, which may include their teaching experience, subject expertise, pedagogical preferences, disposition, preferred learning modalities, level of teacher agency (Herodotou *et al.* 2017, Tapalova and Zhiyenbayeva 2022, Dandachi 2024, Khor 2024). The learning options, however, that data analytics systems project to an individual need to be sensitive to these teacher variables.

The literature advocates the integration of data analytics into TPD as a means to transcend traditional one-size-fits-all approaches and to foster a culture of personalised, data-informed professional learning (Viberg *et al.* 2018). Nevertheless, current data and learning analytics systems often lack the involvement of teachers in the recommendation process, leading to insights that may not align with teachers' needs or contexts. Consequently, a challenge lies in crafting a synergistic approach (involving mapping from data ingestion to predicting PD intervention design) that leverages the technical capabilities of data analytics while remaining attuned to the nuanced realities of teaching practice (Gašević *et al.* 2015). Following this, issues surrounding data collection and generation, such as data purity and representation, raise concerns about the reliability of data. In the same vein, ethical considerations, as discussed by Selwyn (2019) and Datnow and Hubbard (2016), emerge as paramount, advocating for a cautious approach to data privacy, equity, and the mitigation of biases in data analytics.

Given the variability in teacher profiles and dispositions towards technology and pedagogical preferences necessitates a personalised approach to TPD that respects individual differences and contextual factors (Sclater *et al.* 2016, Rodman 2019, Schachter and Gerde 2019). However, the literature indicates a scarcity of frameworks specifically designed to guide teacher PD through data-supported insights. As the field of educational data analytics continues to evolve, it is crucial for emerging frameworks not only to advance the technical capabilities of data analysis but also, to address multifaceted challenges, including aligning with the unique trajectories of teacher professional growth (Ferguson 2012, Ferguson *et al.* 2016, Ferguson and Clow 2017). A comprehensive data analytics framework, therefore, should incorporate levels of teacher agency, consider financial and resource accessibility and ensure systemic feasibility. Such a framework would enable individual teachers to respond to recommendations and pursue professional growth within their means and contexts (Opfer and Pedder 2011).

Moving forward, the current state of data analytics in education reveals a burgeoning interest in leveraging vast amounts of educational data to inform policy and practice; therefore, research efforts should prioritise the development of data-supported TPD models that are grounded in sound pedagogical theory, sensitive to ethical considerations and designed to complement and enhance teacher agency by providing actionable insights rather than replacing professional judgement and expertise. By fostering collaborative data analysis practices, building teacher data literacy and ensuring transparency throughout the process, we can harness the power of data analytics to create a more equitable and effective learning environment for all.

Development of the data analytics framework

Theoretical framing

This paper is grounded in the theoretical lens developed by Pachler et al. (2010, 2013) in the context of their theory building for the field of mobile learning, namely a socio-cultural ecology which seeks to understand a world in transformation due to an increasing infusion of (mobile) digital technologies. The theory understands digital technologies, in particular mobile devices and their services, as cultural resources emerging in a 'mobile complex' consisting of structures, agency and cultural practices in constant flux and which are becoming increasingly integrated into (institutionalised) learning, including professional learning. This theoretical perspective is used to analyse (professional) learning as meaning-making and as appropriation of cultural artefacts within the socio-cultural field of the mobile complex. The ecological dimension is understood as the assimilation of learning and practices and expertise associated with mobile device/technology use in the activity context of everyday life into the formal curricular learning and contexts of educational institutions. Thus, by embracing the principles of socio-cultural ecology, the proposed framework considers structures, agency, and the dynamic interplay between cultural and technological tools and practices in shaping data-supported personalised professional learning. The use of data analytics is framed within this perspective to explore how data-supported insights can be integrated into meaningful, context-specific professional learning to foster personalised growth and reflective practices.

Unlike individualistic or behaviourist models that often emphasise isolated skills or outcomes, a sociocultural ecological perspective, rooted in the work of Vygotsky (1978), emphasises that learning, including teacher learning, is not merely the outcome of an isolated individual's cognitive process, but is an inherently a socially mediated process, deeply embedded within and influenced by cultural and technological contexts at play (Vygotsky 1978). Building on these insights, data-supported personalised PD, when viewed through a sociocultural lens, acknowledges that teachers do not develop in isolation but as members of professional communities that influence and are influenced by their actions, relationships, practices, and the cultural norms of the educational environments in which teachers operate.

In practice, this means that data-supported personalised PD should not merely focus on individual and/or mastering discrete competency development but should also account for the relational, communal, and culturally specific contexts by facilitating opportunities for peer learning, collaboration, and collective problem-solving. Teachers learn best when they are able to engage with colleagues in professional learning communities or (peer) coaching models, where they can share experiences, strategies, and solutions to common challenges. In this context, data analytics can be used to identify not only individual needs but also opportunities for collaborative learning. For instance, teachers with complementary strengths or shared challenges might be brought together in professional learning communities to co-construct knowledge and engage in joint problem-solving activities – facilitating group-based learning initiatives. This sociocultural orientation ensures that data-supported personalised PD does not become an isolated or overly individualistic endeavour but remains connected to the broader, socially mediated processes that drive teacher growth.

Furthermore, sociocultural theory underscores the importance of cultural relevance in PD. As teachers work in diverse settings – urban, rural, or international settings each with its own cultural, social, and educational norms – they may face different challenges that require localised, culturally responsive professional learning pathways. Therefore, data-supported personalised PD, grounded in a sociocultural ecology, must tailor learning experiences to these specific contexts, ensuring relevance and promoting more meaningful and sustained professional growth. For example, a teacher working in a multicultural classroom in an urban school may require PD focused on culturally responsive pedagogy, while a teacher in a rural community might benefit from PD tailored to multi-age teaching or resource-poor environments.

Thus, by incorporating an sociocultural ecological approach into the data-supported personalised PD framework ensures that the learning process is not only responsive to individual teacher needs but also contextually grounded and socially connected. This approach encourages a more nuanced form of data analytics that not only tracks individual progress but also maps out the social and cultural networks that influence teacher development. It prioritises collaboration and collective learning, recognising that professional growth happens within a community and is shaped by shared experiences and cultural values.

To actualise data within such a socio-cultural ecological framework, we must consider the broader context in which data is generated and utilised. This means looking beyond the numbers (not merely a collection of discrete points but a reflection of complex interactions within the educational ecosystem) to understand the interactions, relationships and cultural norms that influence educational practices. To put it another way, by adopting socio-ecological perspective, data becomes a lens through which we view the tapestry of social interactions and cultural influences on learning. It informs interventions that are not only personalised to the individual but also attuned to the social fabric of the educational environment. For instance, when analysing teacher practice data, we must concurrently consider the collaborative and cooperative culture of the school, the support structures within the professional community and the overarching cultural values that that underpin educational goals. This holistic approach ensures that data analytics do not exist in a vacuum but are contextualised within the living, breathing social environment of the classroom and the wider educational ecosystem.

Building the framework

The proposed data analytics framework builds upon existing literature by integrating insights from behavioural, critical, and socio-cultural ecological perspectives, which are often treated in isolation in previous studies on TPD. While prior research has largely focused on data-driven PD models that emphasise outcomes and performance metrics (e.g. Mandinach and Gummer 2016, Hirsch *et al.* 2018, Mangaroska *et al.* 2019, Khor 2024), this framework advances the field by balancing institutional goals with teacher agency and contextual relevance. However, in this paper, we acknowledge the potential of credible metrics that are congruent with a socio-cultural ecological perspective on teacher learning. We contend that the effective use of data analytics in professional development must be underpinned by an appreciation for individual agency, the social nature of learning and the role of cultural and technological artefacts as mediators of educational practice. By weaving together the socio-cultural fabric with data analytics, we aim to construct a nuanced, dynamic approach to professional development; one that is cognisant of the intricate interplay between the cognitive, the social and the cultural dimensions of learning. We have, therefore, selected and analysed literature that specifically addresses the intersection of data analytics, digital technologies and professional development through this lens. The review process involved a systematic search for relevant studies, theoretical papers and empirical research that explore data analytics in the context of teacher professional development; therefore, we envisaged use of metrics vis-à-vis professional development (see Table 1).

The proposed framework (illustrated in Figure 1) serves as a conceptual roadmap, steering the development and execution of personalised PD programmes underpinned by data-supported insights.

The framework depicted in Figure 1 encompasses various aspects related to personalised PD recommendations for teachers. It highlights the importance of considering characteristics such as relevance, accessibility, flexibility and effectiveness in designing a successful PD programme. The inclusion of big data analytics suggests an interest in leveraging large datasets to gain insights and make data-informed decisions. This aligns with the goal of identifying patterns and trends to better understand the needs and preferences of teachers. Additionally, the emphasis on technology proficiency and engagement with digital

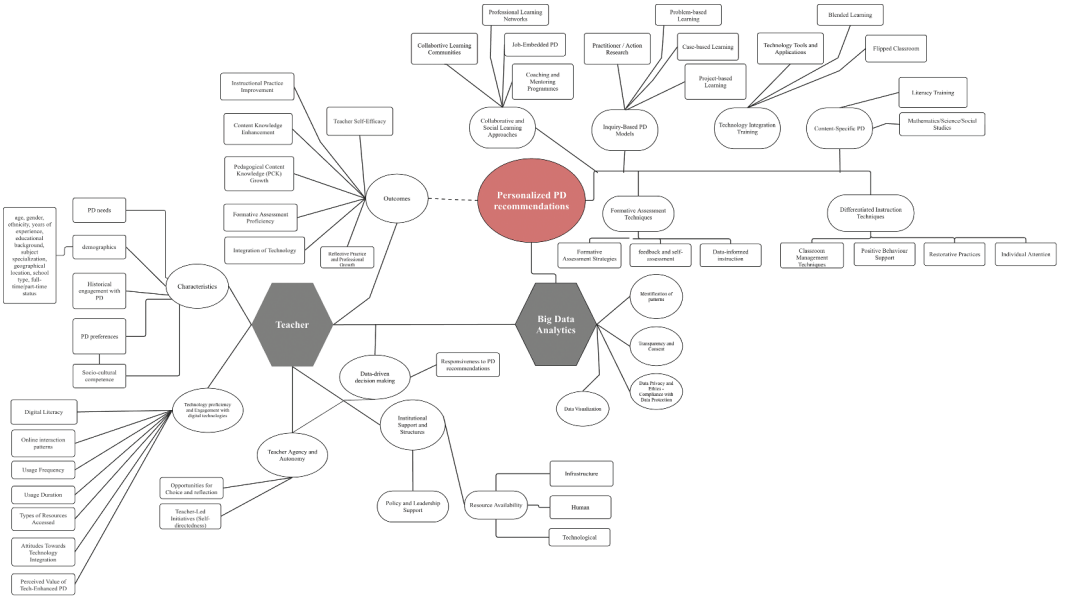

Figure 1. 'A possible data analytics framework'.

technologies underscores the desire to enhance teachers' skills in utilising technology effectively. The framework also acknowledges the significance of teacher agency and autonomy, emphasising the need to empower teachers and provide them with choices to co-construct their own PD pathways. Moreover, the framework tailors professional development strategies to reflect the local needs, resources, and community dynamics. This context-aware approach enhances the applicability and sustainability of PD by recognising that effective teaching practices cannot be divorced from the social and cultural realities in which they occur. Ethical considerations, particularly data privacy, transparency, and compliance with data protection regulations, are also highlighted as crucial elements. This framework explicitly addresses these ethical concerns by ensuring that data analytics is used as a supportive tool rather than a mechanism for oversight or control.

Overall, the proposed data analytics framework stands apart from existing models by integrating personalisation, teacher agency, contextual relevance, and ethical safeguards into the PD process. It moves beyond traditional, standardised approaches by offering a more flexible and holistic model that is responsive to individual needs while being grounded in a critical understanding of the limitations and risks of datafication in education as well as ensuring that professional learning is adaptable and relevant to diverse educational settings.

Discussion and conclusion

By harnessing the potential of data, the framework proposed in this paper as a starting point for discussion and future iteration seeks to offer a nuanced approach to TPD that transcends traditional methodologies. It aligns with contemporary educational demands for personalisation, responsiveness and evidence-based practices. The emphasis of the framework on informing and supporting individual teacher trajectories or developmental pathways, informed by robust data analysis, positions it as a model that can adapt to the evolving landscape of teacher needs and educational technologies. By augmenting AI-supported analyses for recommending different training routes, PD becomes more tailored to the unique contexts and growth areas of individual educators. This

level of customisation enhances the relevance and impact of the training, leading to greater teacher engagement and motivation.

The proposed framework has significant implications for policy and practice by promoting a shift from generic PD programmes to tailored approaches that respond to the unique needs of individual educators. It can guide policymakers and PD providers in allocating resources and courses more effectively, fostering a culture of continuous learning aligned with broader educational goals, and ensuring that PD initiatives are both equitable and impactful. This framework is applicable across diverse educational settings, from resource-rich urban schools in advanced economies to under-resourced rural schools in low-income countries. By considering local contexts and data availability, the framework can be customised to meet the specific professional development needs of teachers globally. For instance, a school district could use the proposed framework to analyse teacher data, identifying patterns that reveals areas for further development or highlighting inconsistencies in teaching practices, while also pinpointing teachers with similar PD needs such as differentiated instruction or classroom management techniques. The framework would allow for continuous monitoring and adjustments based on real-time data, providing teachers with targeted recommendations that align with their professional goals and contexts.

As we look to the future, the next steps in advancing the framework for TPD proposed here, involve several key phases. Initially, the focus would need to be on developing a prototype – an operationalizable representation that can be interactively used by educators and administrators. This prototype would serve as a testbed for the practical application of the principles in order to refine the user experience. Subsequently, rigorous testing would need to be conducted. This phase is crucial for gathering feedback, identifying potential issues and assessing the overall usability of the system. Testing would need to involve a diverse group of educators to ensure that the framework is inclusive and meets a wide range of PD needs. Future research would also be needed to explore its scalability, its adaptability to different educational contexts and the long-term outcomes of its implementation. Continuous iteration and refinement, based on empirical evidence and user feedback, would be essential.

As practice evolves, it will be key to ensure that data analytics serve as a tool to enhance, rather than replace, the human elements of teaching and professional growth. Ultimately, the goal is to foster a human-centric, data-informed culture within TPD that values both quantitative insights and the qualitative experiences of educators.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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