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An Online Support System for Teachers of Mathematics in Regional, Rural and Remote Australia

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Abstract

This article outlines the rationale for, and development of an online support system (OSS) for teachers of mathematics in regional, rural and remote (RRR) Australia as part of an ongoing longitudinal project, *Regional Teachers of Mathematics Networks* (RTMN). The OSS is designed to assist development of interconnected collaborative networks for teachers of mathematics in order to help them develop their professional identity. The article builds on the logic of the broader RTMN project, arguing that the development of a teacher of mathematics identity (ToMI) framework through participation in networked communities of practice (CoPs) is integral to improved practice and teacher retention. Theoretical considerations, framed within the overarching conceptual umbrella of cultural accumulation theory, are provided and relate mathematics CoPs to professional development and its role in the development of a 'localised' teacher of mathematics identity. This framing outlines the importance of an OSS that supports both face-to-face and online (virtual) CoP functions for teachers of mathematics. The article also states the case for a design-based implementation research approach that allows stakeholders to sustain ongoing evaluation and updating of the OSS platform for professional learning exchanges within the ToMI framework.

Keywords: regional, rural and remote; teacher of mathematics; teacher identity; adaptive challenge; innovation; adaptive challenges; communities of practice; professional associations

Introduction

The challenge of retaining teachers of mathematics in regional, rural and remote[1] (RRR) Australia is part of a broader systemic issue related to workforce development. Many communities and business entities, both local and national, are faced with shortages of people qualified and willing to undertake positions that require particular skill sets and/or are in particular locations (Moretti, 2012). This mismatch of the geography of jobs and the geography of population is not uncommon in RRR areas across many countries and has been met with a number of different responses, for example, immigration into and out of a country and movement of population from urban to

regional locations within a country (Chand & Tung, 2019). The Australian education system in many ways typifies this mismatch (Handal, Watson, Petocz, & Maher, 2018) and schools in RRR Australia have for many years faced high teacher turnover and lack of replacement by suitably qualified teachers (Downes & Roberts, 2017). Staffing and retention remains a concern, despite a number of attraction and retention schemes, including immigration of qualified teachers (Datta-Roy & Lavery, 2017), and initiatives such as the 2019 NSW Rural Teacher Incentive[2], (Halsey, 2018).

While much is unknown about why teachers remain in RRR schools, findings from other sectors indicate that mobile skilled workers in a range of professions can be attracted to RRR Australia. Health workers, for example, enjoy *"development of professional skills, autonomy and independence, good working relationships, friendships and the lifestyle associated with rural environments"* (Scanlan, Still, Stewart, & Croake, 2010, p. 103), with retention influenced by *"a myriad of highly interactive dimensions within personal, organisational, social and spatial domains"* (Malatzky, Cosgrave, & Gillespie, 2019, p. 1). In contrast, more is known about why teachers leave RRR schools. Teachers commencing their careers in schools in these areas, for example, identify a number of reasons for leaving their positions, including isolation and loneliness, a lack of support, minimal resources, and burn-out (Broadley, 2012; Halsey, 2018). In addition, RRR teachers may not experience the same working conditions as their urban counterparts, with some having greater workloads and responsibilities and/or assignment to teaching subjects outside their curriculum specialisation (out-of-field) (Kenny, Hobbs, & Whannell, 2019).

To address these issues, the authors, in partnership with the Mathematical Association of NSW (MANSW)[3], are exploring the notion that developing the professional identity of teachers of mathematics[4] through participation in a networked community of practice (CoP) is integral to improved practice and teacher retention (Faughn, Pence, Canzone, & Tuba, 2012; Lynch et al., 2020). The exploration is conceptualised through a Teacher of Mathematics Identity (ToMI) framework with the central tenet being that responding to numerous, and often location-centric, systemic challenges require adaptive solutions that address the changing realities of individual teachers in RRR areas. The ToMI framework is being developed as part of an ongoing longitudinal project, *Regional Teachers of Mathematics Networks* (RTMN), that seeks to meet the professional development and support needs of teachers of mathematics in RRR areas of NSW.

At this point in the development of the project, through ongoing consultations with teachers of mathematics and other stakeholders (reported elsewhere), the identified heart of the RTMN will be a Community of Practice (CoP) that supports teachers professionally and personally. The need for a CoP stems from the isolation RRR teachers experience as a product of extraordinary distances, small and very small schools and a corresponding lack of access to resources, including to other people and materials (Downes & Roberts, 2017; Hudson & Hudson, 2019; Lynch et al., 2020). By necessity of these factors relating to isolation, the proposed CoP will operate as a hybrid model through a combination of in-person and online interactions. It is the latter that has provided the impetus to construct an online support system (OSS) that provides the mechanisms for facilitating both person-to-person and online interactions (both synchronous and asynchronous) for teachers of mathematics, as well as the need for a conceptual framework that will inform OSS development.

From this point, the article provides the context in which the OSS operates (a) outlining the TOMI framework and (b) detailing theoretical considerations of CoPs as related to teachers of mathematics, their professional development and by extension their 'localised' teacher of mathematics identity. Then follows (c) the theoretically positioning of the OSS within cultural accumulation theory which then (d) informs the construction of the OSS framework. The final section is a brief description of how a design-based implementation research (DBIR) approach guides the research project. The authors intend that this article will link the context, that is, the ToMI framework and the CoP, and by providing theoretical underpinnings show how they can instantiate as an OSS for teachers of mathematics in RRR Areas.

The Teacher of Mathematics Identity (ToMI) framework

The ToMI framework (Fig. 1) was constructed as a direct response to the lack of effectiveness of, and in some cases, the total absence of support networks for teachers of mathematics in RRR Australia (Lynch et al., 2020). The innovative theoretical foundation of the ToMI framework is designed to enable these teachers to develop and establish support networks through the identification of systemic challenges and provision of adaptive solutions, beginning with localised challenges faced in RRR communities.

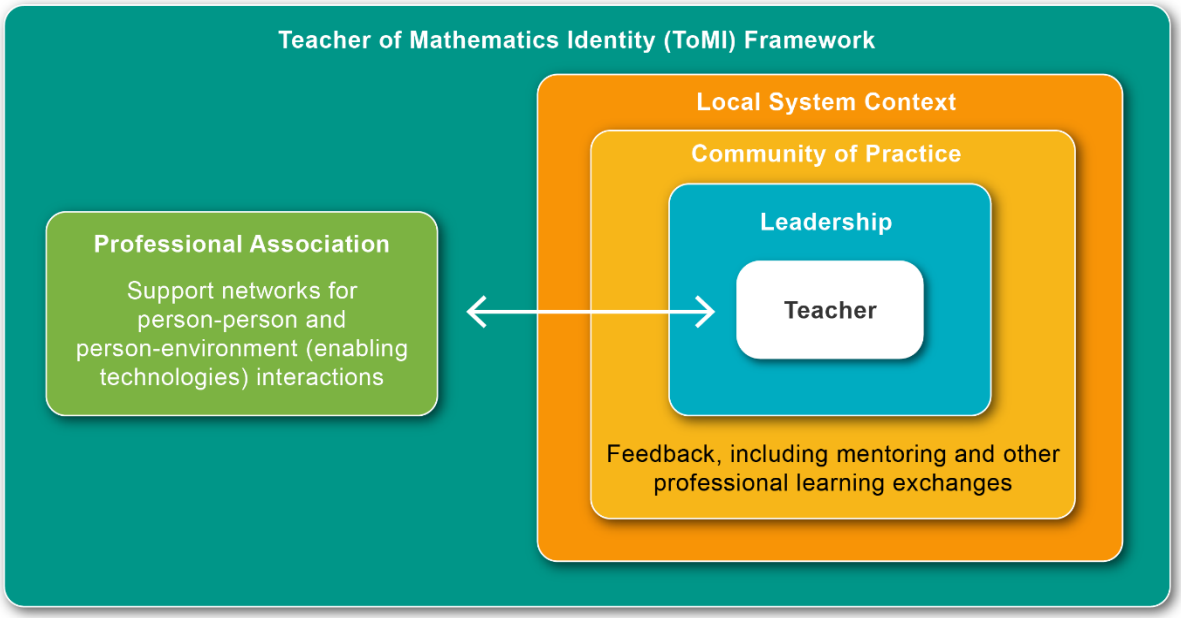


Figure 1: ***Interaction pathways and nested location of the five key elements within the Teacher of Mathematics Identity (ToMI) framework. Adapted from Lynch et al. (2020) and used with permission.***

The framework embraces an interplay of five key elements: teacher; leadership; a CoP; local system context (inside-system elements); and professional affiliation (outside-system element). The framework is designed so that interactions of the teacher, the focus (or 'ego') of the support network, with leadership (and with other staff and students) take place within a mathematics CoP situated in a particular RRR context. In keeping with the work of Fullan (2005) and others (e.g., Lynch, Madden, & Doe, 2015), connection to the outside-system element through professional affiliation offers a ready mechanism for teachers growing and enacting their own support networks at the local level. This emphasis aligns with the consideration of context in policy enactment as proposed by Herbert (2020) and with regard to CoPs as place-based enablers (Ledger, 2020).

Although the conceptualisation of teacher identity can be drawn from numerous identity theories, and remains contentious (Beijaard, Meijer, & Verloop, 2004), the multifaceted nature of identity and its changing shape in terms of external influences suggest a positioning within a sociocultural perspective (Gleeson, O'Flaherty, Galvin, & Hennessy, 2015). Teacher identity can be considered from this perspective as two-pronged, both personal and shared; in relation to a person's sense of belonging to a group, and also in relation to how that person functions across different communities (Beijaard et al., 2004; Wenger, 1998). For a teacher of mathematics, either sense of belonging is arguably determined by how a teacher accounts for their professional practice and how they are positioned within a community of practice discourse (Morgan, 2009). A teacher of mathematics professional identity, therefore, is dynamic and negotiated through experience—the increased sense of self emerges from experiences in different contexts (Darragh, 2016).

Within the ToMI framework, the teacher of mathematics identity is actively constructed via a set of capabilities, developed attitudes and perceptions, specialist knowledge and skills, and participation within a professional community (Fraser, Beswick, & Crowley, 2019; Lynch et al., 2020). As well as signifying good mathematics teaching, a teacher of mathematics identity involves a number of factors: the negotiated experience of self; a learning trajectory; different forms of membership within a single identity; community membership; and, a presumed involvement in local and global contexts (Fraser et al., 2019; Morgan, 2009). Importantly, a teacher of mathematics must establish a positive professional identity by positioning themselves within mathematics teaching contexts *"in ways that allow them to be seen by others and by themselves as 'good' teachers of mathematics"* (Morgan, 2009, p. 3). In this regard, the teacher of mathematics identity effectively scopes, captures, locates and explains what the ToMI framework seeks to achieve for teachers of mathematics in RRR locations.

To overcome geographic and time-related issues, the ToMI framework embraces the development of an online CoP as a key best-practice element for professional development related to industry-specific issues (see Smith & McKeen, 2004). In keeping with Wenger (1998), these CoPs are conceptualised as a professional network of learners with a shared goal, set within norms, expectations, and standards, who systematically exchange information about their practice. At the heart of this conceptualisation of CoPs is the notion of a practitioner-initiated community that engages leadership and expertise within supportive networks—CoPs are sometimes referred to as professional learning networks or collaborative inquiry networks (see e.g., Lantz-Andersson, Lundin, & Selwyn, 2018; Macià & García, 2016; Sinnema, Daly, Liou, & Rodway, 2020). It should be noted that, although the two notions are sometimes conflated, professional learning communities (PLCs) differ from CoPs, with the former primarily organizational structures for providing teachers with professional development, whereas CoPS, as envisaged by Wenger, McDermott, & Snyder (2002), are not usually part of a formal organisational structure (Blankenship & Ruona, 2007; Blitz, 2013). Both PLCs and CoPS, however, can also operate as collaborative networks and their effectiveness can be improved in online environment, which are ideal for sharing knowledge, skills and experiences (Blitz, 2013; Lloyd & Duncan-Howell, 2010; Sinnema et al., 2020).

While establishing a CoP within the ToMI framework appears to be a justifiable and adaptive solution to the systemic challenge of teaching mathematics in local system contexts[5], developing a sustainable CoP in the context of RRR Australia may be problematic. One of the most significant issues lies in theoretically framing professional learning and other interactions within a CoP so that development can be assessed for efficiency and effectiveness, with the resulting influence or impact examined. Further, any theoretical frame must be sufficiently general to allow for a range of possible developments within CoPs in differing local system contexts while remaining sufficiently specific to allow for progress evaluation that informs any planned design cycles (Herrington, Herrington, Kervin, & Ferry, 2006; Kelly, Clarà, Kehrwald, & Danaher, 2016). The next section outlines key conceptualisations needed for these aspects of the OSS in relation to teacher professional learning and, ultimately, effective, sustainable and measurable CoPs. This is followed by an outline of cultural accumulation theory, the general overarching theory within which the OSS is framed.

Communities of Practice (CoPs) and Teacher Professional Learning

The modern conceptualisation of a CoP has its origins in educational contexts, with the first CoPs developed from research on connecting communities of apprentices and more experienced workers (Lave & Wenger, 1991). Wenger, et al. (2002, p. 4), went on to define a CoP as *"a group of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise by interacting on an ongoing basis"*. With the rapid growth of information and communications technology (ICT) that came with the internet revolution

(Tronco, 2010), these interactions can be either in person or online, or as a hybridisation of both (Smith, Hayes, & Shea, 2017). In educational settings, therefore, CoPs can function as professional learning communities that engage teachers in significant educational research and practice, including in online environments (see e.g., Krutka, Carpenter, & Trust, 2016; Lantz-Andersson et al., 2018).

In educational contexts, CoPs can be powerful catalysts for enabling teachers to improve their practice, with Macià and Garcia (2016) outlining a common set of effective professional development characteristics emerging from contemporary CoP literature. Professional learning exchanges characteristic in education settings are now woven in the fabric of CoPs as teacher collaboratives, subject-matter networks, professional development schools, and school-university partnerships, and have proven successful in several reform projects related to teacher professional learning (Bannister, 2018; Patton & Parker, 2017; Woolcott et al., 2017). Literature related to teacher professional learning in online contexts, summarised in Lantz-Anderson et al. (2018), has also shown that CoPs could provide many individual and organisational benefits, such as: improved exchange, acquisition and evaluation of knowledge and practices; improved work performance and contributions towards career progression; improved professional learning and teaching through social learning; establishment of professional networks and alliances; and, increased collaboration that leads to overcoming institutional isolation.

Teacher professional learning (and its parallels with professional development[6]) can be viewed as a long-term, collaborative process that takes place within a particular context where teachers are seen as active learners and reflective practitioners (Kelly, 2019; Mayer et al., 2017). In such contexts, teachers are engaged in concrete tasks of teaching, assessment, observation and reflection to acquire new professional knowledge and experiences based on their prior knowledge (Darling-Hammond, Hyler, Gardner, & Espinoza, 2017). From this perspective, teacher professional learning remains well-aligned with the notion of CoPs, but also with situated learning theory, and the combination has had broad application in the context of online professional learning (Bixler, 2017). Situated learning theory considers learning as a cognitive process that takes place in the same social context in which it is applied—albeit with the drawback of not taking into account the knowledge, skills and experiences that teachers bring to that social context (Stoilescu, 2016)—as such, learning mathematics within a CoP is more like a process of practising mathematics rather than a process of inscribing certain mathematical concepts in the brain.

The CoP model in Figure 2 (from Daele, 2006), developed within a situated learning context, illustrates a close alignment with the ToMI framework. In both, teacher professional learning is seen as related to the construction of professional identity along with improved practice. In the model, a professional practice element is formalised and introduced to the CoP as a topic for open discussion and is acted upon in five sequential processes; exchanges followed by analysis, experience sharing, debate and confrontation, and finally the creation of new methods and practices. The intervention of the CoP participants in each process occurs independently and does not necessarily follow the order in Figure 2—multiple chains of interventions can happen at the same time.

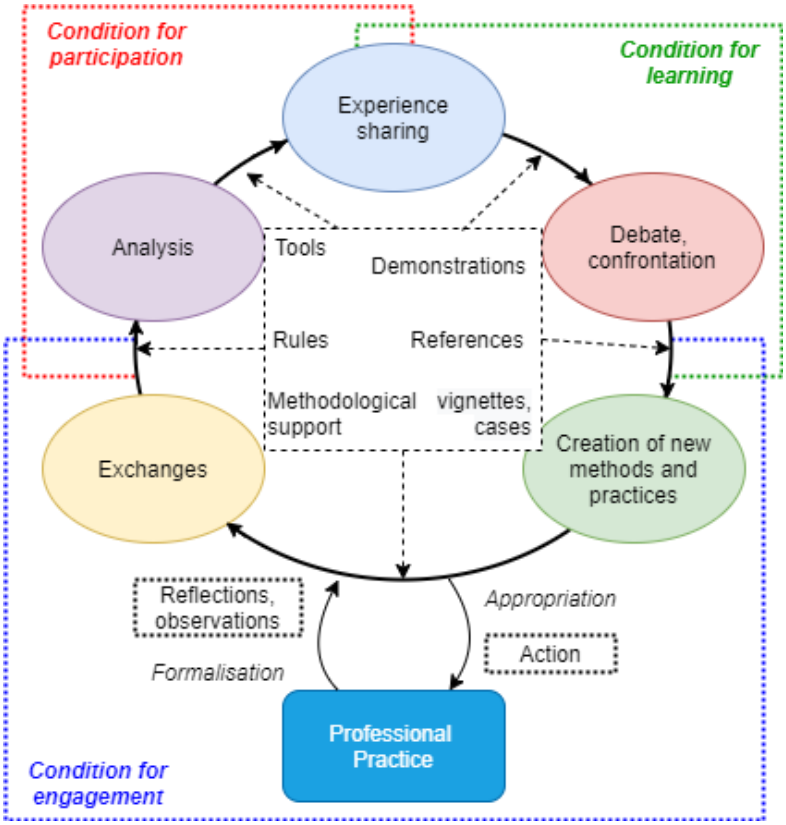


Figure 2: Model of teacher professional learning within a community of practice (CoP). Adapted from Daele (2006) with permission.

Taken together, the conceptual suitability of theory related to CoP, and the identified practice benefits, strongly suggest that application of CoPs is needed and warranted in addressing the challenges facing teachers of mathematics in the RRR education sector. The implementation of the ToMI framework and an associated OSS is dedicated to precisely such an application.

Cultural Accumulation Theory as a Basis for a Community of Practice (CoP)

As mentioned earlier, a significant issue in developing a sustainable CoP in the context of RRR Australia is the lack of an overarching theory that would provide a rationale for professional learning within a CoP. Particularly one that would allow for assessment of the efficiency and effectiveness of how a CoP functions as an interactive support system along with professional affiliation. Cultural accumulation theory offers such a rationale and assessment, supporting the view that any professional learning mechanisms developed within a CoP must consider two types of interaction- person-person (e.g., face-to-face teacher professional learning) and person-environment (e.g., teacher access to an online support system) (see discussion Woolcott, Keast, & Pickernell, 2020). The two interaction types are situated within the notion of human culture[7] that can accumulate—the process of the collecting knowledge, skills and experiences across society is referred to as cultural accumulation (Woolcott, 2016; Tomasello, 2014) and explicated in terms of cultural accumulation theory in Woolcott et al. (2020). By embracing these interaction types, the ToMI framework is designed to facilitate teachers' contributions to cultural accumulation in their pivotal role as agents of cultural change (see Figure 3) while, at the same time, allowing for the use of appropriate methodologies in the formation of professional learning networks (Goodyear, 2014; Kelly et al., 2016; Macià & Garcia, 2016).

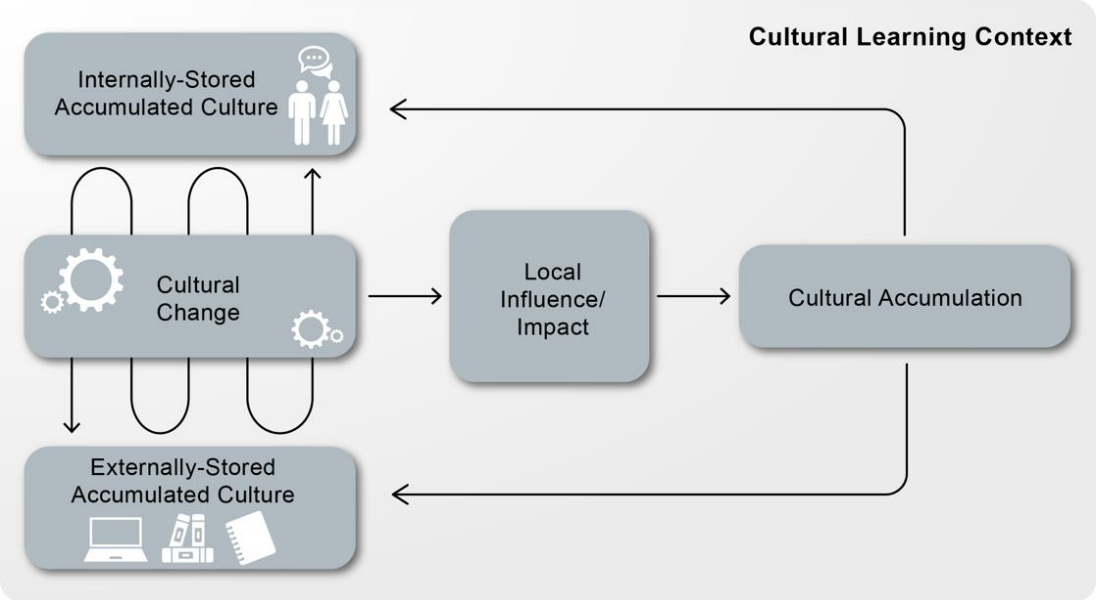


Figure 3: The types of interactions required for cultural accumulation in the cultural learning context of the Teacher of Mathematics Identity (ToMI) framework. Adapted from Woolcott et al. (2020) and used with permission.

For this reason, implementation of the ToMI framework as a purposeful cultural accumulation process seeks to engage an innovative impulse and, at the same time, avoid past fails of educational initiatives (Downes & Roberts, 2017; Halsey, 2018; Kelly et al., 2018). As such, the framework considers the overall environment in which resides the interactions of people with other people, and with their environment, including both offline and online. Within the broader cultural learning context of the ToMI framework, cultural change arises from interactions between the professional affiliate, participant teachers and leadership in developing the CoP, driving cultural accumulation. The conceptualisation of cultural change within a cultural learning context, therefore, underpins the relevance of the local system context—cultural accumulation theory frames the broad context of cultural change as a human phenomenon in a global sense, while the ToMI framework brings focus to the influence and impact on the local system seen as a discrete cultural learning context.

In this respect, cultural accumulation theory provides the overarch within which the ToMI framework is situated. It embraces the capacity of individuals or groups to impact or influence one another through person-person interactions/relationships as well as person-environment interactions in both online and offline settings. As indicated by the wavy line in Figure 3, there are back-and-forth exchanges between the two types of interaction; for example, a discussion with a colleague face-to-face (internally-stored accumulated culture), and then accessing an online resource (externally-stored accumulated culture) followed by another face-to-face discussion regarding the use of that online resources (cultural change). Importantly, the overarching notion of human cultural accumulation provides a means to measure the influence or impact of those interactions in relation to the local system context and CoP collectively—that is, cultural accumulation theory embraces the view that individuals and their multiple interactions can have important and far-reaching change effects at multiple levels in sometimes complex environments (Scott, Woolcott, Keast, & Chamberlain, 2018; Woolcott et al., 2020).

Taking up the Challenge of an Online Support System (OSS)

Supporting a Sustainable Community of Practice (CoP)

CoPs, in particular those that operate as online learning networks, typically have a relatively high degree of identification between members of the community and a degree of informality in interaction more in tune with a community than an organization (Hoadley, 2012). An OSS that enables a sustainable teacher of mathematics CoP should, therefore, situate learning in an environment that engenders community interaction, hence, building identity through the sharing of knowledge, skills and experiences of teaching—that is, the cultural learning context of mathematics educational practice (see also Mayer et al., 2017). In considering a localised context, the ToMI framework embraces the role of the CoP in enabling a deeper sense of professional identity and makes a clear link between the personal and professional self of a teacher and their practice (Alsup, 2006; Wenger, 1998).

Overall, the intention of the ToMI framework is to connect teachers to both other people and to online support environments in order to sustain and support member involvement systemically through those networks. This framework is distinctive in engaging the use within professional learning of feedback regimes, including those involving mentoring and/or other professional learning exchanges, as mechanisms for building support networks within a CoP (Lynch et al., 2020). Potentially, these regimes can operate both within and across CoPs in different RRR school communities. The emphasis on using both types of interaction (person-person and person-environment) is supported by Trust, Krutka, & Carpenter (2016), who suggest that multiple means of engagement, face-to-face learning activities and leadership roles are critical elements that shape participation and learning in a CoP.

It is important to note that an enabling technology is crucial to supporting these interactions within RRR contexts; such technology would provide a broadly applicable, open-ended mechanism that is capable of supporting strategies for professional learning using face-to-face as well as both synchronous and asynchronous online interactions as a basis for the development of ongoing relationships within the CoP (Kelly, 2019; Wawire, Okeyo, & Kimwele, 2018).

Enacting Cultural Accumulation Theory within the ToMI framework

In Australia, there have been some successes in establishing nurtured CoPs aligned to the teacher-leadership interactions and outside-system elements envisaged in the ToMi framework (Falkner, Vivian, & Williams, 2018; Kelly et al., 2016; 2018). Nurtured CoPs are created by and facilitated from a group of volunteering members who act as champions to maintain a participant-driven agenda and focus, with awareness and support from the organisation's top-level managers. CoPs of this type are often sustainable in the longer-term, continuing to serve the needs of participants provided there is sufficient organisational support, whereas intentional (top-down) or organic (emergent) CoPs may not (Raeburn & McDonald, 2017).

Perhaps the best example of alignment is the CSER Digital Technologies teacher professional development program (Falkner et al., 2018), which established and implemented an ecosystems model embedded within the organisational theory of Thomas and Autio (2014). The model was able to be scaled across both urban and RRR areas in South Australia where, in effect, the university administrative centre acted as an outside-system hub in the same way that the ToMI framework envisages professional affiliation for the OSS.

The CSER Digital Technologies ecosystem model instantiated the two types of interactions required for cultural accumulation (Figs 3 and 4) summarised as follows.

- *Person-person interactions*: Professional Learning-in-a-Box as person-to-person connections or collaborative networks (connections of more than three people); and,

face-to-face professional development events, including mentorship, for confidence building.

- *Person-environment interactions*: a fully developed Massive Open Online Course (MOOC) for flexible, provision of just-in-time learning; a lending library to overcome technology anxiety; and, the development of online communities (called communities of learning rather than CoPs) for sustained peer-to-peer learning.

Their ecosystem model also provided opportunities for *back-and-forth interactions* enabled by the overall ecosystem network and its inbuilt support systems within the CSER professional development structure. The overall ecosystem was constructed so that each component was sustainable, that is, with minimal maintenance or ongoing financial contributions apart from in-kind partnership agreements related to the technology platform.

The OSS model outlined in the current article (Fig. 4) draws on the cultural accumulation interaction types described for the Falkner et al. (2018) ecosystem model. In using the model to enact an OSS within the ToMI framework, professional affiliation can move from a role as outside-system to a 'surround-system' element, playing a role in enablement at all levels of interaction to build and sustain support networks that nurture teacher of mathematics identity.

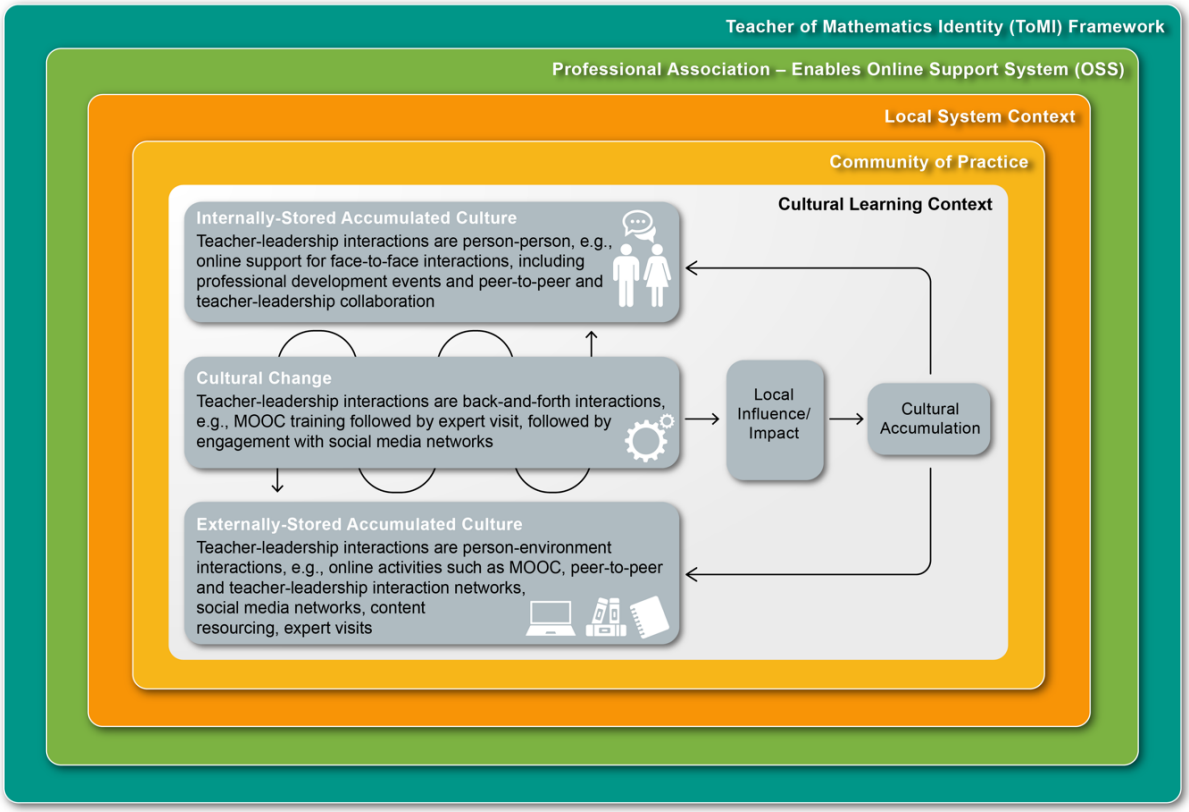


Figure 4: ***A model for an online support system (OSS). Adapted from Woolcott et al. (2020) and Lynch et al. (2020) and used with permission.***

Designing the Online Support System (OSS)

The situational necessity of overcoming isolation due to substantial geographical distances, combined with unreliable internet connectivity, is a significant driver for designing an OSS that moves professional learning, typically delivered face-to-face, to include online delivery. Such an OSS offers expanded opportunities for joint learning exchanges and reflection among colleagues, mitigating disconnections across practice (Hoadley, 2012; Lantz-Andersson et al., 2018). Despite the suite of suitable characteristics outlined above, few professional learning projects have resulted in the kind of CoP that is sustainable[8] in supporting teachers as they enter the profession

and grow toward teaching mastery, either online or face-to-face (Admiraal, Schenke, De Jong, Emmelot, & Sligte, 2019). In this regard, a critical issue has been the poverty of studies that focus on technology's role in transforming, sustaining, or scaling up CoP-based teacher professional learning efforts (Lantz-Anderson et al., 2018). Other major issues centre on the absence of effective online models (Falkner et al., 2018; Krutka et al., 2016) and perceived risk or potential for harm associated with the use of technology, including excessive time and energy investment in technology-related learning (Breakstone, McGrew, Smith, Ortega, & Wineburg, 2018; Kelly et al., 2016).

The end result, however, is the need for a dedicated OSS that underpins the development of CoPs for the purpose of providing mathematics professional learning while overcoming the current reliance on existing collaboration platforms and social networks (Blyth, 2013; Kelly, 2019; Tripet, Patel, Thornton, & Walker, 2018). In drawing on the Falkner et al. (2018) model, the OSS embraces a set of clear managerial and functional contingencies that address the issues reported above for both face-to-face and online CoPs. These contingencies can perhaps be best summarised in terms of professional learning networks that are *"uniquely personalized, complex systems of interactions consisting of people, resources, and digital tools that support ongoing learning and professional growth"* (Trust et al., 2016, p. 35).

From this perspective, the current OSS model (Fig. 4) situates both the CoP model (Fig. 2) and the ToMI framework (Fig. 1) within cultural accumulation theory. This theoretical positioning enables the professional affiliate to manage the technology platform and guide the development and sustainability of CoP support networks at both global and local levels. It acknowledges that the core business of the professional affiliate is, as exemplified in this project, to support teachers of mathematics as outlined in its strategic goals, and mission and values statements. The stated aim of the OSS, therefore, is to provide CoP members, and the professional affiliate, with synchronous and asynchronous connections across professional learning networks, within the context of the ToMI framework.

The OSS aim is elaborated as four embedded goals and four associated operational aspects (Table 1) that draw on guidelines for platform development from Herman, Grobbelaar and Pistorius (2020), a recent perspective on design and development of technology platforms in the health sector. These conceptualisations are also closely related to the *"regulative and normative elements that underpin its functionality"* of the governance system of Thomas and Autio (2014) referred to in Falkner et al. (2018).

Table 1: ***The four goals embedded within the OSS aim and their operational aspects related to the ToMi framework within the OSS design***

OSS Goals	OSS Operational Aspects related to the ToMi framework
Situate professional learning of online CoPs in authentic practice fields that provide acquisition of appropriate knowledge, skills and experiences (see, e.g., Falkner et al., 2018), that is, situated as cultural learning related to professional mathematics teaching practices in RRR areas. The OSS platform should be designed, for example, to enable improved work performance and contribute towards career progression through developing mathematics CoPs (e.g., Gómez-Blancarte et al., 2019).	**Ecosystem & Environment (Partnership):** Active teacher-leadership interactions to drive the nurtured CoP. For example: 1) enabling coordination by a well-respected CoP member; 2) involving key thought leaders in mentoring or feedback regimes; 3) developing an active and passionate core group; 4) creating a critical mass of engaged members; and, 5) creating rhythm in the CoP (weekly meetings, regular learning regimes)
Provide opportunities for teachers of mathematics to co-construct a CoP through collaboration and	**Ecosystem Evolution: S**uitable conditions and environment should be created to develop and

OSS Goals	OSS Operational Aspects related to the ToMi framework
co-creation (e.g., Woolcott et al., 2019b; Daele, 2006) to optimise person-person and person-environment exchanges, including back-and-forth interactions. Thus, a teacher can develop their identity through cultural learning in local system contexts.	guide CoP evolution, rather than a structure be imposed. For example: 1) support for multilevel participation that is critical and/or meaningful; 2) support for professional and public CoP interactions; 3) facilitation of personalised/group learning; and, 4) provision of social learning opportunities.
Facilitate the development of support networks that recognise the unique nature of each CoP within its local system context. Each CoP may have its own unique mathematics teaching domains, as well as a need for unique support networks through which to develop the CoP, for example, through "*engaging, discovering, experimenting, reflecting, and sharing*" (Krutka et al., 2016, p. 35).	**Ecosystem Network:** Memberships have a set of behavioural characteristics that determine their identity – status, reputation, influence - as members of a networked community. For example: 1) a focus on topics important to the members (critical exchanges, Lantz-Anderson et al., 2018); 2) knowledge of network, purpose, structure and function (Woolcott et al., 2020); and, 3) provision of guiding principles and codes of conduct.
Allow for a process of local influence/ impact that leads to generation, application and reproduction of knowledge, skills and experiences that contribute to cultural change in the localised system context in which the CoP is operating, including CoPs that are self-initiated (e.g., Tour, 2017).	**Ecosystem Generation:** Continuous generation of knowledge through collaboration spaces for thinking together, sharing or exchanging ideas and resources. Furthermore, in terms of knowledge, skills and experiences, generating ways that have positive impacts on pedagogy, including: confidence and competence in lesson planning; conceptual knowledge and curriculum development; as well as, enhanced emotional literacy, motivation and reflective practice (Woolcott et al., 2017; Lantz-Anderson et al., 2018).

Each of the four goals is aligned with four operational aspects (Table 1 and Fig. 5) within the OSS design, also drawn from Herman et al. (2020): 1) ecosystem and environment—situating professional learning of online CoPs in authentic practice fields through consideration of partnerships within local system contexts and with the professional affiliate; 2) ecosystem evolution—provide opportunities to co-construct CoP through collaboration that create conditions for CoP development and sustainability; 3) ecosystem network—facilitate the development of support networks for unique localised CoP through consideration of interaction networks within local system contexts and with the professional affiliate; and, 4) ecosystem generation—allow a process of local influence/ impact that contributes to localised cultural change by ensuring that the continuous generation of knowledge, skills and experiences is in line with overarching cultural accumulation theory. These operational aspects are set within collaboration spaces provided for by dedicated technologies that are modularised (Fig. 5) to allow for application as needed in CoP development within the ToMI framework.

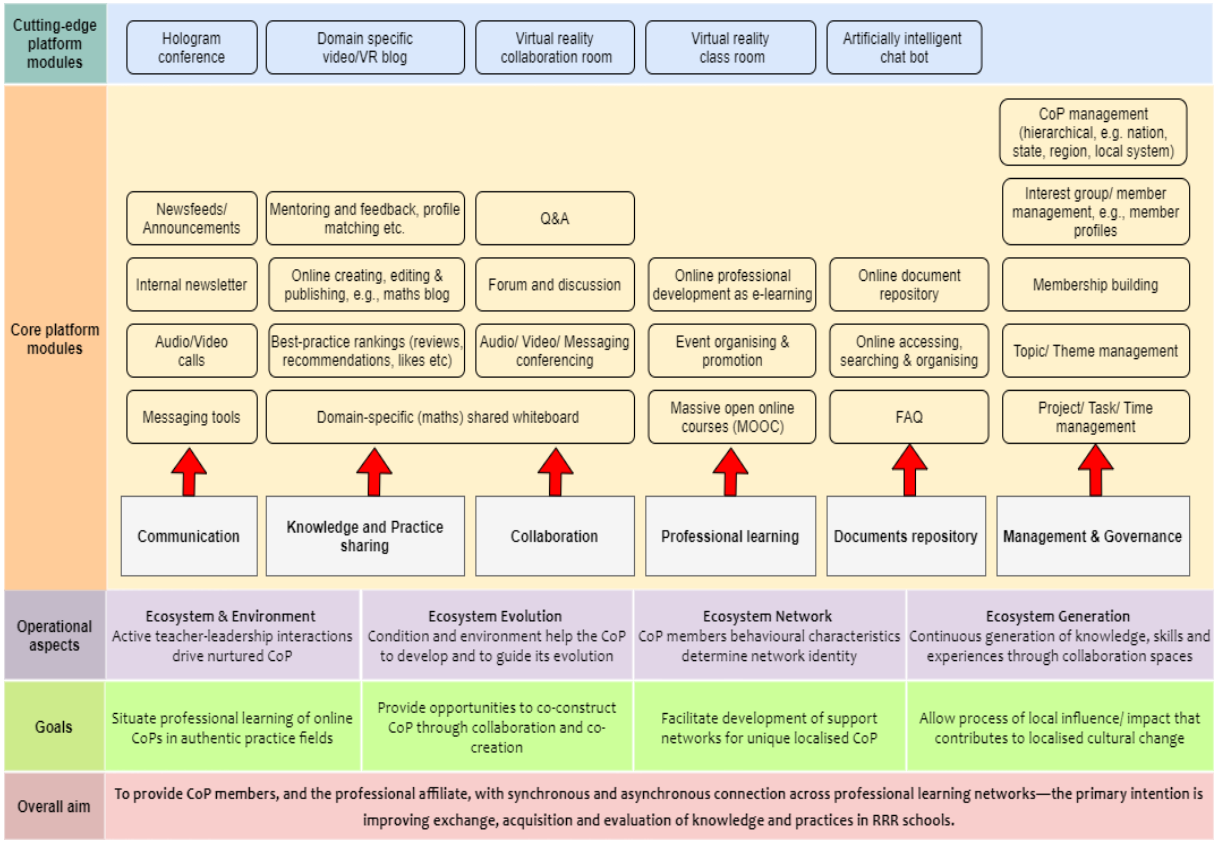
The OSS as elaborated would support teachers of mathematics engaging with others across CoPs in RRR schools—that is, the OSS has a primary intention of improving exchange, acquisition and evaluation of knowledge and practices. Operationally, the OSS provides for open dialogue between inside-system elements and with the outside-system professional affiliate, maintaining connection, for example, by building personal relationship among CoP members and by supporting teacher of mathematics identity through professional development.

What does the Online Support System (OSS) look like?

In many RRR contexts within Australia, internet connectivity is problematic across geographical distance, especially where there is a lack of resources with which to construct and maintain the required digital connection systems (Park, 2017). An enabling technology platform of low bandwidth is critical in sustaining and supporting member involvement in any OSS that engages both person-person feedback and person-environment interactions. This platform should serve in providing a time- and place-independent, broadly applicable and open-ended mechanism that is capable of supporting professional learning networks. The platform should also engage strategies for enabling face-to-face interactions as well as both synchronous and asynchronous online interactions as a basis for the development of ongoing relationships within a given CoP and its local system context. The 'right' platform, therefore, should be flexible in its effective and efficient establishment and development of CoPs that are driven by professional practice—knowledge, skills and experiences created and shared by members, and knowledge sharing, filtering, and transformation supported as is typical of nurtured CoPs (Raeburn & Macdonald, 2017).

Given the embedded OSS goals, the open-system design has a modular architecture (Fig. 5). Each module provides a dedicated functionality inside a unified technology platform that satisfies requirements for both technology building objectives (e.g., resources, question and answer, audio/video conferencing, and online professional development courses) and system management objectives (e.g., scalability, platform performance indicators, maintenance indicators, and reliability and safety controls). The modules are grouped by their common functionality, but are partitioned additionally as either core modules (features required to support the essential activities of the OSS) or cutting-edge modules (features designed to improve the effectiveness of network connections and create innovation within the OSS).

Figure 5: ***The architecture of the online support system (OSS) technology platform***



This open-system architecture design allows an incremental development of a dedicated platform and a suitable database structure, with authenticated modules implemented at need, but not necessarily in a linear sequence or at the same time, in a similar way to the 'introductions' to CoPs in Daele (2006, Fig. 2). This design also allows modules to be added, reconfigured or removed to match network development in the CoP and changes in technology and, as such, provide an adaptive mechanism that is at the heart of the ToMI framework. A set of core modules, with cutting-edge technology providing potential enhancement modules, collectively provides for a blend of both informal and formal professional learning networks and alliances that interface with the Internet, including social media (e.g., Delello & Consalvo, 2019). The modularised platform, therefore, should provide a low-to-medium degree of institutionalisation, high connectivity and flexibility, and a relatively high degree of identification within a CoP, increasing collaboration and overcoming isolation (e.g., Lantz-Anderson et al., 2018; Liberatore, 2018; Kelly, 2019). The core and cutting-edge modules are aligned with the overall aim and embedded goals and with the operational aspects, including those related to management and operation of the platform (Fig. 5).

The design of the OSS takes into account issues of bandwidth and connectivity, for example, the majority of the OSS modules do not require a high-speed network connection. The OSS can function well without the modules which require high speed connections, such as virtual reality or hologram modules (see cutting-edge on Fig. 5), and their dedication as optional does not change the embedded goals of the OSS—other alternatives are available (e.g. audio/messaging conference). In addition, the collaboration is available in both synchronous and asynchronous mode to minimize the impact of unstable network connection, for example, through availability of downloads for recorded sessions and materials. Additionally, the OSS without high-speed network connections can be assessed from multiple platforms, such as desktop, web and mobile.

A nurtured CoP, such as envisaged here, would require ongoing support and feedback from teachers in the RTMN project and consideration and consultative action of the professional affiliate (MANSW in this case) by, for example: building on core values of the CoP; making sure that building the CoP is part of the everyday activity and workload; and, allowing people to participate in the CoP at different levels based on their needs (Lynch et al., 2020; Mayer et al., 2017). It is anticipated, therefore, that the OSS should help teachers to further build their teacher of mathematics teacher identity within the construct of the ToMI framework. It is envisioned that teachers should find the OSS valuable in a wide range of activities as stated in Table 1, especially since it is designed to help teachers work more effectively with greater efficacy. Use of a nurtured CoP does not assume teachers will automatically engage with the CoP (see e.g., discussion in Kelly et al., 2018), rather, a nurtured CoP is predicated on establishing an initial group of teachers and leader members who act as champions to maintain a participant-driven agenda and focus, with awareness and support from organisational leaders the professional affiliate.

The User Interface (UI) for the Technology Platform

The following are the key features and functionalities of a conceptual user interface (UI) for the platform, supported by a backbone comprising a Virtual Conference/Classroom App, accessible using a desktop computer, mobile device and potentially a virtual reality (VR) headset:

- the platform manager can choose/control the content, invite participants, add/remove participants, schedule, provide information about the show;
- participants can access a content together in synchronous or asynchronous mode;
- participants can discuss the content using text, voice (video) in synchronous or asynchronous mode; and,
- participants can take note, record sessions in which they participate from their device.

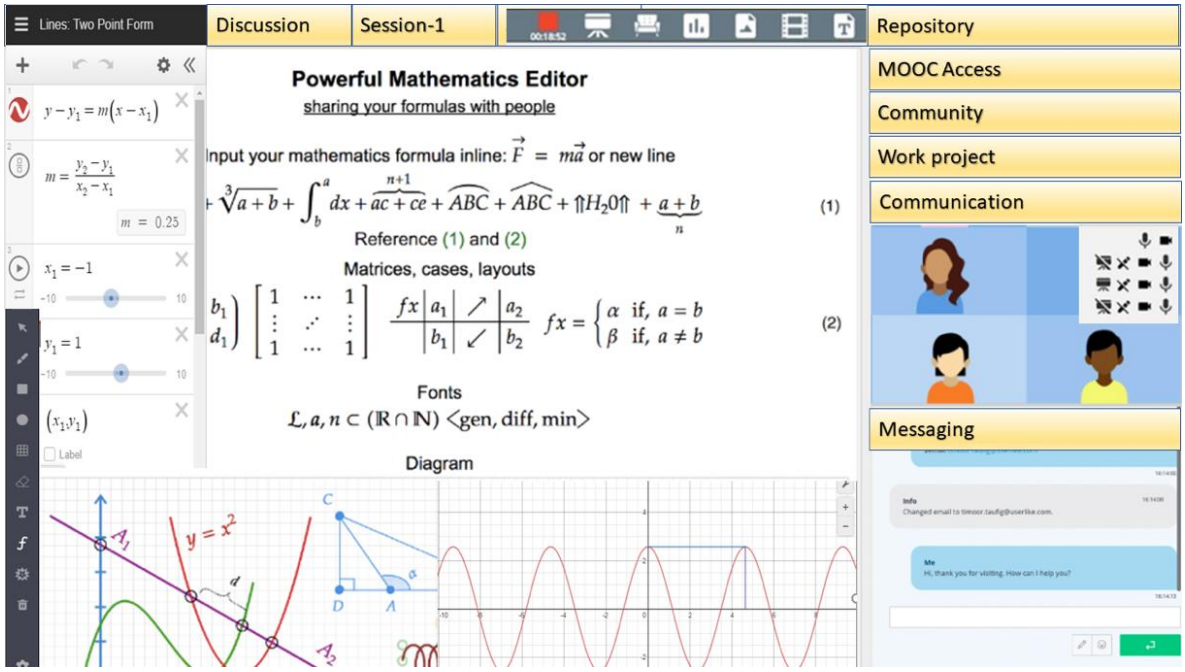


Figure 6. ***The proposed User Interface (UI) for the online support system (OSS) technology platform***

The features and functionalities suggest a UI designed as a centralised virtual collaboration space, as shown in Figure 6. In this collaboration space, each member can create and share domain-specific content (such as mathematics classes), participate in training or collaboration sessions, access learning materials, and communicate with other members via such means as messaging, audio and video conferencing. The member can also browse or search for content and learning sessions or record, save and retrieve sessions.

Using Design-Based Implementation Research (DBIR) to Report on, Evaluate and Update the Online Support System (OSS)

While the ToMI framework underpins the conceptualisation of how theOSS is positioned within the RTMN project, it is the design-based implementation research (DBIR) approach that provides the mechanism through which iterative innovation cycles, necessary for the development of the OSS, are conducted. Specifically, DBIR is concerned with educational contexts and ways to promote learning, integrating practice through its combination of design-based research, developed from design and testing of innovation within learning contexts, and implementation research which is allied with the implementation of innovations (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013). DBIR is ideally positioned for reporting on, evaluating and updating the OSS, since DBIR can be used across a range of educational settings (both face-to-face and online) as an emerging approach to innovation (Penuel, Fishman, Cheng, & Sabelli, 2016). DBIR also has a strong relationship to theoretical frameworks within a number of online educational research and practice contexts and methods, including technology platforms (e.g., Swartz, Hanlon, Childress, & Stenner, 2016; Wong & Looi, 2019).

DBIR initiatives can meet multiple identified needs within the education settings of the localised system contexts that lie within the ambit of the ToMI framework, including networks that support new learning and ways of learning, policy development, social science, research, and interrelated improvements to build/rebuild educational systems. Most importantly, the DBIR approach can be used within the educational intervention by employing the OSS to innovate collaboratively; and additionally, to help all stakeholders better understand when to apply a particular method or model for intervention in classroom settings and other educational practice environments, and why and how this may be achieved (e.g., Getenet, 2019).

Implementation of the OSS brings to the fore the importance of the design base of implementation and research, involving considerations, perspectives, tools and methods, to meet a number of success factors; designing and testing innovative solutions in collaborative ways that can be used to address and study issues concerning implementation (both research into and application of implementation) and combining this design work with building knowledge related to educational settings (learning, teaching, and research). In a similar way to policy research, DBIR implementation of educational initiatives is considered a key element for ongoing theoretical development and analysis (Fishman et al., 2013; Penuel et al., 2016).

Use of DBIR in enabling the OSS seems especially useful in guiding the construction and development of online learning that is self-paced and curriculum-based, while at the same time facilitating the scaling up of programs (Penuel et al., 2016; Woolcott et al., 2019a). In practice, therefore, DBIR should enable the OSS to be constructed on known theoretical research and apply it to problems that are clearly articulated, persistent and repeatable. Further, using the DBIR approach in the development of the OSS facilitates a focus on an integrated, practical application of professional learning resulting in transformative innovations aimed at improving learner outcomes. In this sense, system evaluation is ongoing—such processes are integral to DBIR.

Conclusion

The OSS design outlined here is devised to enable the development of teacher of mathematics support networks that are flexible, adaptable, intrinsically connective and able to create distributive knowledge and understandings. Additionally, this design considers the appropriate technology for support in RRR environments, with the platform using a modular, open architecture intended to allow for the collaborative creation and testing of ideas and solutions related to assisting teachers of mathematics in developing their professional identity in a self-directed and sustainable way. The use of a DBIR approach enables stakeholders to sustain continual evaluation and updating of the OSS platform in service of professional learning exchanges within the ToMI Framework. This approach recognises that the OSS will likely undergo a range of adaptive and potentially disruptive changes, due in part to rapidly changing technologies, but also to interactions that may occur within the implementation of the project using the ToMI framework within rural and remote contexts.

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[1] There are various terms used for non-urban contexts and this article prefers use of all three terms, regional, rural and remote, recognising that in some references these may be referred to under an umbrella term, such as rural, or discussion may be confined to just one or two of these terms, defined appropriately.

[2] https://www.teach.nsw.edu.au/find-teaching-jobs/choose-rural/benefits-and-incentives

[3] The Mathematical Association of New South Wales (MANSW) is a professional association of mathematics educators that is dedicated to improving the quality of mathematics education and learning throughout New South Wales (https://www.mansw.nsw.edu.au/about-us/our-association)

[4] The term "teachers of mathematics" is preferred to "mathematics teachers' since primary school teachers of mathematics are generally not specialist mathematics teachers as is the case in secondary schools.

[5] The term 'local system context' is based on pragmatics intersections of educational jurisdictions and natural geographic and man-made boundaries (such as transportation links).

[6] Bobis, Kaur, Cartwright and Darragh (2020, p. 118) make a distinction between professional learning and professional development: PL is a more accurate term to reflect the key characteristics of reflective practice, critical thinking and continuing learning that is typical of what are considered to be effective or quality teacher learning experiences than the term PD."

[7] This view of human culture is not based in the singular popularist view of culture as, say, music, art and dancing, but a broader view of culture that aligns with Ginzberg (2017, p. 19) in his review of definitions of culture, as: "understanding of culture as an all-encompassing human phenomenon, and a more effective means for selecting the appropriate methodologies needed for the analysis of relevant questions."

[8] The definition of sustainable preferred here is adapted from Scott et al., 2018 (p. 1070); A CoP is considered sustainable if collaborative effects are continued beyond the resource (funding) allocation and timeframe and, both the CoP and/or its related effects are deemed to have value by relevant stakeholders.