Teaching Mathematics Meaningfully With Technology: A Tentative Professional Development Framework

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Abstract
Professional development initiatives for teachers regarding technology use are often based on frameworks that lack cultural responsiveness. This is a common practice in many developing countries. Consequently, teachers use technological knowledge for personal genesis. This paper introduces a tentative culturally responsive professional development framework with holistic goals for progression, interpreted from the Vygotskian perspective of knowledge progression to scientific knowledge. The tentative framework was designed through (a) a critical analysis of existing technological integration frameworks for integrating technology and (b) collaboration with secondary school mathematics teachers on the idea of meaningful technological mathematics teaching. The analysis yielded a tentative progression tetrahedron professional development framework for teaching Mathematics meaningfully in secondary schools. The study also concludes that knowledge developed through learning progresses from a person's spontaneous knowledge base to scientific knowledge. The framework aims to influence the perspectives of professional developers and mathematics educators concerning knowledge development, from the spontaneous knowledge level to the scientific knowledge level to facilitate the meaningful teaching of mathematics with technology.

Keywords: Professional Development, TPACK, Meaningful Teaching

Introduction

With the advent of technological advancement teaching and learning methods have evolved "dramatically" (Alam, 2022, p. 1). The modern learning environment demands that teachers prioritize the development of students' critical thinking, problem-solving, and analytical skills (Hıdıroğlu et al., 2021). The rise of new technologies has also led to a paradigm shift and transformation in teacher development, as teachers' competencies impact their teaching and learning processes and success (Commonwealth Business Communications Limited, 2022; Das, 2019). Scholars (e.g. Dike, 2015; Young, et al., 2020) encouraged education systems to continuously adopt innovative and imaginative ways to train and support teachers to able to deliver quality teaching in an era dominated by technologies of different kinds.

Many countries have embraced professional development goals and introduced initiatives for mathematics teachers to enhance their knowledge and awareness (Drijvers, et al. 2014; Sullivan 2012; Tabach & Trgalová 2020). Such professional development initiatives also aim to enhance teachers' capability and proficiency in using technological tools in the teaching processes. For example, in developing countries, these initiatives are pathways to improve the quality of life of people to the level of their counterparts in the developed world (Government of the Republic of Namibia, 2004). However, Tabach and Trgalová (2020) argued that there is a discrepancy between teachers' expectations and the content of these initiatives, thus calling for the development of standards and competency frameworks geared toward Mathematics. Similarly, professional development policies are too general and insufficient for mathematics teachers to teach using technology (Drijvers et al., 2014).

Notably, approximately 45% of the world's population has access to mobile technologies (Groupe Speciale Mobile Association (GSMA), 2022). However, the percentage of Africans with access to technological tools in teaching is relatively low compared to other parts of the world (Mohammed & Jamie, 2019). The implication is that any educational activities, including teachers' professional development involving the use of technologies in education, in countries such as Africa, should be responsive and ethically considerate. Learning is "context sensitive" and should be responsive to the intricacies of its context Bruner (1985, p.6). Asino (2023) concurs and argues that context matters since ignoring context "introduces cognitive noise" and "promotes the idea of not belonging". Professional development occurs in the community of practice. In addition, cultural differences affect the demands and types of professional development.

Professional development can be understood as a work activity that involves historical transformation and reorganization of the teaching process. Therefore, the objective of this paper is to

- Design a professional development framework for teaching secondary school mathematics meaningfully with technology.

Notably, this paper reports findings on the critical analysis of existing technological frameworks for integrating technology culminating into a professional development framework for teaching mathematics meaningfully.

Literature Review

Technological Pedagogical and Content Knowledge (TPACK)

Technological Pedagogical Content Knowledge (TPCK) (Figure 1) changed to the Technological Pedagogical and Content Knowledge (TPACK) framework, which builds on the Shulman theory to integrate the knowledge of technology into pedagogical practices (Garba, 2018; Thompson & Mishra, 2007). The TPACK framework connects technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) to represent knowledge of teaching content using appropriate pedagogical approaches and technologies.

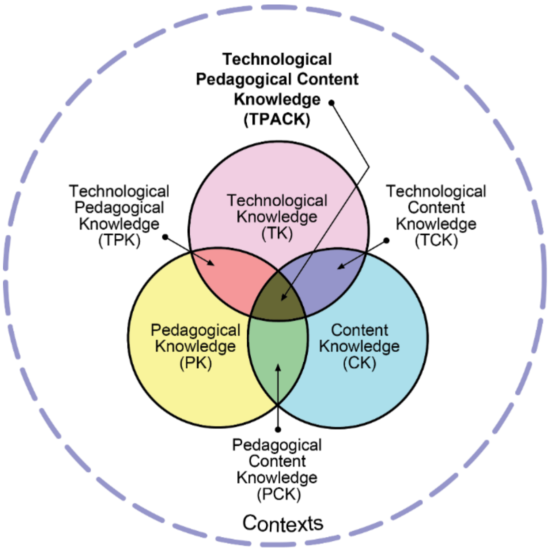


Figure 1: Components of the TPACK framework (http://tpack.org)

TPACK encompasses,

> Knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as a result of using particular technologies. (Mishra & Koehler, 2006, p. 1028)

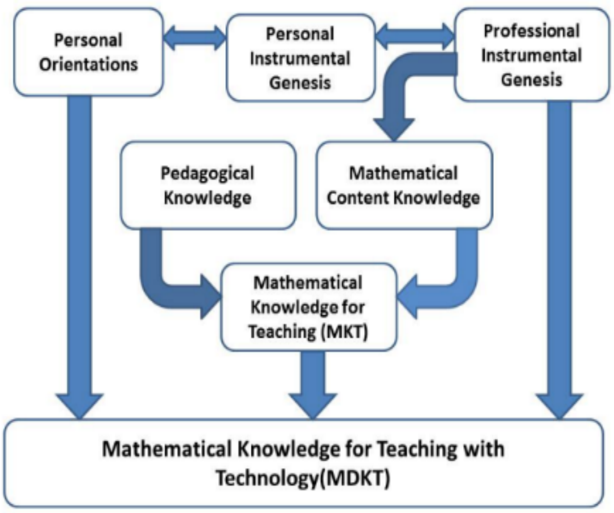
The TPACK framework is useful for thinking about how teachers might develop knowledge for integrating technology into teaching (Schmidt, et al., 2009) and designing professional development (Kadijevich, 2012). It is also believed to be a yardstick for 21st century teachers to integrate technological knowledge into pedagogical practices (Garba, 2018; Gur & Karamete, 2015; Mishra & Koehler, 2006). As a result, various studies have used it to describe and capture the essential qualities of knowledge, that Mathematics teachers need to possess to effectively integrate technology into their teaching (Çam & Erdamar Koç, 2021; Garba, 2018; Getenet, 2017; Mishra & Koehler, 2006; Niess, et al., 2009). However, Koehler and Mishra (2009) as well as Mishra and Koehler (2006) argued that since technology is rapidly changing provisions need to be made to instil pedagogical practices to help teachers cope with rapid changes. Notably, the TPACK framework is not subject-specific, even though proponents have noted that the advent of digital computers has changed the nature of Mathematics (Koehler & Mishra, 2009). Correspondingly, TPACK cannot be used as it is for professional development in relation to Mathematics education pedagogy, for technology-skilled teachers (Benson & Ward, 2013; Garba, 2018; Gur & Karamete, 2015; Harris & Hofer, 2011). However, subject teachers, such as those for Mathematics, need the skills and knowledge to select appropriate technological tools that can fit into pedagogical designs to facilitate the attainment of teaching goals.

Various studies have adapted TPACK to enhance its effectiveness in the professional development of mathematics teachers, as discussed as follows.

TPACK-Based Frameworks

The Pedagogical Technology Knowledge (PTK), an extension of TPACK by Thomas and Hong (2005) accommodates the Mathematical Content Knowledge (MCK), Mathematical Knowledge for Teaching (MKT), teachers' personal orientations, and their role in influencing goal setting and decision making. In PTK, Thomas and Hong (2005) argued that teachers advance through the phases of instrumentation and instrumentalization of resources and gain a personal understanding of the role of resources in the teaching and learning of Mathematics. In these phases, teachers' beliefs and goals regarding the significance of technology should be influenced, while developing an understanding of the essence of learning mathematical knowledge, affordances, and constraints involved, as well as the affective aspect (Jafri, 2020; Tabach & Trgalová, 2019; Thomas & Palmer, 2014).

In addition, the Mathematics Digital Knowledge for Teaching (MDKT) developed by Tabach and Trgalová (2019) expanded the TPACK and PTK frameworks. The MDKT framework was necessary, as teachers' personal orientations and personal instrumental genesis are not acknowledged as spontaneous sources of knowledge for teaching in existing models (Tabach & Trgalová, 2019). It therefore, "emphasises the decisive role played by the components of mathematical knowledge for teaching with technology that is related to teacher orientations, personal, and professional instrumental genesis" (Tabach & Trgalová, 2020, p. 201) (Figure 2).



**Tabach and Trgalová (2019) rephrased MDKT as Mathematical Knowledge for Teaching with Technology, as shown in Figure 2.*

Figure 2: Mathematical Knowledge for Teaching with Technology (MDKT) framework (Tabach & Trgalová, 2019, p.219)

Moreover, in the context of the standards-based curriculum for Mathematics, widely adopted in the USA, Niess et al. (2009) developed the five-stage Mathematics teacher TPACK standards and a development model. The model bridges mathematics-content-specific professional development and teaching and learning of Mathematics with technology (Niess et al., 2009). The authors argue that the absence of professional development in teaching technology and curriculum materials for technology integration poses the risk of not using technology-rich tasks in teaching subjects. However, the challenge with the stage levels (Niess et al., 2009) is that technology is advancing at a rapid pace. Thus, moving through the stages might not be sustainable and may delay the full implementation of technology integration in Mathematics teaching and learning as COVID-19 proved. As a result, teachers need holistic professional development. Moreover, Niess et al. (2009, p. 13) remarked on the Mathematics teacher TPACK standards and development model that “moving from one level to another may require different sets of experiences for different levels and for different teachers. What are these sets of experiences? Do experiences exist that cause teachers to regress from one level to a previous one? Do teachers skip out levels?”

Niess et al. (2009) stop short of suggesting kinds of experiences that can serve as actionable guidelines for professional development. Similarly, the digital competency of teachers’ frameworks, such as the Digital Competence Framework for Austria, Digital Competency Framework for Teachers, and UNESCO’s 2011 ICT Competency Framework for Teachers, omitted ethics concerning limited access to technological resources (Joshi et al., 2021). The frameworks on professional development for teaching with technology relate to each other, as depicted in Figure 3.

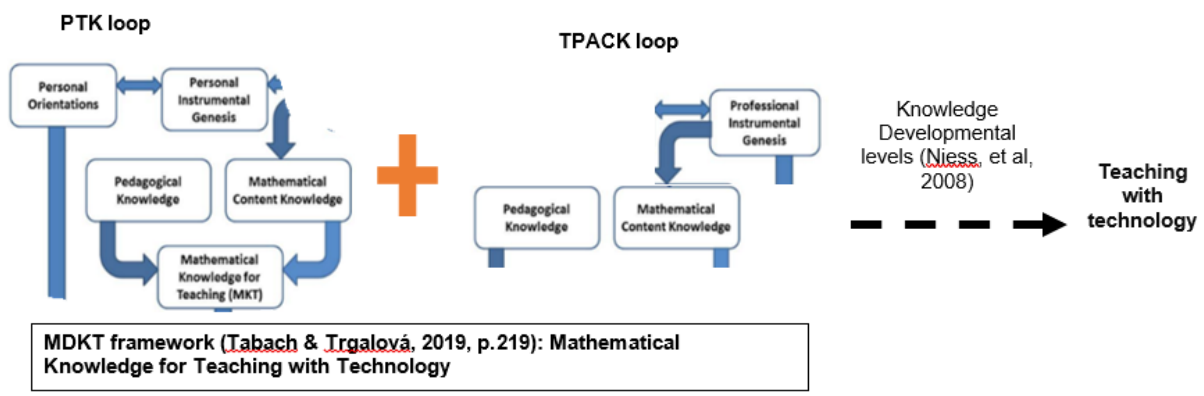


Figure 3: Relationship between TPACK and TPACK-based frameworks

Theoretical Framework: Vygotsky’s Sociocultural Learning Theory

Vygotsky’s sociocultural learning theory on adult learning argued that knowledge is socially constructed, and knowledge originates from culture. Learning occurs through experiential learning within the zone of proximal development (Chaiklin, 2003; Vygotsky, 1986). Moreover, Vygotsky (1986) argued that knowledge progresses from the spontaneous knowledge level to the scientific level. The composition of scientific knowledge are the answers to the question “What knowledge do we want the students to acquire?”. Vygotsky’s sociocultural learning theory explains that knowledge progresses from a spontaneous to a scientific knowledge level (Vygotsky, 1986). Progression refers to relating personal instrumental genesis to spontaneous knowledge and professional instrumental genesis to link scientific knowledge that professional development should aim to bridge. Spontaneous knowledge is grounded in everyday personal experiences without guidance. Scientific knowledge, however, emerges by strengthening an individual’s spontaneous knowledge and it expands through spontaneous knowledge, Vygotsky argues (Alves, 2014, p. 25):

> By forcing its slow upward trajectory, an everyday concept paves the way for scientific concepts and their descendant development. It creates a series of structures necessary for the evolution of the most primitive and elementary aspects of a concept, giving it a body and vitality. Scientific concepts, in turn, provide structures for the upward development of spontaneous concepts in relation to consciousness and deliberate use by the child [adults].

Vygotsky's description of learning regarding a child is similarly interpreted as an adult learning process in terms of professional development. This is because adult learners' learning is similarly characterised by structures and purpose which consider their preferred ways of engaging and social dimensions (Blair, 2016). The implication of Vygotsky's views as quoted by Alves (2014), may mean that scientific knowledge requires other knowledge to expand. It might also imply that development from the spontaneous knowledge level to the scientific knowledge level proceeds through progression levels. Notably, scientific knowledge can also emerge from the context of related theories and frameworks (Alves, 2014). Scientific knowledge is structured, formally organised, and defined in this paper in terms of Kilpatrick et al. (2001) and technology frameworks. Vygotsky holds that cognitive development happens through learning, and there should be development after learning, thus learning is development.

Implications for Designing a Professional Development Framework

Professional development designs seem under researched; researchers define professional development according to TPACK. The reviewed frameworks for professional development on teaching with technology uniquely offer an opportunity to interpret and understand the knowledge teachers need to be able to integrate technology into teaching. The generic TPACK (Mishra & Koehler, 2006) without linking to subject pedagogy runs the risk of knowledge being used for personal genesis instead of professional genesis in the classroom. This knowledge may also take time to develop into professional instrumental genesis. As a result, technology would be substituted (Puentedura, 2010) as an efficiency tool. Moreover, all existing frameworks reviewed have no explicit guidelines for professional development focusing on teachers' use of technology to promote integrated and relational understanding of Mathematics, as well as reasoning and problem-solving. Further, teachers' personal instrumental genesis and professional instrumental genesis are more about teachers' decisions on using technology tools. These decisions are mainly left to the teachers' initiatives without guidelines. This resonates with Neubrand (2018) who argued that knowledge-driven frameworks are limited as there is a ‘‘gap between knowing and acting’’(p. 609). Likewise, Tabach (2021) argues that,

> One can know a subject but may not have the skills required to apply that knowledge to specific tasks since knowledge does not provide skills. A teacher may know Mathematics and pedagogy, but this only makes her knowledgeable about teaching. However, knowledge [alone] does not make one a good practitioner. To become a good teacher one must teach, practice one's techniques, and improve one's skills… (p. 100)

The implication is that professional development should have actionable guidelines, be sustainable, consider ethics in terms of access to technological resources, and Mathematics teaching goals should be explicitly stated. Further, professional development should be holistic and progressive from teachers' spontaneous knowledge to scientific knowledge level.

Moreover, Vygotsky (1978) argued that all knowledge develops from a person's spontaneous knowledge base and scientific knowledge is developed through learning. However, most TPACK-based frameworks (Mishra & Koehler, 2006; Tabach & Trgalová, 2019; Thomas & Palmer, 2014) seem to suggest that spontaneous knowledge is already scientific knowledge, even though some acknowledged that Mathematics teachers' TPACK progresses through developmental levels (Niess et al., 2009).

Methodology

The tentative framework was developed in a doctoral design-based study, from which this paper is extracted. This was done through (a) a critical analysis of existing technological integration frameworks for integrating technology, and (b) collaboration with secondary school mathematics teachers on the idea of meaningful technological mathematics teaching. Mathematics teacher participants of interest were identified through the snowball sampling method (Cohen et al., 2007; McKenney, 1987). Senior education officers for Mathematics at regional professional development sub-divisions helped to locate teachers who took the initiative and responded to the ministerial call to use technology platforms such as YouTube channels, WhatsApp, and Google classrooms to teach mathematics during the pandemic lockdown. Nine participants participated in this study. The data were triangulated through two phases of a design-based research study, using two online questionnaires and two focus group interviews to enhance the trustworthiness of the data. This paper reports on the critical analysis of existing technological frameworks for integrating technology. Ethical clearance to conduct the study was given by the Stellenbosch University research ethics committee.

Conclusions

Findings and Discussions

The reviewed frameworks for professional development on teaching with technology uniquely offer an opportunity to interpret and understand the knowledge teachers need to integrate technology into teaching. The generic TPACK (Mishra & Koehler, 2006) is viewed as formed by four flat-interconnected permeable triangles (Figure 4). The triangles represent content knowledge, pedagogy knowledge, and technology knowledge. The infusion of technology, pedagogy, and content knowledge (TPACK) is represented by the triangle at the centre. The positions of technology, pedagogy, and content knowledge in figure 4 are of no importance, however, the triangle at the centre will always represent the infusion of content knowledge, pedagogy knowledge, and technology knowledge to form TPACK. The triangles are permeable (shown with dotted lines) to imply that knowledge infuses within knowledge triangles and influences an individual's ability.

Figure 4: TPACK conceptualisation

The generic TPACK (Mishra & Koehler, 2006) without linking to subject pedagogy runs the risk of knowledge being used for personal genesis in the classroom which may take time to develop into professional genesis. The role of curriculum, teachers' views and beliefs, ethics, and professional development play a greater role in the design of professional development. The teachers' personal orientations towards technology (the affective domain) as well as teachers' personal instrumental genesis are spontaneous sources of knowledge for professional development. This creates space to propose that teachers' TPACK is situated within ethics, personal orientations, and the Mathematics curriculum (context) (Figure 5).

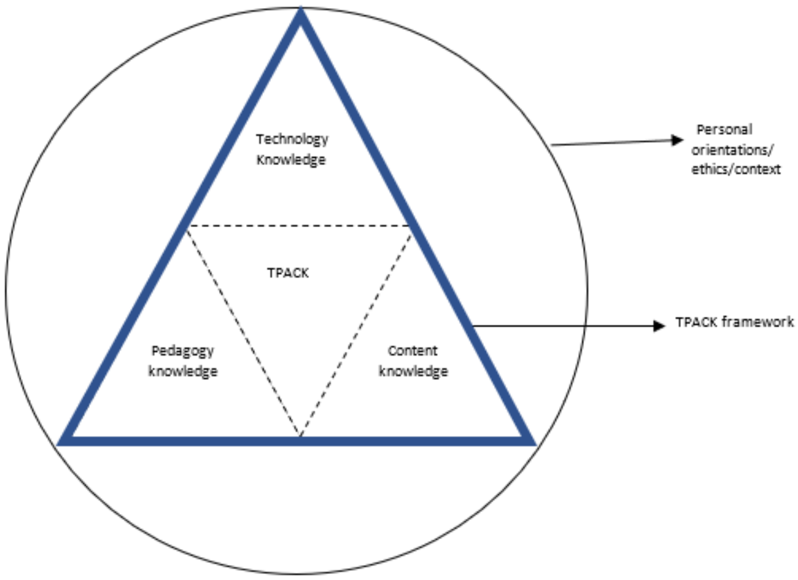


Figure 5: Infusion of TPACK within an individual personal orientation

A professional development session on any of the knowledge areas of the triangle will certainly lift it and influence the knowledge set of an individual. An individual's knowledge triangles also expanded from university training, the workshops, and any professional development the teacher received as per the study findings. When an individual grows in all knowledge areas through professional development in teaching Mathematics meaningfully, the triangles "wing up" and form a tetrahedron (Figure 6).

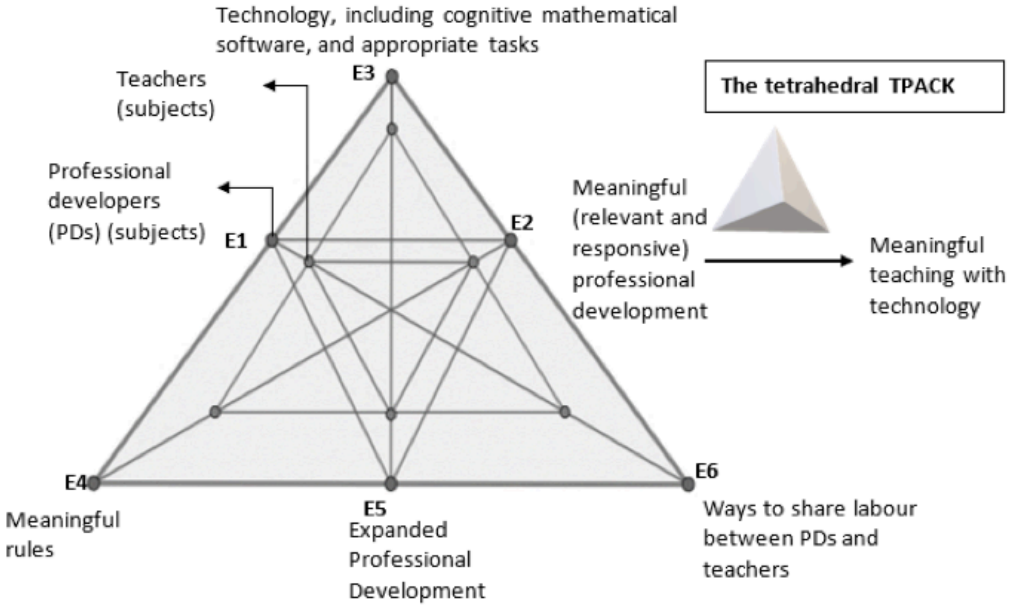


Figure 6: A combination of an expanded relationship between professional developers' and Teachers' activity systems, and tetrahedral TPACK

Taking cognisance of teachers' views and beliefs, their professional development needs, and the role of curriculum in the design of professional development, the researcher needed to know how knowledge develops in such a situation. Vygotsky (1978) argued that all knowledge progresses and develops from a person's spontaneous knowledge base and scientific knowledge is developed through learning. However, most TPACK-based frameworks (Koehler & Mishra, 2009; Tabach & Trgalová, 2019; Thomas & Palmer, 2014) seem to suggest that spontaneous knowledge is already scientific knowledge. Furthermore, the findings showed that teachers have some sort of spontaneous knowledge. The CHAT states that knowledge develops from the bottom up so that expansive learning can occur (Engeström, 2001).

Consequently, a holistic and sustainable professional development for developing Mathematics teachers' knowledge to teach Mathematics meaningfully with technology in Namibian schools, progresses through three levels (Figure 7). At each level, professional development should holistically influence Mathematics teachers' personal orientations and personal instrumental genesis for professional instrumental genesis. The knowledge is also not static but keeps changing according to the changes in technology and in the answer to "What knowledge do we want the students to acquire?". The levels are presented bottom-up with expansive learning and idealised design notions in mind. The ideal Mathematics teacher to teach Mathematics meaningfully with technology is one at the scientific knowledge level (level 3). The findings of the study allowed us to describe spontaneous knowledge level (level 1). The strategic knowledge level (level 2) and scientific knowledge level (level 3) were described theoretically (Figure 7).

Level 3: Scientific Knowledge Level – This is idealised knowledge of teaching Mathematics meaningfully with technology. Through structured professional development, professional developers should develop teachers to teach Mathematics meaningfully with technology to be able to:

- Influence, participate, expand, or adapt Mathematics curriculum and pedagogy when cognitive technologies become available;

- Expand or adapt applications of technology that make Mathematics meaningful for pedagogies for changes in the Mathematics curriculum;
- Carry out research as new problems and demands arise in Mathematics and technology education;
- Develop professional development interventions on different scales in different communities, e.g., develop ways to improvise where access to technologies is problematic;
- Imagine and enact ways to overcome problems of access to technology for Mathematics; and
- Reflect critically on new information about how people with technologies think and reason.

Level 2: Strategic Knowledge Level – At this level, a community of Mathematics teachers may emerge whose spontaneous knowledge has expanded. These Mathematics teachers can be co-demonstrators applying skills and knowledge and amending existing knowledge. These Mathematics teachers should have fully implemented learned skills and knowledge and have extracted the maximum benefits of knowledge learnt. Through structured professional development, professional developers should develop teachers to teach Mathematics meaningfully with technology to be able to:
- Apply mathematical pedagogies with an understanding of what technology is suitable for;
- Co-demonstrate and lead mathematical pedagogical processes with technologies to a larger extent; and
- professionally guide meaningful exploration with and without technology.

Level 1: Spontaneous Engagement and Knowledge Level – Professional development at this level was imagined and developed based on the teachers' views. Through structured professional development, professional developers create a zone of proximal development of mathematical opportunities (e.g., mathematical tasks) and various technological pedagogical environments. The opportunities should afford Mathematics teachers knowledge for teaching Mathematics meaningfully with technology to:
- Reflect on and imagine the implications of the Mathematics curriculum and teaching with technology;
- Yearn to know how technology works, by allowing their desire and their professional development needs to teach Mathematics meaningfully with technology to drive their quest;
- Develop Mathematics teachers' ability to "marry" technology to mathematical concepts;
- Engage in critical review and analysis of both representational and cognitive technologies;
- Engage in mathematical tasks that will result in expanded demand to reason, justify with technologies to others through social or sharing; and
- Experience expanded conceptual knowledge, and improved attitudes, interest, and enthusiasm.

Hence, professional development developers should carefully facilitate the development of knowledge for teaching Mathematics meaningfully with technology by flexible demonstration. The professional development developer hugely stimulates meaningful teaching with technology conversations. The professional development developer also plays both roles to solidify teaching conceptions and strengthen them.

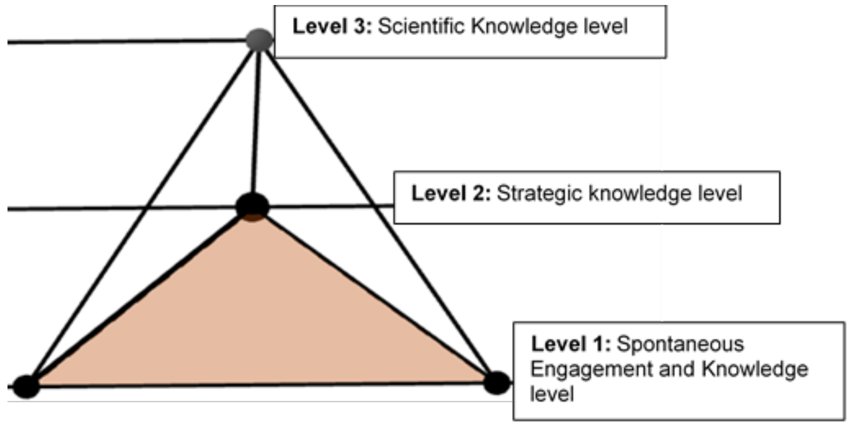


Figure 7: The progression tetrahedron for a professional development framework for teaching Mathematics meaningfully in Namibian secondary schools

The progression tetrahedral of a professional development framework for teaching Mathematics meaningfully holds teachers' practices and beliefs for teaching which have levels. Professional development engagement throughout the levels is structured. Consequently, a professional development framework for teaching Mathematics meaningfully with technology in Namibian secondary schools (Figure 8) is a culmination of (a) design principles, (b) an expanded relationship between professional developers' and Teachers' activity systems, and (c) the knowledge progression tetrahedron. The culmination ends with a framework (Figure 8) with the desired outcome of teaching Mathematics meaningfully with technology.

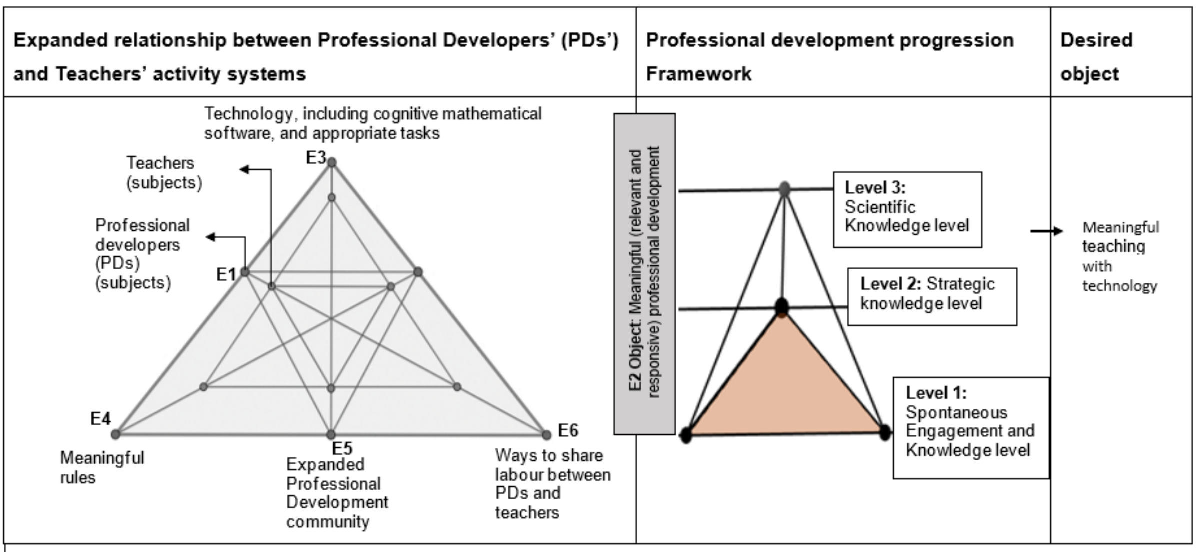


Figure 8: The professional development framework for teaching Mathematics meaningfully with technology

Implications and Limitations

In conclusion, knowledge develops from a person's spontaneous knowledge base and scientific knowledge is developed through learning for expansive learning to occur. The holistic and sustainable professional development for developing Mathematics teachers' knowledge to teach Mathematics meaningfully with technology in Namibian schools should progress through three levels. The knowledge progression tetrahedron is not fixed nor static but keeps changing with the changes in technology and in answer to *“What knowledge do we want the students to acquire?”* The levels are presented from the bottom up with expansive learning and idealised design notions in mind but acknowledge and develop from the spontaneous knowledge level. We suggest that any professional development framework for meaningful teaching with technology should engage with curriculum rules and be structured. The study cannot make fully conclusive and empirical statements due to pandemic restrictions. Thus, ending with a framework with tentative status. In future research, the framework must be implemented in professional development where it can be evaluated.

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