

Exploring Mathematics Teachers' Professional Development: Embracing the Fourth Industrial Revolution

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Abstract Exploring aspects that promote teachers' professional development is the key to improve and sustain teachers' development at universities. Additions to Curriculum and Assessment Policy Statement documents together with our entry into the Fourth Industrial Revolution require a transformation in teachers' pedagogy. To equip learners with 21st century skills, it is quintessential for teachers to keep abreast with new educational trends, pedagogies and its accompanying pedagogic tools. We therefore argue that teachers' professional development serves as leverage for teachers to embrace new pedagogies, innovative practice and create learning opportunities. This study, which explored mathematics teachers' professional development within the Fourth Industrial Revolution at a university in Kwa Zulu Natal, embraced a qualitative approach. The study was framed using Koehler and Mishra's technological pedagogical content knowledge framework. Data was generated from 24 participants via workshops, a questionnaire and semi-structured interviews. Data analysis employed thematic coding. The findings provide a glimpse of what is valued, enabling or constraining mathematics teachers with respect to their professional development. Globally, these findings provide new insights on mathematics teachers' professional development experiences and needs in terms of blended teaching and learning with regard to data handling, data coding and analytics in preparation for the fourth industrial revolution.

Keywords Mathematics, Teacher Professional Development, Technology, Fourth Industrial Revolution

1. Introduction

As we embrace, the Fourth Industrial Revolution (4IR) there are debates on how the various technologies associated with the 4IR may be used: Firstly to address the challenges encountered by citizens of Africa such as exacerbating poverty, inequalities, famine and lack of proper housing and secondly to equip learners with 21st century skills needed in an evolving job market. In addressing these concerns, it is critical for learners to have access to teachers who are au fait with the innovative application of technology and can equip learners with skills needed for the evolving career and job landscape. If there is no balance between the current and the future in terms of curricula, skills development or teachers' adaptability, then neither teachers nor learners will be 4IR ready.

Teachers are ideally positioned to equip learners with 21st century skills needed to address the challenges encountered by Africa's citizens. To be able to facilitate the development of 21st century skills among learners, techno-savvy pedagogies are required to foster in learner critical thinking, complex problem solving, effective communication and collaboration, and self-direction. To equip teachers with the necessary techno savvy pedagogies, effective professional development is needed. Scholars such as Borko, [1] and Darling-Hammond [2] argue to bring about change in practice, schooling and learning outcomes. Teachers' professional development and learning is key. This paper elucidates the findings of a study that explored mathematics teachers' professional development to embrace the Fourth Industrial Revolution. The paper is organised in six sections, namely, introduction, literature review, theoretical considerations, research methodology, presentation of findings and discussion and lastly conclusion.

1.1. Literature Review

This section focuses on three aspects, the Fourth Industrial Revolution, professional development and teaching with technologies.

1.2. Fourth Industrial Revolution

While the first, second and third revolutions were driven by steam power, electricity and electronics (computers and internet), 4IR is driven by artificial intelligence (AI), which refers to computers that can “think” like humans, recognising complex patterns, processing information and drawing conclusion, big data, robotics and the internet of things. In other words, the Fourth Industrial Revolution interfaces the physical and virtual world. This interface allows for global innovation and the flourishing of an interconnected economy. Previously co-workers and learners sat at desks alongside each other to collaborate. However, in the 4IR virtual, global collaborations is just a zoom meeting or google search away.

According to Schwab [3], the Fourth Industrial Revolution is a technological revolution that has altered our very being in terms of how we live and work. Key to the 4IR is the reality that the youth of today will no longer start a career path or grow in one role, roles will change regularly. Moreover, within the 4IR the most important skill by far is the ability to (re)learn in order to navigate the major technological, environmental, economic and societal changes. The 4IR affects the roles that universities and colleges play in preparing youth for the workforce for this new world. The critical question, therefore, is whether schools are preparing the youth to apply these key characteristics in the workplace along with the digital skills needed to face the future.

1.3. Professional Development

Teachers' professional learning is necessary to develop the key critical 21st century skills learners require to navigate their way through the 4IR--a critical way to support the increasingly complex skills learners need to learn in order to succeed in the 21st century and the 4IR. Teachers' professional learning can occur in formal and informal settings. Formal settings according to Timperley [4] include professional development programmes, teaching research group and formal mentoring programmes while informal settings include peer teaching, collaborative planning, and mentoring between colleagues [Little,5]. In whatever form teachers' professional learning may occur, evidence suggest that professional development is best when it is entrenched in teachers' specific subject areas [Darling-Hammond et al.,6]

Avalos [7] and Yoon et al. [8] assert that over the last decade there has been an interest in mathematics teachers' professional development and its resultant effect on teachers' learning and learners. To elaborate reference is

made to Liang et al. [9] cross sectional study that explored fourth and eighth grade mathematics teachers' participation in professional development and its influence on learners' achievement. These scholars' findings confirm the positive relationship between teachers' professional development (that focuses on Mathematics content, pedagogies, use of technology to develop 21st century skills as well as knowledge of the curriculum) and increase in learners' achievement in Mathematics.

Likewise, Unal et al. [10] analysed data from the TIMSS 2007 test, of participants from Turkey, and concluded that mathematics teachers' professional development impacted learners' performance positively. Studies by Kwon and Ju [11] and Desimone [12] report on the positive correlations between teachers' professional development / learning and learners' achievement. The above studies highlight the importance of teachers having deep content knowledge, appropriate pedagogies, in-depth knowledge of the curriculum and learners.

1.4. Use of Technologies

Technology has been used to facilitate learners' learning for decades and thus forms an indispensable tool in the classroom. Teaching and learning with technologies is fast becoming a norm in most schools, OECD [13]. The types of technologies available to teachers as their daily teaching resources are evolving rapidly, for example, mobile laptop computers, tablet devices and smartphones now as part of the educational context.

Learning with technologies provides learners with important grounding for later in life. Even though many learners have been born in a digital era, many of them are not competent or skillful users of technology Bennett [14]. Hence, it is important for learners to be technology savvy and technology literate to be able to participate in society using different modes of communication OECD [13]. Thus it is necessary to integrate technology into teachers' pedagogy and the learning process. Presently, technology is regarded as being distinct from teaching and learning and professional development workshops generally explain how to use technology but not how and when to embrace technology within classrooms. Hence, there is a need to create learning opportunities for teachers to embed technology into their pedagogy.

1.5. Theoretical Considerations

As we embrace the 4IR, employing technology-based pedagogy is essential in that it provides teachers with various approaches that accommodate different learning styles within an educational context. Moreover, when technology-based pedagogy is integrated credibly into mathematics classrooms, it is beneficial in delivering content Joshi [15]. Within the context of this study, pedagogic strategies that include the use of computers,

web-based technology, the internet and the use of Information and Communication Technology (ICT) are regarded as technology-based pedagogy.

However, one must concede that while there are many challenges associated to the use of technology-based pedagogy, technology-mediated research is an emerging domain within education Dunne [16]. Since technology is used as a tool for pedagogy Qing [17], teachers' knowledge, discussion and engagement are essential to ensure that technology-based tools are used applicably. Similarly, Mishra and Koehler [18] proposed that new technologies extend both opportunities and challenges for teachers.

Thus, when using technology-based tools, a teacher ought to be efficient at using these tools successfully within their educational context. Knowing how to use appropriate technology-based tools to facilitate the learning of content is known as technological pedagogical content knowledge (TPACK) Koh [19]. The basis of this framework is that teaching is multifaceted and necessitates numerous categories of intersecting knowledge as illustrated in Figure 1.

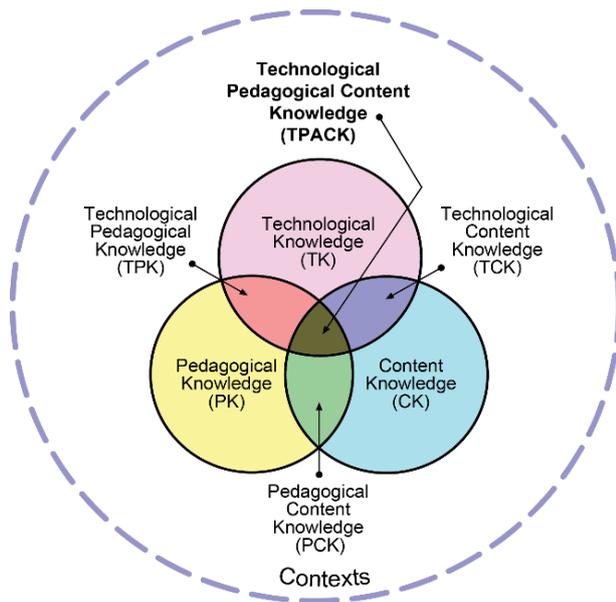


Figure 1. The TPACK framework. Adapted from20 Koehler, Mishra, Akcaoglu and Rosenberg,(2013, p. 3¹) [20]

The concepts within the TPACK framework as defined by Mishra, and Koehler [18, p. 63] are theorised in this study as follows: Content Knowledge is knowledge of the mathematics concepts (for example statistics with respect to data handling, data coding and analytics) that were discussed during the workshop. Pedagogical Knowledge is knowledge of how to teach data handling, data coding and analytics for effective learning. Technology knowledge is knowledge about the technology-based tools that were used during the workshops. These technology-based tools

included the document camera, the laptop, the data projector and the smart phone. Pedagogical Content Knowledge is knowledge of pedagogy for teaching data handling, data coding and analytics; Technological Content Knowledge is understanding which technology-based tools are appropriate for the teaching and learning of data handling, data coding and analytics. In other words, it is Technological Pedagogical Knowledge that is the knowledge essential for understanding the challenges and strengths of using technology-based tools. In other words, it is knowledge about teaching mathematics concepts with specific technology-based tools (the document camera, the laptop, the data projector and the smart phone) effectively.

Thus, the TPACK framework undergirded this study which explored participants' knowledge development as they interacted during the workshops. During the workshops, the participants were engaged with tasks which were designed to advance both mathematics content knowledge, pedagogical knowledge and technological knowledge. Thus, the TPACK framework was embraced to understand the types of knowledge that the teachers were accessing during the workshops to develop, support and advance their professional development.

2. Research Methodology

This qualitative study which sought to explore mathematics teachers' professional development to embrace the Fourth Industrial Revolution (4IR) was located within an interpretive paradigm. Data was generated using interactive workshops, questionnaires and semi-structured interviews.

2.1. Ethical Issues

Permission was sought from the participating university's research office. Participants were provided with an informed consent form detailing the purpose and process of the study. They were informed of their right to withdraw from the study, the duration of the interviews and that the interviews were to be audio recorded. Furthermore, the anonymity and confidentiality of participants were guaranteed using pseudonyms. Each participant was assigned a code 'P' representing Participant and a number.

2.2. The Participants

The population for the study were Bachelor of Education Honours, Masters and Doctoral mathematics education students registered at the participating university. In total there were 38 students who registered to pursue postgraduate studies in mathematics education. All participants were mathematics school teachers. Of the 38 postgraduate students who were invited to participate, only 29 accepted the invitation to participate in the study. Five

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of the 29 participants were randomly selected for the pilot study. Data was generated through workshops, a questionnaire and semi-structured interview schedules.

2.3. The Pilot Study

A pilot study was undertaken to ensure the validity and reliability of the research process and the research instruments. Conducting the workshops and administering the questionnaire during the pilot study increased validity and reliability since aspects of the workshop and questionnaire were modified. For example, through the pilot study it was observed that there was an error during the demonstration for the second workshop. Thus, this led to the modification of this demonstration. In addition, some participants in the pilot study were uncertain of what was required for certain questions on the questionnaire. Subsequently, questions were rephrased to eliminate ambiguity and to ensure that each question was clear. The language used was clear, simple and specific to enhance reliability.

2.4. The Research Process and Tools

2.4.1. Workshops

Two workshops were conducted with 24 participants. These workshops were facilitated by the researchers and held on two Saturdays during the first semester of the 2018 academic year.

The workshops focused on:

1. Exploring blended teaching and learning during data handling the mathematics classroom
2. An introduction to data coding and analytics.

At each workshop, participants had access to teaching notes, sample lesson plans, sample assessments and demonstrations of how technology-based pedagogy could be embedded effectively within mathematics classrooms in order to embrace the 4IR. Participants were informed at the end of the second workshop in 2018 that they would be invited to complete a questionnaire on what they have learnt during the workshop. The questionnaire was designed to gain insight into the pedagogical occurrences in each participants' classroom after they had participated in both workshops.

2.4.2. The Questionnaire

Subsequently, a questionnaire comprising of three sections was distributed to the 24 participants. Section one and two paid attentions to the profile and the infrastructure of the schools at which each participant taught, in order to identify the context and social background of each school.

The third section of the questionnaire concentrated on each participant's profile, to ascertain the experience and exposure each participant had with respect to embracing the 4IR. Biographical data with regard to each participant's training, qualifications with respect to using

technology-based tools in the classroom, professional development, professional bodies to which each participant belonged was sought in section three. The above information was considered important for re-envisioning the curriculum for teachers' professional development and preparation at institutes of Higher Education.

Although 24 participants attended the two interactive workshops, only 15 of the 24 participants who completed and handed in the questionnaire were willing to be interviewed. The 9 participants who did not submit the questionnaire cited high workloads, inability to balance study, work and family commitments as factors that prevented them from participating in the study. Consequently, these 15 participants were interviewed using a semi-structured interview schedule.

2.4.3. The Semi-Structured Interviews

All interviews were audio recorded and transcribed verbatim. Transcripts were sent to participants to ensure the accuracy and validity of what was stated during the interview. This is known as member checking. The interviews allowed for the probing of questionnaire responses and to gain insights on each participant's professional development to embrace the 4IR. The duration of each individual interview was 45 minutes. Interviews were schedule to suit the participants' availability.

2.5. Data Analysis

All data generated was read and re-read many times before coding could begin. Open coding was used to analyse the data. The purpose of this type of open coding was to reveal unanticipated insights from participants focusing on their professional development to embrace the 4IR. Secondly, all codes were re-examined across data set to note each participant's professional development. Finally, the convergences and divergences between the participants' responses were noted.

3. Presentation of Findings and Discussion

The majority (80%) of the participants utilised technology-based tools for the effective teaching and learning of mathematics in their classrooms. This alluded to the notion that they felt empowered to embrace the 4IR. Based on the interview responses, the participants who did not use technology-based tools in their teaching (20%) attributed this to the lack of facilities and resources at their schools. The participants (P3, P9 and P13)² stated that the

² Codes were assigned to each participant to ensure anonymity of the participants. Each participant was assigned a number from 1 – 15 as they submitted their completed questionnaires: P 3: Participant 3, this was the third of the fifteen participants who submitted their completed questionnaire. P 9: Participant 9, this was the ninth of the fifteen

absence of resources and facilities did not allow them the freedom of choosing to use technology-based tools in the classroom. Two major themes emerged from the analysis of interviews and questionnaire responses, namely transformation of pedagogy and reflective practice.

3.1. Transformation of Pedagogy

Based on the data analysed, the participants indicated that participating in the workshops allowed them the opportunity to transform their pedagogy within their classrooms. Two categories emerged within the theme of Transformation of pedagogy:

- Reorganising existing pedagogy
- Acquiring new knowledge and improving pedagogy

3.1.1. Reorganising Existing Pedagogy

Reorganising existing pedagogy requires teachers to be active in the learning process, to learn through the same methods they will be using with their learners, and to engage in collaborative inquiry and reflection. All the participants indicated that they had to shuffle their pedagogy when teaching mathematics is visible in the excerpts from the interview:

P1: *...as a teacher of maths I felt I always had to be in charge ... my voice was important ... after this workshop I see myself as a facilitator. I know how to use the phone to teach ... letting go of control was hard ... using the smart phone to teach data handling helped ... it allowed learners the opportunity to take control of their learning...*

Similar views were expressed in the questionnaire.

P5: *... I realise with a bit of effort on my part and by incorporating tablets ... smart phones in my teaching ... learners can take ownership ...activities and learning... I notice...learners actually complete their tasks timeously. This hands on workshop allowed me to accept... technology confidently in my teaching of math.*

The excerpts above reveal that when teachers are provided with the opportunity during professional development programs with experiences in learning mathematics with the technology and if they are further provided the opportunity to model teaching with the technology, then they can be confident to implement the ideas in their own classrooms. The above finding concurs with that of Darling-Hammond and McLaughlin [21] who maintain that teachers need to learn through the same methods they will be using with their learners during professional development. What is of importance is the ability to use technology effectively, consequently,

teachers ought to be provided with professional development workshops so that they have adequate TPACK.

3.1.2. Acquiring New Knowledge and Improving Pedagogy

Mathematics teachers' professional learning due to their engagement in a hands- on professional development workshop helped to transform their instructional practice in ways that support learners' learning as is visible in the excerpts below:

P3: *...the sense making activities during the workshop helped me focus on the content to be taught ... I engage in the same learning activities designed for learners, it got me thinking ... how best to get the information across to the learners ... my role was changed... this kind of workshop is really useful as I am improving my content and teaching strategies ... I'm thinking about how I teach...*

Equally, corresponding views were noted in the questionnaire response:

P7: *...this workshop...helped me with teaching mathematics with technology ... improved my instructional strategies for teaching mathematics with technologies; knowledge of learners' learning in mathematics with technology; and knowledge of curriculum ... curricular materials that integrate technology. I now think about my teaching ...*

The above excerpts reveal that active professional learning during professional development resulted in desirable changes in teachers' practice in terms of content knowledge, instructional strategies and the use of technology to enhance learners' learning of mathematics. Furthermore, it afforded teachers firstly the same hands-on learning opportunity as their learners and secondly to anticipate the kinds of thinking or challenges learners will engage in or encounter. Buczynsk. and Hansen's [22] study supports the above finding. Buczynski and Hansen [22] describe how 4th through 6th grade teachers had the opportunity to participate in *constructivist, hands-on experiences* using science kits, which teachers would then go on to use in their classrooms with their learners. The teachers who practiced *teaching* with their peers were better able to understand learners' thinking and their learning, thereby improving their pedagogy. Kleickmann et al [23] found that teachers who engage in collaborative active professional learning that focuses on integrating technology to facilitate the teaching of difficult concepts facilitate learners' learning and consequently their learners' achievements. A key aspect of improving pedagogy was that teachers started to think about their teaching. They were starting to reflect on their practice.

3.2. Reflective Practice

Based on an analysis of the data, the participants

participants who submitted their completed questionnaire. P 13: Participant 13, this was the thirteenth of the fifteen participants who submitted their completed questionnaire.

indicated that participating in the workshops allowed them the opportunity to reflect on their practice in the classroom. Reflective practice in the classroom entails that teachers reflect on their action to engage in a continuous learning process. Reflective practice plays an essential role in teachers' professional development Kleickmann et al [23] and requires that teachers think carefully about their own experience while undergoing professional development Mathew et al. [24].

Based on an analysis of the data three categories emerged within the theme of Reflective practice: The use of technology-based pedagogy:

- created an interactive and relevant educational context
- created a practical approach to deliver content
- created learning opportunities that are continuous and ubiquitous

3.2.1. The Use of Technology-Based Pedagogy Created an Interactive and Relevant Educational Context

The participants indicated that using technology-based tools created an interactive context which was relevant to their learners. By using technology-based tools, the participants indicated that teaching and learning became more collaborative and relevant. Similarly, Schön [25] maintain that technology-based tools enable learners to communicate effectively within their educational context. In addition, the participants indicated that learners would be able to identify with their use of a smart phone during lessons. These sentiments are reflected below:

P2: *...interesting to see how relevant the maths is when using technology...looking back at my teaching... technology will help my lessons become more enjoyable...the class will collaborate and talk more...they relate to this technology...*

P4: *...when we use the cell phone...the lesson is more relevant to the learner...they know what to do...they can share...learning will be more interesting and fun for them...*

P15: *...this is the first professional development workshop I have attended...I can see how using technology in the class makes the lesson more interactive...my friends told me...I didn't believe it...I will need to change my belief now...I need to get more support...*

Similar ideas were reflected in the questionnaires. Participant 15 indicated that through reflecting on his practice, he was willing to change his attitude towards using technology in the classroom, but he needed more professional development to help him. Thus, it is important that teachers are provided with support to improve their TPACK as they embrace the 4IR. Along similar lines, Ojo, and Adu [26] maintains that the incorporation of technology into educational contexts ought to be supplemented by continuous reflection.

3.2.2. The Use of Technology-Based Pedagogy Created a Real-World Approach to Deliver Content

The participants were of the opinion that using technology-based pedagogy, the mathematics content was delivered in a more realistic way. The use of technology-based tools allowed the teachers to reflect on their practice to include real-world contexts and examples. This is reflected in the interview data that follows:

P8: *...when I tried this in my class...allowed me to search for real examples to show learners...they could identify with the maths...it allowed for meaningful learning...*

P9: *...this is my first workshop of this kind ... made me think about how I teach...I need to change my attitude about using technology...we don't have projectors at school...but I can now use a video on my phone and show learners examples of sampling and how to arrange real examples of data into categories...*

P13: *...I don't use technology in my teaching...we don't have access to technology at school...but I think I need to change how I do things...I can use my phone...my class can see how maths is real...I can use real world examples...technology makes it easy to do this...the workshops made me rethink what I do in class...*

These sentiments were also echoed in the questionnaires. Additionally, the participants indicated that as the workshops progressed, they continuously thought about their own educational contexts and how they would apply what was being demonstrated in each workshop within their own classrooms. Similarly, the use of technology-based pedagogy is about thinking about and constructing real world contexts in meaningful ways to improve knowledge production and understanding of concept Cloete, [27]. We also need to concede that access to technology (for example P9 and P13) may create concerns with using technology-based tools Ojo and Adu [26], however, the issue of TPACK is of importance Montrieux et al. [28]. We ought to support teachers by continuously providing professional development to support them as they embrace the 4IR.

3.2.3. The Use of Technology-Based Pedagogy Created Learning Opportunities That Are Continuous and Ubiquitous

The participants indicated that using technology-based tools created teaching and learning opportunities that could be continuous and ubiquitous. This is evident in the interview transcripts that follow:

P6: *... maths problems could be found on the net...I can use this in my teaching... and my learners can get this at any time ... they don't need to be in the class...*

P8: *...by using technology ... learning can take place all the time ... any time or place...and my learners can continue learning even without me...*

P11: *...I could have tried this earlier...I heard about*

AMESA³ providing support to teachers...I am not part of AMESA...technology makes a huge difference...teaching and learning can take place all the time...

P13: ...this would be perfect if we had these tools at school...but I am going to use my own phone to teach...I am going to show my learners how to use phones at home to get information...whenever they need help...

P15: ...I know other teachers who use this...I never knew it would help...I will start trying by using my phone to show my class...this will help with teaching and learning...with our phones we don't have to stop learning...

Similar responses were noted in the questionnaires. Similarly, using technology-based tools which may be used in and out of the classroom, the traditional textbook is not needed. Finger et al. [29]. Instead, learners may be directed to carefully selected online resources where they may find contemporary, applicable and stimulating resources and exercises to scaffold their understanding of fundamental concepts. Using technology-based tools, learning can take place at any time and any place, Schön [25], learning is continuous and ubiquitous. However, to ensure that teaching and learning is effective within a technology mediated educational context, the teacher ought to have adequate TPACK Montrioux et al. [28].

4. Conclusions

The use of technology-based pedagogy is part and parcel of the teaching and learning process within the 21st century, more so as we embrace the Fourth Industrial Revolution (4IR). Our findings reveal that most participants used technology-based tools for effective teaching and learning of mathematics in their classrooms. The overall aim of the article was to illustrate mathematics teachers' professional development as they embraced the 4IR. Based on an analysis of the data generated, mathematics teachers transformed their pedagogy which necessitated a reflection on their practice. Our findings highlight that mathematics teachers value constructivist hands-on professional development workshops as opposed to information dissemination workshops. This particular finding has implications for policymakers with regard to what quality, hands-on teacher professional learning looks like. Policy can help support the kind of evidence based on professional development described in this study. Furthermore, participants indicated that they required support with using technology-based pedagogy effectively within their educational context. This implies that teachers'

professional development workshops focusing on TPACK is necessary.

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