COVID-19 Pandemic as A Catalyst for Fostering Reformed Pedagogy in Science Education

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Abstract

The study examined the role of COVID-19 pandemic as a catalyst for fostering reformed pedagogy in science education within the South African context. The prevalence of COVID-19 pandemic compelled teachers as key agents of educational change to fundamentally rethink their pedagogical practices with a view to bring about reformed pedagogy. The study adopted a phenomenological design located within the critical paradigm. The empirical investigation involved 21 purposively selected in-service science teachers enrolled for postgraduate studies in science education at a South African university. Critical theory was adopted as a theoretical lens to provide insightful elucidation into how science teachers negotiated and transformed their pedagogical practices in response to the formidable challenges posed by COVID-19 pandemic. The COVID-19 pandemic critically exposed socio-economic disparities in science teaching and learning within the broader South African context. Under-resourced schools represented inappropriate educational entities which rendered encouragement of critical thinking and promotion of innovative pedagogical practices extremely difficult to realize. Science teachers at under-resourced schools were largely left to their own devices when navigating formidable challenges posed by the prevalence of COVID-19 pandemic. This dilemma represents a structural problem that ought to be addressed as a matter of priority in order to ensure social justice in terms of the creation of conducive teaching and learning environments at under-resourced schools in particular. Meaningful transformation of pedagogy remains an arduous task in the face of fundamental challenges afflicting teacher professional growth and its ramifications.

Keywords: critical theory, critical pedagogy, pandemic, teacher agency, social justice

1. Introduction

COVID-19 pandemic has unexpectedly permeated all spheres of life and science teachers and learners are not spared. This pandemic has compelled schools and universities to change their mode of teaching and learning without prior appropriate planning. As such, remote teaching and learning can be perceived to have caused alienating experiences for both teachers and learners. The shift from face to face to remote teaching and learning was based on the assumption that both teachers and learners have access to connectivity and spaces conducive to teaching and learning among other things (Lederman, 2020). The pandemic appears to be widening the educational and digital divide between privileged elites and the poor particularly teachers and learners in disadvantaged townships, informal settlements and rural communities. Schools and teachers have often been complicit in perpetuating these inequalities in science education by blaming it on school context and learners' socio-economic backgrounds. In this regard, Mavuru and Ramnarain (2017) have reiterated that learners' socioeconomic background should be used as a resource and not as an excuse to deny learners meaningful learning. The purpose of this paper is to stimulate a sustainable constructive dialogue on the transformation of pedagogy with a view to foster enhanced pedagogic innovation.

1.1 Background

COVID-19 pandemic permeated all spheres of life but its impact is more prominent in the disadvantaged schools and communities (OECD, 2020). Due to lockdown restrictions imposed, not all learners had alternative learning opportunities in South Africa. This dilemma exposed structural inadequacies pertaining to science pedagogy and inequities due to socio-economic disparities in South African schools. In response to inevitable and mandatory changes, teachers had to adopt innovative pedagogical practices overnight in order to assist their learners remotely (Kaur & Bhatt, 2020).

Lockdown measures implied that learners from disadvantaged communities would fall behind due to lack of digital learning resources. Although some schools had the capacity to continue teaching remotely, the key issue is whether teachers and learners were knowledgeable and skilled to adapt to the new mode of teaching and learning. By its very nature, science is a practical subject which requires learners to not only acquire knowledge but to develop manipulative and investigative skills. The situation called for the provision of virtual laboratories where learners could design, conduct and learn from experiments instead of simply learning about them (OECD, 2020). In addition to exposing socio-economic disparities within science education domain, the pandemic catapulted schools, parents, teachers and learners to embrace digital learning opportunities associated with the advent of the Fourth Industrial Revolution (4IR) without prior exposure. There has been a significant transformation regarding the role of the teacher and learner in science teaching and learning (Kaur & Bhatt, 2020).

1.2 Purpose of the Study

The study investigated the extent to which COVID-19 pandemic served as a catalyst for fostering reformed pedagogy in science education within the South African context. The empirical investigation was guided by the main research question: To what extent has COVID-19 pandemic served as a catalyst for fostering reformed pedagogy in science education within the South African context? The following sub-questions were formulated to answer the main research question.

- What are science teachers' views regarding the role of COVID-19 pandemic in exposing socio-economic disparities that exist in science teaching and learning?
- What are science teachers' views about the efficacy of pedagogical practices adopted as part of remote teaching and learning during COVID-19 pandemic?
- How has COVID-19 pandemic transformed the pedagogical practices of science teachers?

1.3 Socio-Economic Disparities Existing in Science Education

According to Taylor and Yu (2009), South Africa is regarded as a highly unequal society in terms of income and wealth distribution and education is viewed as an institution of transformation. Riegle-Crumb and King (2010) reflected on the entrenched disparities that exist in science achievement of learners from disadvantaged communities compared to advantaged learners. Occupations in science, technology, engineering and mathematics (STEM) are key drivers of the economy worldwide and South Africa is no exception (Shepherd, 2017). Consequently, science and technology are the forces behind social change and growth of any economy (Atkinson & Mayo, 2010).

Due to the socio-economic inequalities in South African schools and communities, the pandemic has widened the digital divide amongst learners. This is confirmed by UNESCO (2020b) that only 20% of households in South West Asia and sub-Saharan Africa have internet connectivity. As such, learners from disadvantaged families were most affected when it comes to the transition from face-to-face to virtual learning as the transition required technological devices, internet connectivity, and conducive home environments for learning (Kraur & Bhatt, 2020). Further inequalities are therefore imminent (Tam & El-Azar, 2020). Several researchers argue that the level of parental education influences how parents raise and support their children in terms of aspirations and skills in science learning (Davis-Kean, 2005; Hoff, 2003). Educated parents have high expectations for their children, hence provide stimulating environments for science learning (Davis-Kean, 2005; Hoff, 2003). In a similar vein, Betancur, Votruba-Drzal and Schunn (2018) found that parental income and level of education whether science related or not, has a huge influence on learner achievement in science.

Such findings point to the existence of inequitable conditions in various families when it comes to learning science remotely during COVID-19 pandemic where parents are required to be co-teachers of their own children. The key question that arises is: How much help did learners from disadvantaged backgrounds get considering that science teachers were not physically present and that technological devices and connectivity could not be easily accessed to allow virtual learning of science to take place? Issues of social justice come into play. Social justice in science education encompasses issues of fairness and equal access to the important experiences; opportunity for both teachers and learners to participate; and the relevance of the science knowledge and skills taught (Ayers, Quinn & Stovall, 2009). To this end, Atwater (2010) alludes to relevance, rigor and possibility of changing the existing situation for a social justice science curriculum to be achieved. COVID-19 pandemic has exacerbated the inequalities that have existed in the science education domain for a long time in South Africa. Such sentiments are echoed by Adams-Prassl *et al.* (2020) who focused on the seamless transition from face-to-face to online learning by schools with resources and by Du Plessis & Mestry (2020) who bemoaned lack of basic sanitization facilities in disadvantaged communities. The paper argues that the education system in South Africa faces the inevitable key

imperative to carefully consider the role of COVID-19 pandemic as a catalyst for fostering reformed pedagogy in science education.

1.4 Pedagogical Practices Adopted in Remote Teaching and Learning

Before COVID-19 pandemic, digital platforms have been used by science teachers as complementary learning tools to the 'normal' face-to-face learning which is referred to as blended learning (Kaur & Bhatt, 2020). Such virtual platforms were an exclusive preserve of learners from socioeconomically advantaged families who could afford to purchase expensive technological devices. While schools from disadvantaged communities faced fundamental challenges on the migration from face-to-face to remote teaching and learning, digital literacy remained a professional challenge for some teachers (Saunders, 2012). While generation Z found it easy to transition to virtual learning, they however found it overwhelming to learn, complete assessments and take responsibility to manage their own learning without their teachers physically guiding them (Goldstein, Popescu & Hannah-Jones, 2020; Kaur, 2017). This can be attributed to inadequate capacity for autonomous and self-directed learning on the part of learners.

There is likely to be a fundamental transformation of the teaching and learning process post COVID-19 pandemic (Luthra & Mackenzie, 2020). Consequently, teachers' roles would change in response to the 21st century demands on the use of technology (Luthra & Mackenzie, 2020). Science teachers would have to re-evaluate their function of facilitating, guiding, monitoring and motivating learners remotely to ensure occurrence of meaningful learning. Luthra and Mackenzie (2020) posit that learners have been weaned from constant dependence on teachers as they acquire the knowledge and develop skills through technological tools/apps. Learners have no physical contact with their teachers for enquiry, which in a way leaves teachers with more time for preparation of teaching and learning materials. Virtual platforms such as video conferencing allow teachers and learners to record lessons for later retrieval (Kraur & Bhatt, 2020), and this process is not possible with face-to-face teaching. This advantage can serve to enhance autonomous learning as learners can retrieve the work at any time and place.

Professional development of teachers becomes easy as they can share best practices by attending virtual conferences and webinars (Hutt, 2017). Online teaching has enhanced teacher-learner and learner-learner interactions through social media (Ahern, Feller & Nagle, 2016). Science teachers need to develop excellent interpersonal skills in order to manage virtual learning and ensure that their learners remain engaged. While teachers need to develop technological skills, learners are largely self-sufficient in this regard (Hung, Chou, Chen & Own, 2010). However, learners still need to develop self-directed learning skills and self-control (Hung *et al.*, 2010). On the other hand, teachers need to develop skills in managing learner emotions and to recognize and address learner emotional and psychological needs.

1.5 Critical Pedagogy

The prevalence of COVID-19 pandemic compelled teachers as key agents of educational change to fundamentally rethink their pedagogical practices with a view to bring about reformed pedagogy. Fundamental transformation of pedagogy hinges to a large degree on critical pedagogy as an essential curriculum tenet. Critical pedagogy is largely viewed as a transformation-based approach to education. McLaren (1998) defines critical pedagogy as "a way of thinking about, negotiating, and transforming the relationship among classroom teaching, the production of knowledge, the institutional structure of the school, and the social and material relations of the wider community, society, and nation state" (p.45). While Abraham (2014) observed that critical pedagogy is criticized for its abstract nature and considerable emphasis on macro level system without a coherent model for classroom implementation, this paper argues that it provides meaningful opportunities for critical interpretation of reformed pedagogy. As an essential tenet within the realm of curriculum implementation, critical pedagogy can serve as an innovative catalyst to promote teacher agency and sustainable realization of social justice in science teaching and learning.

The teacher makes decisions on whether learners' voices can be heard, how, when and under what context in science classrooms (Atwater, 2010). This leaves learners in the receiving end. The issue is whether remote teaching and learning provides teachers with meaningful platforms to cater for the critical needs of diverse learners. Disadvantaged children of various cultures often harbour unacknowledged anger towards the system that they perceive to have established barriers and lessened expectations for them (Mosley-Howard, 1995). Conversely, more advantaged learners do not perceive barriers or discrimination within the social system but rather see many opportunities afforded to them (Mosley-Howard, 1995). Mezirow (1977) highlighted the need for change of perspectives in light of reality which can be achievable through a reflection on the transformation of one's own practices. Accordingly, Archer (2007) views teacher agency as a key element of human reflexivity. The interpretation by Archer (2007) of human reflexivity stems from the idea that teachers need to be agents of change to re-evaluate their teaching practice.

1.6 Theoretical Framework

The study is underpinned by critical theory as the underlying theoretical framework. Critical theory is a source for critical pedagogy (McKernan, 2013). According to Abraham (2014), the key essence of critical pedagogy is that education should go beyond transfer of knowledge and training of future labour force in order to help develop critical consciousness which engenders transformation of the individual, learning environment and society at large. Critical theory is adopted as a theoretical lens to provide insightful elucidation into how science teachers negotiated and transformed their pedagogical practices in response to formidable challenges posed by COVID-19 pandemic. This disposition is predicated on the notion that "critical pedagogy encourages critical thinking and promotes practices that have the potential to transform oppressive institutions or social relations" (Breunig, 2005, p.109).

2. Methodology

2.1 Research Design

The study adopted a phenomenological design located within the critical paradigm. COVID-19 pandemic represented the phenomenon under investigation. As a qualitative research approach, phenomenology focuses on the commonality of a lived experience within a particular group. The fundamental goal of the approach is to arrive at a description of the nature of the particular phenomenon (Creswell, 2013). The general purpose of the phenomenological study is to understand and describe a specific phenomenon in-depth and reach the essence of participants' lived experience of the phenomenon. The critical paradigm provides opportunities to venture beyond understanding the scope of the phenomenon with a view to change, emancipate and empower participants (Cohen, Manion & Morrison, 2018).

2.2 Sampling

The empirical investigation involved 21 purposively selected in-service science teachers enrolled for postgraduate (Masters and Doctoral) studies in science education at a South African university on a part-time basis. The teachers taught science at various schools in South Africa.

2.3 Data Collection

Data was collected through the administration of a survey questionnaire with the participants. The questionnaire items primarily elicited teachers' views on the role of COVID-19 pandemic in exposing socio-economic disparities that exist in science teaching and learning, the efficacy of pedagogical practices adopted as part of remote teaching and learning during COVID-19 pandemic as well as the impact of COVID-19 pandemic on the transformation of their pedagogical practices.

2.4 Data Analysis

Data was statistically analysed and key themes associated with various key focus areas were generated. The consolidated themes provided insights into teachers' views about the constructs investigated.

3. Research Findings

The findings are presented in response to each of the three research questions. The first part provides the demographic information obtained from the analysis of data from the quantitative section of the questionnaire. The demographic information sheds light on the profile of science teachers (participants) and the context within which the researchers could critically reflect on the extent to which COVID-19 pandemic served as a catalyst for fostering reformed pedagogy in science education within the South African context.

Study context

The study drew information from a majority of female science teachers (75%) and a minority of male science teachers (25%), which is a true reflection of the demographic distribution of teachers in most high schools in South Africa. The teachers comprised of mostly Blacks (90%) and only 5% Whites and 5% Coloureds. Such a distribution is not surprising because typically Black teachers teach in schools in the townships as portrayed in Table 1 below. It is mostly township schools that enroll learners coming from underprivileged socioeconomic backgrounds. This learner enrollment pattern has implications on the quality of remote teaching and learning that could have occurred during COVID-19 pandemic considering the lack of technological gadgets and connectivity in township schools.

Table 1. Distribution of teachers by school type

Type of school	Number of teachers (%)
Private School	15
Suburban School	25
Township	60

Table 2 below shows the age distribution of the participants.

Table 2. Teachers' age distribution

Age range (years)	Number of participants (%)
Below 25	15
25-30	45
36-40	15
40+	25

The majority of the teachers (60%) were under the age of 30 years. This information is important in this study given the fact that younger generation is considered to be technologically savvy and hence they should have found it easier to make a transition from face-to-face to remote teaching due to the COVID-19 pandemic. The participants represented all the three sciences taught in South African schools. 55% taught Natural Sciences as the only science taught in grades 8 and 9 in the Senior Phase (SP) while 20% taught Physical Sciences and 75% taught Life Sciences in the Further Education and Training (FET) phase. Table 3 below illustrates participants' teaching experience. Majority of the participants (52%) had teaching experience ranging from 0 to 5 years while 44% of the participants had teaching experience exceeding 5 years.

Table 3. Participants' teaching experience

Teaching experience (Years)	Percentage (%)
0-5	52
6-10	10
11-15	10
20	24

The majority of the teachers (52%) had limited teaching experience. This is a key advantage within the context of this study as teacher development programmes intensified the development of pre-service teachers' technological pedagogical content knowledge and skills in science teaching in recent years. The young teachers should have found it manageable to harness pedagogical affordances of technology integration during remote teaching and learning. The following section provides findings in response to the first research question: What are science teachers' views about the role of the COVID-19 pandemic in exposing socio-economic disparities that exist in science teaching and learning?

Teachers' views about the role of COVID-19 pandemic in exposing the inequalities in science education

The participants strongly felt that before the pandemic, a gap existed between private schools and public schools in terms of availability of resources as most township schools do not have science laboratories, equipment for science

investigations, and interactive white boards. The situation was exacerbated by inadequately qualified, inexperienced, and demotivated teachers. Learners in well-resourced schools have consistently performed better than those in under-resourced schools as learning occurs in supportive environments in well-resourced schools. In addition, overcrowding in science classrooms has been a perennial problem in township schools. The situation is different from affluent schools where school governing bodies can appoint additional teachers. Affluent schools have adequate resources including functional laboratories, technological gadgets, internet connectivity, textbooks as well as infrastructure. The participants believed that COVID-19 pandemic exposed inequalities within the South African education system.

As a consequence, the pandemic widened inequalities between the rich and the poor, hence the disparity is more prominent. Pindi (pseudonym), one of the participants said, "Some well-resourced schools continued to teach online yet poorly-resourced schools were not teaching at all". Some schools continued with teaching and learning programmes despite the raging pandemic since they had infrastructure for online teaching in place which included internet connectivity, appropriate devices such as laptops and tablets for both teachers and learners to access online lessons. Well-resourced schools could afford to develop teachers for remote teaching. Teachers and learners from under-resourced schools were largely left in the lurch. The participants pointed out that learners from well-resourced schools would be ready to sit for examinations at the end of the year, and if in grade 12, they would continue to further their studies e.g. enrolling in tertiary institutions the following year. The existing inequalities are a consequence of socio-economic disparities within the South African education system and communities by extension. It was also noted that even when public schools reopened after lockdown, there were inadequate resources such as sanitisers, masks, and the schools could not employ extra science teachers to cater for reduced numbers in science classrooms. Schools did not receive the same assistance as evidenced by the nature and quality of the personal protective equipment (PPEs) and water reservoirs received.

Given the fact that the disease does not discriminate on the basis of colour, race, creed, ethnicity, religion or economic status, people from disadvantaged communities suffered the most by virtue of their living conditions and inadequate access to quality health care. While teachers sent notes and video/audio recordings to the learners, learners living in informal settlements did not have the privilege of harnessing the information as their home environments were not conducive. Learners from privileged backgrounds had the space, comfort and gadgets to access online classes and materials. They could engage with virtual laboratories to broaden their understanding of science concepts. Thando (pseudonym), one of the participants shared her sentiments regarding the experiences of transitioning from face-to-face to remote teaching. She said, "The transition from face-to-face teaching and learning to virtual classrooms was seamless in private schools". The situation in public schools resembled navigation of unchartered territories. As such, one participant said, "There is a likelihood that learners from disadvantaged schools will drop out of school or stop studying science once things go back to normal".

The participants' stance is that social class matters when it comes to the impact COVID-19 has on remote teaching and learning of science. Learners from advantaged backgrounds could access remote teaching as they had technological devices, connectivity to the internet, a dedicated study area, a desk, a chair, and parents who could assist them or could afford to hire private tutors. Although the government introduced initiatives such as STEM lockdown digital teaching aimed at providing learners with live lessons during the national lockdown, such initiatives were only helpful to learners who had electronic gadgets as well as stable internet connection at home.

Efficacy of pedagogical practices adopted during remote teaching and learning during COVID-19 pandemic

The findings answer the second sub research question: What are science teachers' views about the efficacy of pedagogical practices adopted as part of remote teaching and learning during COVID-19 pandemic? The participants expressed a variety of views about the efficacy of pedagogical practices adopted during remote teaching and learning during COVID-19 pandemic. The adopted pedagogical practices largely made it possible for short-term learning goals to be achieved. While the participants appreciated exposure to virtual digital platforms, they bemoaned the lack of professional competence to use technology to demystify abstract scientific concepts. Sustaining active learner participation proved to be an immense instructional challenge during remote teaching and learning. Additional structural limitation highlighted by the participants is that remote teaching and learning does not make provision for meaningful development of practical laboratory skills. Lack of access to data packages served to stifle effective use of WhatsApp as an instructional tool in particular. The participants felt that the adopted pedagogical practices failed to cater for the critical needs of diverse learners. The use of video recordings was largely preferable as it was perceived to provide meaningful opportunities for revision of content covered as part of remote teaching and learning.

Remote teaching and learning proved to be very effective for learners who do not normally enjoy collaborative work and group interactions. Learners with disciplinary problems actively participated and enjoyed virtual learning sessions which showed that peer influence plays a pivotal role in learner classroom behaviour. Constant assessments in the form of online quizzes helped to monitor learners' conceptual understanding unlike in a face-to-face instructional setting where constant assessments may lead to fatigue and demotivation on the part of learners. Remote teaching and learning was effective in terms of enforcing parental involvement in their children's day to day class activities as they had to monitor, assist with research, and ensure timeous completion of assessments. The participants indicated that the effectiveness of remote teaching and learning can be attributed to its convenience in affording learners access to learning materials at any time and ability to replay audios, videos repeatedly, which is not possible with face-to-face learning. In addition, remote teaching and learning provided opportunities for learners to interact with teachers without any fear of reprimand and peer pressure. Even reticent learners participated actively during virtual sessions.

Learners in disadvantaged communities did not have parental assistance due to contextual factors such as poor education, poor learning environment and lack of connectivity. The learners felt overwhelmed with work and assessments with strict submission deadlines. One of the participants, Themba (pseudonym) said, "Sometimes as teachers, we were worried about saving the academic year. We focused on content coverage and administration of assessments at the expense of learner conceptual understanding". Weaker learners relying mostly on remedial work by the teacher were left to their own devices. The participants also reflected on gaps in their professional training. For instance, Celeste (pseudonym) said, "Not all of us possess the necessary technological knowledge and skills to ensure meaningful online teaching occurs". Table 4 below depicts the participants' rating of their ICT skills.

Table 4. The participants' rating of their ICT skills

Participants' rating of their ICT skills	Percentage (%)
Excellent	0
Very good	29
Good	48
Average	19

The participants' rating paints a gloomy picture about the quality of their ICT skills. Less than 50% of the participants indicated that their ICT skills are good. 29% of the participants intimated that their ICT skills are very good while 19% provided an average rating for their ICT skills. Teachers also questioned the authenticity of online assessments as they failed to obtain the necessary feedback on whether the work done online is being done sincerely without systemic irregularities. Some of the teachers pointed out that online teaching will only be effective if all learners are given resources to ensure active participation. In this regard, Khumo (pseudonym) said, "To be honest online teaching and learning is applicable to urban areas with the necessary internet connectivity. As for rural areas, face-to-face is the answer". The contentious issue here is that remote teaching and learning is perceived to benefit fewer learners as many are left behind due to inadequate access to bandwidth.

Challenges faced by science teachers when teaching remotely during the pandemic

There was a myriad of challenges teachers encountered during remote teaching and learning. These challenges included low learner participation in live sessions due to connectivity issues or learners choosing not to participate due to laziness or lack of interest. There was poor submission of assessment tasks, which retarded the rate at which teachers could assist the learners in covering content. Most learners from disadvantaged communities did not possess smart phones or necessary gadgets, lacked data, and hence failed to access videos and voice notes shared by the teachers. Frequent load shedding related disruptions had a detrimental impact on remote teaching and learning. The majority of both teachers and learners did not possess the requisite technological knowledge and skills necessary for remote teaching and learning. One of the participants, Thandi (pseudonym) shared a challenge where in a supposedly synchronous teaching and learning session, she failed to set the online platform properly and only found out at the end of the lesson that she had restricted learner participation unknowingly. In own words, "With technology, minor mistakes can jeopardise the whole session". One of the challenges raised by the participants was parents' lack of commitment to assist their children with school work. Some parents were not supportive as they assigned household

chores to their children or babysitting roles to their young siblings. As a result, learners were not afforded adequate opportunities to engage with school work. Due to lockdown regulations, parents of children from one school complained that it was impossible to secure private learning for their children at home without disturbances. As such, remote teaching was completely abandoned to the chagrin of learners.

The lockdown period presented fundamental challenges to science teachers. Pulane (pseudonym) said, "This pandemic really affected my view of teaching and learning". The participants bemoaned loss of quality teaching and learning time. Some schools lack basic resources such as proper infrastructure and sanitation and the spike in infections rendered teaching and learning extremely difficult. Learner attendance was negatively affected and teachers were fearful that at the end of the year there will be a high failure rate. According to some of the participants, virtual teaching and learning was not conducive because not all learners had the technology or connectivity to access remote teaching and essential resources. Most of the learners came from poverty stricken communities, have challenges in understanding English as the language of learning and teaching (LOLT), which is different from their home languages. For this reason, learners suffered because they normally rely on teacher explanations and code switching between English and learners' home languages to make science concepts intellectually accessible. Less contact classes resulted in learners being demotivated to learn and making it difficult to teach. In addition, some learners did not have access to any form of teaching due to their circumstances whereas others were privileged in terms of availability of resources.

Several participants specifically highlighted challenges they faced with regard to practical/laboratory work. They pointed out that it is easier to engage learners in the actual laboratory activities where learners physically touch different equipment, manipulate different variables and make observations. While virtual laboratory simulations and videos could be used, learners, however, became overwhelmed and intimidated by their constant use, and in particular giving explicit instructions on what learners should do, how to do it, why they should do it, and assessing some of the tenets of the nature of science was a daunting task. Learners did not view their cell phones as learning tools, but rather as tools for entertainment, hence they failed to engage fully when some of the teachers used WhatsApp in the teaching and learning process. The efficacy of adopted pedagogical practices was essentially compromised by lack of appropriate professional training on the use of virtual digital platforms to facilitate acquisition and assimilation of content knowledge. Highlighted instructional challenges ought to be adequately addressed if teachers are to develop a sense of appreciation for technology-enhanced teaching and learning.

How COVID-19 pandemic transformed pedagogical practices of science teachers

The findings answer the last sub-research question: How has the COVID-19 pandemic transformed the pedagogical practices of science teachers? Although it was challenging, the participants indicated that the pandemic brought new opportunities. For instance, one of the participants who taught Life Sciences indicated that she utilised COVID-19 pandemic as an opportunity to teach micro-organisms and to elaborate to learners about how viruses operate with practical examples. Another participant saw it as an opportunity to emphasise concepts such as immunisation and vaccines. Some indicated that they used resources that they would normally not use under normal circumstances which enhanced their technological knowledge. One of the participants, Mebo (pseudonym) said, "We are currently living in the Fourth Industrial Revolution and the pandemic has encouraged us to embrace it". The teachers' responses show that they tried to reach out to their learners by giving learners pages from a textbook to read and questions to answer; sending voice notes explaining the concepts; posting activities and notes on the schools' websites, sharing links of videos on WhatsApp groups; and even designing learning materials shared with learners from rural and township schools.

Key lessons drawn from the prevalence of COVID-19 pandemic

The participants provided a critical reflection on key lessons drawn from the prevalence of COVID-19 pandemic. By its very nature, the pandemic served to develop consciousness of the need for humanity to galvanize efforts geared towards the creation of a socially inclusive and cohesive society. The pandemic critically exposed socioeconomic disparities within the broader South African context. In particular, structural problems that faced learners coming from underprivileged socioeconomic backgrounds included lack of access to technological devices and data packages. Schools were generally not prepared for remote teaching and learning due to inadequate infrastructure. The pandemic compelled teachers to fundamentally rethink their pedagogical practices with a view to foster reformed pedagogy. Fundamental challenges associated with the pandemic pointed to the critical need to provide sustainable teacher professional development in order to maximize opportunities for embracing digital transformation in its broadest sense. As an integral part of remote teaching and learning, technology-mediated assessment posed formidable instructional challenges for teachers. The realization of requisite pedagogic innovation

hinges to a large degree on sustainable enhancement of teacher professional skills as a key requirement for effective remote teaching and learning.

The role of COVID-19 pandemic in accelerating the penetration of the Fourth Industrial Revolution (4IR) in various critical areas of human endeavour

The participants expressed varied views about the role played by COVID-19 pandemic in accelerating the penetration of the Fourth Industrial Revolution (4IR) in various critical areas of human endeavour. The participants' disposition pointed to the significance of the nexus between the development of 21st century skills and 4IR skills. In essence, the symbiotic relationship between 21st century skills and 4IR skills is crucial for developing professional capacity to fully embrace digital transformation in its broadest sense. In particular, skills such as critical thinking, collaboration, communication and problem solving were perceived to be vitally important for the acceleration of 4IR in various critical areas of human endeavor. Meaningful exposure to coding and robotics would serve to pave the way for the development of digital competencies required to navigate fundamental challenges associated with the development of 21st century skills. The participants expressed fundamental appreciation for the significance of platforms such as Microsoft Teams, Zoom and Google Meet in facilitating virtual interactions as part of a new normal. Artificial intelligence and machine learning are poised to have a profound impact on coherent evolution of remote teaching and learning going forward.

4. Discussion

The research findings showed how the COVID-19 pandemic acted as a catalyst for fostering reformed pedagogy in science education. Due to the lockdown restrictions imposed in South Africa in particular, many schools resorted to remote teaching and learning in order to save the academic year. Over the years, science teachers have been urged to embrace the development of 21st century skills with a view to harness the affordances of 4IR by appreciating the benefits of online instruction and the role of technologies (Fish & Gill, 2009). The findings demonstrated that COVID-19 pandemic transformed the pedagogical practices of science teachers. For instance, teachers realised that they were not the only source of information and appreciated the importance of the critical role of all stakeholders in the teaching and learning process. Such a realisation is instrumental to change teachers' conception of digital platforms as complementary learning tools to the 'normal' face-to-face learning but rather as the sole forms through which teaching and learning could occur (Kaur & Bhatt, 2020). In a similar vein, Luthra and Mackenzie (2020) postulated that teachers' roles should change in response to 21st century demands on the use of technology.

The research findings revealed that COVID-19 pandemic enforced parental involvement in their children's day to day class activities as they had to monitor, assist with research, and ensure timeous completion of assessment tasks. The prevalence of the pandemic transformed the manner in which science teachers prepared teaching and learning materials and activities for learners as they mobilised various digital platforms such as WhatsApp, videos, and lesson recordings to elaborate and make science concepts explicit and more comprehensible to their learners. Such a change in the pedagogical practices was due to the science teachers' realisation that not all parents were capable of assisting their children accordingly. Davis-Kean (2005) posits that educated parents have high expectations for their children and hence they provide stimulating environments for science learning. The reality is that learners coming from underprivileged socioeconomic backgrounds do not enjoy such privileges.

Teachers adopted a more caring approach and had more contact with their learners particularly those who had technological gadgets and internet connectivity. Reticent learners could freely seek their teacher teachers' help and contributed without peer pressure. This can be attributed to the fact that remote teaching enhances teacher-learner and learner-learner interactions through social media (Ahern, Feller & Nagle, 2016). Teachers identified how socioeconomic disparities that existed before the pandemic became more prominent in the wake of remote teaching and learning imposed by COVID-19 pandemic. They bemoaned failure by learners from disadvantaged homes to access online learning materials while those from well-resourced schools and families navigated the transition with relative ease.

The teachers were worried that prolonged periods of no teaching and learning would demotivate learners leading to learners dropping out and subsequent dismal performance in science subjects. These observations are consistent with a study conducted by Riegle-Crumb and King (2010) which revealed entrenched disparities between science achievement of learners from disadvantaged communities and advantaged learners. Taylor and Yu (2009) contend that South Africa is a highly unequal society in terms of income and wealth distribution and education. Hence the science teachers pointed out that the pandemic widened the inequalities between the rich and the poor as fewer learners are likely to pursue science related careers which are the key drivers of economic growth. Atkinson and

Mayo (2010) concur by stating that science and technology are the forces behind social change and growth of any economy.

While the participants appreciated exposure to virtual digital platforms, they bemoaned lack of professional competence to use technology to demystify abstract scientific concepts. This is also evidenced by the participants' rating of their ICT skills which largely painted a gloomy picture. These findings are consistent with the study conducted by Saunders (2012) which found that while challenges of migrating from face-to-face to remote teaching and learning are faced by schools from disadvantaged communities, digital literacy remains a challenge for teachers. Teachers' poor technological skills made it increasingly difficult to embrace mandatory remote teaching and learning imposed by COVID-19 pandemic. Teachers' lack of confidence in online teaching and learning and inadequate experience in online delivery have been identified as key impediments (Hinson & LaPrairie, 2005; Koehler, Mishra, Bouck & Deschryver, 2011).

Interpretation of key findings in terms of the adopted theoretical framework

As indicated earlier, the study is underpinned by the critical theory as the underlying theoretical framework. Critical theory is adopted as a theoretical lens to provide insightful elucidation into how science teachers negotiated and transformed their pedagogical practices in response to the formidable challenges posed by COVID-19 pandemic. The COVID-19 pandemic critically exposed socio-economic disparities in science teaching and learning within the South African context. While private schools seamlessly migrated to remote teaching and learning, township schools struggled due to inadequate infrastructure and general lack of essential resources. The COVID-19 pandemic compelled science teachers to fundamentally rethink their pedagogical practices. However, lack of professional training on technology integration in science teaching and learning was a major impediment. This implies that lack of professional training on technology integration in science teaching and learning stifled teachers' inclination to transform their pedagogical practices.

By its very nature, critical pedagogy encourages critical thinking and promotes practices that have the potential to transform oppressive institutions or social relations (Breunig, 2005). Under-resourced schools represent "oppressive institutions" which render encouragement of critical thinking and promotion of best professional practices extremely difficult. Teachers were largely left to their own devices when navigating formidable challenges posed by the prevalence of COVID-19 pandemic. This dilemma represents a structural problem that ought to be addressed as a matter of priority in order to ensure social justice in terms of the creation of conducive teaching and learning environments at township schools in particular.

COVID-19 pandemic was largely perceived to be instrumental in accelerating the penetration of the Fourth Industrial Revolution (4IR) in various critical areas of human endeavour. However, harnessing the key pedagogical affordances of technology integration in science teaching and learning requires the enhancement of teacher professional capacity for purposes of embracing digital transformation in its broadest sense. The efficacy of adopted pedagogical practices during remote teaching and learning was essentially compromised by lack of appropriate professional training on the use of virtual digital platforms to facilitate acquisition and assimilation of content knowledge. While the teachers indicated that remote teaching and learning provided rich learning experiences to some extent during COVID-19 pandemic, more should be done to enhance the operational efficiency of township schools. Teacher agency can play a pivotal role in the realisation of the key goals of critical pedagogy. This mission cannot be accomplished in instructional environments characterised by lack of opportunities for pedagogic innovation and lack of opportunities for teachers to discharge their professional responsibilities as reflective practitioners in their own right. Meaningful transformation of pedagogy remains an arduous task in the face of fundamental challenges afflicting teacher professional growth and its ramifications.

5. Conclusion

The prevalence of COVID-19 pandemic imposed mandatory remote teaching and learning without prior preparation. COVID-19 pandemic accelerated the transformation of pedagogy in science education in response to the complex demands of remote teaching and learning. However, the transformation of pedagogy remained an arduous process which required scaffolding by key stakeholders with vested interest in education.

To answer the question: What are science teachers' views regarding the role of the COVID-19 pandemic in exposing socio-economic disparities that exist in science teaching and learning? The teachers expressed serious concerns about inequalities associated with socio-economic disparities within the South African education system and communities. In particular, public schools are increasingly marginalised when it comes to the provision of funding support. The

transition from-to-face to remote teaching was largely seamless for well-resourced schools as opposed to under-resourced schools.

In answering the second question that sought science teachers' views about the efficacy of pedagogical practices adopted as part of remote teaching and learning during COVID-19 pandemic, teachers expressed views characterised by ambivalence. On the one hand, teachers indicated that remote teaching and learning afforded them opportunities to exploit various virtual platforms. Some teachers faced a myriad of challenges that included the lack of technological knowledge and skills. Teachers also questioned the authenticity of online assessments and bemoaned that online teaching and learning benefitted fewer learners who had access to technology and connectivity.

In answering the last question: How has the COVID-19 pandemic transformed the pedagogical practices of science teachers? The teachers firstly reflected on their pedagogical practices. Secondly, the teachers transformed their teaching practices as they embraced and appreciated the significance of the nexus between the development of 21st century skills and 4IR skills. Thirdly, they harnessed the information about COVID-19 to teach Life Sciences concepts on respiratory diseases, microorganisms, vaccines and issues of hygiene.

The research findings have profound implications for teacher professional development programmes. There is a critical need to develop both pre-service and in-service science teachers on how best to exploit virtual platforms to teach different science topics at various levels. Future studies could focus on the development of teachers' interpersonal skills to support learners with emotional and psychological difficulties that accrues from the isolation due to remote teaching and learning. The study contributes to an existing body of knowledge on the transformation of pedagogy as an essential curriculum tenet.

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