Teaching science through information and communication technologies: 'enablers' and 'constraints'[1]

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ABSTRACT

The ability of information and communication technologies (ICTs) to improve teaching and learning explains its inclusion in policy prerogatives in countries around the world. Efforts to realise ICT's potential in the teaching of science across the world are ongoing. In this qualitative study, we purposively sampled six beginning teachers with up to two years' teaching experience to unpack the enablers and constraints they encounter when using ICTs to teach science in South African schools. The participants responded to semi-structured interviews, wherein they narrated their experiences on the teaching of science using ICTs. We used a thematic mode of analysis. Findings indicate a range of enablers and constraints that influence beginning teachers' abilities to teach science using ICT tools. Despite exposure and competence, beginning teachers are unable to integrate ICTs effectively in teaching as indicated in the country's education policies due to certain constraints. The paper recommends, among others, that the Department of Basic Education (DBE) should activate its monitoring and evaluation mechanisms that would assist in identifying context-specific challenges. In addition, it is recommended that the government relook its budget allocation to schools in the domain of technology to enhance school capacity to purchase internet data on a regular basis and to repair broken computers timeously. These findings call for more interdisciplinary studies to provide additional information relating to the use of ICTs by beginning teachers to teach science across a variety of classroom contexts.

Keywords: Information and Communication Technologies (ICTs), science education, beginning teachers, enablers and constraints

INTRODUCTION

Over the years, researchers in South Africa and elsewhere have continued to present evidence of low levels of learner achievement and underperformance, especially in science and mathematics subjects (Ndlovu, 2011; Venkat & Mathews, 2019). These low levels of learner achievement are associated with the poor quality of teaching, which has not changed over a number of decades (Mlachila & Moeletsi,

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2019; Spaull, 2013). This phenomenon exists despite the integration of information and communication technologies (ICTs) in teaching and learning (Dixon, 2020; Tachie, 2019). The instability and inconsistency of teaching practices in classrooms are not unique to South Africa but have been observed (for decades) in other countries also (Garegae, 2016; Mikeska et al., 2019).

Consequently, there has been an upsurge in efforts, locally and internationally, which prioritize the search for strategies to improve the teaching of science subjects (among other subjects) in schools (Arends, Winnaar & Mosimege, 2017; Jimoyiannis, 2010; Michos & Hernández-Leo, 2020). It is against this background that ICTs, due to their potential, have come to be a contender to improve the quality of teaching in science classrooms across the globe, including those in South Africa (Amuko, Miheso & Ndeuthi, 2015; Gui, Parma & Comi, 2018; Kaur & Singh, 2020; Umugiraneza, Bansilal & North, 2018). However, Daya and Laher (2020) note that what takes place in individual schools indicate that the ICT integration agenda in South Africa is yet to achieve satisfactory results holistically. Therefore, this paper seeks to understand the 'enablers' and 'constraints' beginning teachers face in teaching science subjects with ICT tools.

Science is one of those subjects in the school curriculum in which the potential for ICT usage is high, especially in practical laboratory work. However, many researchers describe the ability of technology to enhance the teaching and learning of science and mathematics as being below expectations for varied reasons (De Freitas & Spangenberg, 2019; Masango, Van Ryneveld & Graham, 2019; Mlambo, Rambe & Schlebusch, 2020). The present study contributes to this discourse by examining beginning teachers' narratives of using ICTs in teaching science subjects in South African schools, specifically in the context of potential enablers and constraints. The improvement of quality teaching using ICTs is urgent as South Africa seeks to improve performance in science subjects, where traditional methods of teaching have not produced the desired results across subjects (Department of Basic Education [DBE], 2014; Ndlovu, 2011). As such, efforts are ongoing to ensure an improvement in performance for all learners (Venkat & Mathews, 2019).

There are ongoing efforts to integrate ICTs into teaching due to its potential to introduce varied opportunities (Meyer & Gent, 2016; RSA. Department of Telecommunications and Postal Services, 2016; Wilson-Strydom, Thomson & Hodgkinson-Williams, 2005). However, it is not clear how beginning teachers are able to deal with such opportunities or engage potential challenges in their individual school contexts for teaching science. We therefore ask the following question:

- What are the 'enablers' and 'constraints' beginning teachers face in teaching science subjects with ICT tools?

LITERATURE REVIEW

The use of ICTs in teaching has advantages for both teachers and learners (Chisango et al., 2019; Daya & Laher, 2020; Steiner & Mendelovitch, 2017), hence the need to accelerate its integration in schools. For example, ICTs provide room for teacher-learner interaction and expose learners to a variety of knowledge types and task activities (Kamal & Diksha, 2019). Despite having some challenges, though, Cloete (2017) argues that technology is an integral part of living in the 21st century.

The use of ICTs in the teaching of science directly and indirectly affects learner achievement since it meets learners' varied learning styles. Apart from motivating and engaging learners in the learning process, ICTs also facilitate learner understanding of science concepts when integrated into teaching (Hilton, 2018; Yang & Baldwin, 2020). For example, technologies such as smartphones have the potential to assist learners with learning difficulties in the science classroom (Sormunen, Lavonen & Juuti, 2019). Additionally, Ekici

and Pekmezci (2015: 173) argue that '[e]ffective and sustainable science education is enriched by the use of visuals, auditory, and tactile experiences'. In this regard, Tomljenović and Zovko (2016) demonstrate how the use of technology to teach mathematics to 7th grade primary school learners in Croatia led to a significant increase in performance. Since technology is part of teaching in many classrooms across the globe, it is appropriate to pause and explore the enablers and constraints involved. This paper therefore focuses on exploring enablers and constraints beginning teachers face in teaching science subjects with ICT tools in South African secondary schools.

The use of ICTs in the teaching of varied subjects, including science, has been explored in various contexts over the years (Ameen, Adeniji & Abdullahi, 2019; Amuko et al., 2015; Genlott & Grönlund, 2016; Sudha, 2019), although not so much with beginning science teachers in South African schools. Numerous teacher education programmes have made extensive efforts to ensure meaningful use of technology during the training of pre-service teachers. However, there is limited information about the experiences of beginning teachers in teaching science-related disciplines using ICTs (Beisel, 2017; Zakaria & Khalid, 2016). Therefore, a comprehensive evaluation of the experiences of beginning teachers is a necessary step in understanding what happens in individual school contexts in terms of ICT integration in the classroom. These experiences, including enablers and constraints, can help to guide both researchers in exploring context-specific research on ICT integration and curriculum developers on the realities of policy implementation, especially concerning what to consider when outlining policy expectations. They could also guide school management, district officials and Ministry of Education officials in developing countries such as South Africa on how to ensure that policies related to ICT integration are successful.

Reconceptualising the teaching of science using information and communication technology

Irrespective of the relevance of ICTs in the teaching of science, its availability in schools and associated benefits, its effective utilisation and its degree of impact depend largely on existing enablers and constraints. Teachers have a crucial role to play in terms of evaluating and recommending the relevant kinds of technologies and figuring out how best to use them to improve classroom teaching and learner performance. As such, teacher knowledge concerning ICT usage in the classroom is critical (De Freitas & Spangenberg, 2019). Although beginning teachers may be competent and confident to teach using technology, various factors that act as enablers and constraints could stifle effective implementation. These include the necessary skills required to use ICT resources, understand the nature of resources, and access these resources in diverse school contexts (Ottenbreit-Leftwich et al., 2018).

Having explored ICT integration in South African schools, Padayachee (2017) posits that pedagogical challenges also obstruct the process of integrating ICTs in teaching, a view shared by Olika, Moses and Sibongile (2019). Other researchers attribute this challenge to inadequate training in the use of technology in the classroom by pre-service teachers (De Freitas & Spangenberg, 2019; Nkadimeng & Thaba-Nkagimene, 2019; Ojo & Adu, 2018). The lack of knowledge to use ICT resources in the classroom contributes to technological resources being underutilised or unused in some school contexts in South Africa (De Freitas & Spangenberg, 2019; Dixon, 2020; Masango et al., 2019; Mlambo et al., 2020; Ojo & Adu, 2018). In this regard, Dlamini (2018) proposes the need for effective ongoing professional development for teachers on the use of ICTs in the classroom.

Furthermore, research indicates that limited access to ICT resources by teachers impedes the integration process – in some cases, resources are available but locked up in computer laboratories (Tachie, 2019), thus inhibiting usage (Aikins & Arthur-Nyarko, 2019; Ojo & Adu, 2018). Furthermore, Bester (2016) argues that electricity challenges exacerbate the limited access to the internet in some schools, thus restricting the use of multimedia during lessons. In other schools, unstable internet connections (De Freitas & Spangenberg, 2019) and frequent computer breakdowns are to blame (Munje & Maarman, 2017).

Additionally, overcrowding puts pressure on the limited ICT resources in some schools, thus impeding smooth integration (Ojo & Adu, 2018). According to Masango et al. (2019), some schools have technological resources that are not proportionate to the number of learners. The surge in discourses such as these aligns with Dixon's (2020) assertion that there is an increasing digital divide in South Africa, which threatens efforts aimed at ensuring equity and quality education for all through ICT integration.

Worthy of noting is that the Department of Education in 2003 advocated for the provision of technology in all schools by the year 2013 (RSA. Department of Education, 2003). However, ongoing discourses reveal a skewed and fragmented ICT-integration process slowed by limited capacity (Dlamini, 2018; Meyer & Gent, 2016; Wilson-Strydom et al., 2005). Hence, Olika et al. (2019) note that strategies put in place to achieve the stated objectives of ICT integration are not sufficient. That being an indication of eminent challenges regarding ICT integration in South Africa, this paper looks at enablers and constraints that influence beginning teachers' ability to teach science with the use of ICTs.

METHODOLOGY

This qualitative case study aims to explore the enablers and constraints that beginning teachers encounter in their endeavours to teach science using ICTs. To achieve this, we involved beginning teachers, aged between 23 and 32 years, who graduated from an initial teacher education programme from Thuto University (pseudonym). Thuto University is a formerly white and advantaged university that embraces science education and uses ICTs in its teaching and learning. Participants attended Thuto University while it was still a dual-medium (English and Afrikaans) institution, and were working at English-medium schools, except for one white male participant, who was teaching at an Afrikaans-medium urban school. All participants, including the Afrikaans speaking male participant, were comfortable being interviewed in English. This longitudinal case study involved beginning teachers (with up to two years' teaching experience) who teach science to learners in grades 8 to 12 in secondary schools. Table 1 displays the frequency counts on six demographic variables of the participants. These variables are (i) gender, (ii) age range, (iii) teaching qualification, (iv) school type, (v) teaching experience, and (vi) number of schools taught at since commencing teaching as a career.

Table 1:
*Frequency counts for demographic variables of participants (n=6)**

Variable	Category	n	(%)
Gender	Female	3	50
	Male	3	50
Age range (years)	23-26	4	67
	27-32	2	33
Teaching qualification	Bachelor of Education (B.Ed.)	2	33
	Postgraduate Certificate in Education (PGCE)	4	67
School type	Urban (Quintile 5)	1	17
	Rural (Quintile 1)	1	17
	Township (Quintile 3)	2	33
	Farm school (Quintile 1)	1	17
	Informal settlement (Quintile 1)	1	17

Variable	Category	n	(%)
Teaching experience	0 years (less than a year)	1	17
	1 year	1	17
	2 years and a few months	4	67
Number of schools taught at since commencing teaching	1 or less than a year	2	33
	More than 2 schools	4	67

*The percentages have been rounded off.

The frequencies of the variables in Table 1 reflect data of the beginning teachers in selected South African schools purposefully selected as participants based on proximity and distance. The data show that most of the selected participants (67%) have a one-year teaching qualification, PGCE, while the rest (33%) have a four-year B.Ed. degree. It is interesting to note that within their first two years in the field, 67% of participants had already changed schools more than once, due to lack of stability in employment in the South African economy.

The collection of data took place from April 2017 to August 2018, with participants engaging in 15-20-minute individual semi-structured interviews. The interviews created space for participants to express their views and experiences concerning factors that enhance or inhibit the use of ICTs in the teaching of science.

The interviews were audio-recorded and complemented by note taking. After transcribing the interviews, we analysed, described and organised the data into relevant themes (Alhojailan, 2012). Through this process, inferences were drawn from the data to make sense of what the participants discussed in relation to the research question posed. In the process, major themes emerged that answered the set research question, which focused on understanding enablers and constraints beginning teachers encounter when using ICTs to teach science.

In terms of ethics considerations, respect for the privacy of the participants and research sites was paramount (McLain & Kim, 2018). Ethics approval was obtained from the ethics committee of the selected university and from the provincial department of education under which the schools are located. In addition, participants signed consent forms to make their acceptance to participate official. At the beginning of each interview, participants' rights to confidentiality, to take part in recorded interviews, and to opt out at any time were explained to them.

RESULTS AND DISCUSSIONS

After comparative analysis of all interview data against each other had been done for cross-case analysis, the data were categorised into the two main themes informed by the research question guiding the study – 'enablers' and 'constraints' beginning teachers face in teaching science subjects with ICT tools. The main categories for each main theme as drawn from the data are displayed in Table 2.

Table 2:
Summary of findings

Enablers	Constraints
Teaching practice experience	School contexts – unsupportive environments

Enablers	Constraints
Teacher-teacher interactions – inspiration from colleagues	Lack of resources and/or lack of access to ICT tools
Availability of resources	Unstable internet connection
Access to ICT resources	Lack of computer skills and/or interest by colleagues
Mentor teachers as positive role models	Security – theft and vandalism

Enablers for teaching science using information and communication technologies

The study aimed to determine factors aiding teachers in their efforts to use ICT tools in teaching science. Participants responded to the following question during the interviews: 'Can you tell me about what or who has motivated you to teach science using ICTs?' The summary of ideas shared across the six semi-structured interviews on enablers were captured in five major categories, as depicted in Table 3 below.

Table 3:
'Enablers' for ICT usage during first years of teaching

'Enablers' category	P1	P2	P3	P4	P5	P6
Teaching practice experience	X	X		X		
Other teachers/colleagues		X	X			
Teacher educator						X
Access to ICTs				X		
High school teacher/ Apprenticeship					X	

The categories emerging from the theme 'enablers' relate to what motivated the participants to use ICTs to support the effective teaching of science content. It is interesting to note that 'teaching practice experiences' was the category mentioned most frequently by participants in motivating them to teach science using ICT tools. Teaching practice experiences during the teacher education programme enhanced their competencies in teaching science using ICTs. Some participants explained as follows:

> P1: I will refer to when I was doing teaching practice. The teacher at St. Maria's [pseudonym] always used ICTs, which motivated me.

> P2: My mentor teachers during teaching practice always used technology. I've found that learners are able to learn more, recall whatever was taught when using ICT.

> P4: During our teaching practice, we used the smartboard and computers in those small classes (micro classes) and I used it in a school where I did teaching practice.

Such experiences in teaching practice seem to have increased participants' determination to teach science with the use of ICTs, considering that learner motivation, concentration and understanding could contribute to improving performance. Evidently, mentor teachers' beliefs and practices directly influence what beginning teachers do during field practice, including teaching with technology (Buatip, Chaivisuthangkura & Khumwong, 2019; Compton & Jordan, 2019; Nelson & Hawk, 2020).

The second category that stood out is that of 'other teachers as colleagues', with these other teachers using ICTs to teach science having impacted on participants. In this regard, P2 and P3 recounted encounters whereby colleagues had inspired them to use ICTs in teaching science:

> P2: There was this other teacher… He is so technological, quite young as well. He created something like a game for learners… he used his cell phone and laptop. Even marking, he does it with apps.

> P3: A teacher by the name of Mr Mayisa at VV School [pseudonyms] where I started as a teacher motivated me to use ICT. He also teaches physical science.

Adnan and Tondeur (2018) corroborate the views of P2 and P3 by saying that where there are positive emotions and collaboration through role modelling, there is likely to be an improvement in using technology to teach, with positive implications for learners.

The availability of infrastructure and ICT-related resources in schools where pre-service teachers do their teaching practice further boost their experiences (Batane & Ngwako, 2017). This is because exposure to technological resources enhances teachers' competence to teach effectively when using ICTs in the classroom (Nelson, Voithofer & Cheng, 2019). When asked to comment on the impact of available ICT tools in the context of teaching, P2 narrated the positive effects of readily available ICT resources in a school:

> … during teaching practice, ICT was available in the school. They had all the necessary resources available that assisted me with the preparation for my lessons… they had overhead projectors, I could present the work in PowerPoint documents, show the learners videos and play games related to sciences using the computer.

Participants overwhelmingly indicated their exposure to ICT resources either during teaching practice or during the first two years in the teaching profession. Despite this exposure and competence, many beginning teachers are unable to integrate ICTs into teaching, as indicated in the country's education policies, due to varied constraints.

Constraints beginning teachers encounter in using ICTs to teach science

In addition to determining enablers for beginning teachers in using ICTs for science teaching, the study aimed to determine factors that inhibit beginning teachers' efforts to teach science with ICT tools. The aim was to obtain answers to the stated research question: 'What are the 'enablers' and 'constraints' beginning teachers face in teaching science subjects with ICT tools?' Participants were asked to state the challenges experienced when using ICTs in the teaching of science.

The participants had an opportunity to express themselves in their own words, and to share insights on their practical experiences during their first two years of teaching science. Data analysis reveals constraints such as school contexts, lack of access to ICT tools, lack of a supportive environment and security concerns (also see De Freitas & Spangenberg, 2019; Dixon, 2020; Masango et al., 2019; Mlambo et al., 2020). In some schools, entire computer laboratories are stolen, leading to a total stagnation of the ICT integration process (Munje & Maarman, 2017). The categories of constraints and their frequencies are presented in Table 4.

Table 4:
'Constraints' for ICT usage during first years of teaching

'Constraints' category	P1	P2	P3	P4	P5	P6
Access to ICT tools	X	X	X			X
School context	X					X
Unsupportive environment	X		X			
Security	X					X

Table 4 shows the category of 'access to ICT tools' as the category mentioned most by participants in hindering them from using ICT tools to teach science. In the view of participants, ICT resources need to be readily available in schools to encourage and motivate passionate teachers to use them to teach science. P1, P2, P3 and P6 explained the effects the lack of access to ICT resources have on the teaching of science:

> P1: … there was a time when we were doing the body structure and because they don't have the required resources, it becomes difficult to teach learners because we have to draw just for them to remember; they also have to always draw and label so that they are able to remember the model you taught. This is such a waste of time.

> P2: … the grade 9 classes don't have access to ICTs and, as a result, they get bored [and] are not interested in studying sciences because they think it is hard.

> P3: Internet access is a problem, I think, if you teach almost seven classes a day like me. I only get access to two classes, then the rest do not get to use 'plickers' [a free interactive technological tool that uses printable 'paper clickers'] because of, maybe, the data depleting. In addition, I think computers are a problem because we do not have enough computers at the school and those which are available are there for a subject called CAT [Computer Application Technology].

> P6: We don't even have a computer in the staff room, so anyone that wants to use a computer will have to bring their own laptop at home. But, it is not safe to bring the laptop to school, so I rather do it at home, save whatever documents I need to print on a memory stick…

The excerpts above highlight the limitations participants encountered in their efforts to teach science using ICT tools. These concerns align with the findings of researchers such as Tachie (2019). Ottenbreit-Leftwich et al. (2018) corroborate that passionate teachers' ability to integrate ICTs in the classroom are perhaps hindered by the availability of resources or the school contexts in which they find themselves.

Some schools allegedly restrict teacher access to ICT facilities deliberately, or unknowingly, based on the assumption that teachers may exploit these resources for their personal benefit (see Ghavifekr, Kunjappan, Ramasamy & Anthony, 2016; Tachie, 2019). P1, P5 and P6 explained that despite their competence and passion to teach science with the use of ICTs, access was restricted at their schools:

> P1: It is safe to say that the situation at the school was demotivating because there was not even a way to book the computer lab.

> P5: My biggest challenge is having access to ICTs or the room where ICT tools are available… so access and expenses. The school tends to want to save money and refusing us to use the school's Wi-Fi for the benefit of the learners because they think we are going to use [it] for own personal gain…

> P6: … But now that I work in a township school… it's unfortunate that classroom environment there are not suitable for ICTs lessons; all you can do is teach verbally. Although there is a science lab… it [is] not always accessible because you'll find that the senior teacher, responsible for grade 12 classes, uses it as his own.

Munje and Maarman (2017) and Overaa (2014) agree with Fairchild, Meiners and Violette (2016) that the lack of regular access to internet services for teachers deprives learners of opportunities to learn. When access to the internet is restricted, teacher abilities to present a variety of examples to learners or to demonstrate what they teach are restricted (Ghavifekr et al., 2016). Such constraints have negative repercussions for learners (Fairchild et al., 2016; Pholotho & Mtsweni, 2016). Although some teachers in schools with irregular connectivity may resort to using their personal resources to ensure that learners have access to the internet by creating Wi-Fi hotspots, there are bound to be limitations as they may give up when overstretched financially.

The participating beginning teachers lamented that ICT facilities were available in the schools but were not in use. Teachers at these schools were either not interested to integrate ICTs into teaching or did not have the skills to do so, a thought supported by Mailizar and Fan (2020). Like Mlambo et al. (2020), Dlamini (2018) suggests that the lack of interest by some South African teachers to use technology in the classroom probably results from the less aggressive approach towards digital empowerment of pre-service teachers at teacher training institutions. Up to 72% of teachers involved in Dlamini's (2018: 5) study were not comfortable engaging with various forms of technology in their classrooms. The participants in this study who are in alignment with such discourses recounted some not-so-positive experiences:

> P1: Currently, I haven't seen my colleagues that are part of science doing that, using technology to teach.

> P3: Teachers… in this school [second school] don't use ICTs at all… they are not interested to use it. So even if you are trying to ask them what you know… the ICTs tools are just closed in a storeroom, they are not used at all.

Incidences where ICT resources are available but not put to use are neither new nor unique to specific contexts, thus aligning with the findings of De Freitas and Spangenberg (2019), Mlambo et al. (2020) and Tachie (2019). In a Kenyan study, Amuko et al. (2015) also highlighted lack of interest, inadequate technological knowledge to integrate ICTs in the teaching of mathematics and lack of confidence as common challenges in varied contexts.

Another constraint brought up by participants is the lack of security at schools, which creates spaces for vandalism and theft of school property in some school neighbourhoods, preventing the integration of ICTs in the classroom. Arguably, the lack of ICT resources in some schools in South Africa is not because of the lack of provision on the part of the government, but sometimes due to theft. P2 explained:

> [In] the first school, the class was vandalised around January and April when learners did not have a teacher. Wires were cut; I could not even dream to even bring my own devices for safety…

Theft and vandalism seem to be an ongoing challenge constraining the integration of ICTs in developing countries such as South Africa (see Masitsa, 2011). The South African government has to date incurred losses of more than R17 million through the theft of technological equipment in schools (Ramorola, 2018). As such, there is an urgent need for both government and schools to develop policies for responsible internet usage, with strict guidelines for all teachers.

CONCLUSION AND RECOMMENDATIONS

The paper aimed at understanding the enablers and constraints that influence beginning teachers' ability to use ICTs in teaching science. Participants overwhelmingly indicated that learners become motivated and more engaged, with the likelihood to perform better, when taught using technology. Although the participants possessed the competence and passion to use technology in teaching science, they were restricted due to existing challenges. These challenges include lack of ICT resources, access to ICT tools, the school context, unsupportive environments and security concerns. The paper thus highlights enablers and constraints that influence beginning teachers' ability to use ICTs in teaching science. The findings indicate that for South Africa's ICT-integration plan to succeed as intended, it is important to consider the dynamics of implementation in individual school contexts. This therefore calls for the provision of ICT resources in schools and the enactment of policies that can ensure practical use of ICTs in teaching by beginning teachers in subjects such as science and mathematics. The paper recommends a robust approach in the capacitation of teachers in the use of ICTs in the classroom by providing ongoing professional development opportunities. Considering that constraints related to ICT usage are diverse, it is important for the DBE to activate its monitoring and evaluation mechanisms that would assist in identifying context-specific challenges. In addition, the DBE should provide the necessary solutions to enhance the integration process. Furthermore, it might be recommended for the government to relook its budget allocation to schools in the domain of technology to enhance school capacity to purchase internet data on a regular basis and to repair broken computers timeously. Considering that this research focused on a particular province, similar research in other contexts in South Africa is essential to provide a rational picture of the state of ICT integration to holistically inform policy makers on the way forward.

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