A South African Rural Teacher's Experience with Technological Pedagogical Reasoning

Maxwell Tsoka, University of Venda,
Jeanne Kriek, University of South Africa, &
Byung Seo, Chicago State University

Abstract

This study sought to narrate the experiences of a digital novice South African rural teacher, using technological pedagogical reasoning (TPR). The ubiquity and pervasiveness of digital technology is creating a need for teachers to develop TPR to remain relevant in this ever-changing global teaching community. TPR is developed in the real context of a teacher's practice; hence, teachers need to have the experiences of learning to teach with technology in their actual classes. In this study, one South African rural teacher found computer simulations (CS) to be curricular materials with the potential to transform how physical sciences can be taught in South African rural schools. Their affordances are many, depending on how they can be manipulated by the user to add value to their pursuits. In addition, they have pragmatic value to the practice of South African teachers. The benefits of using CS were informed by using the technological pedagogical reasoning (TPR) framework. These affordances were relational, uncovered through an active interaction with the technology and the learners. The use of technology in teaching does not come with a pedagogical manual; hence, their use by the individual teachers is idiosyncratic. Hence, this creates a need for more research in the use of specific technology while teaching in rural schools to develop a more nuanced understanding of TPR.

Keywords: *Computer simulations, South African rural teaching, technological pedagogical reasoning*

Introduction

Schools in South African rural areas are characterized by lack of basic teaching and learning materials, classrooms with adequate furniture, computers and connectivity to the internet (Bo et al., 2018; National Education Infrastructure Management System [NEIMS], 2020). These challenges not only constrain but perpetuate the teaching of physical sciences via rote learning (Banilower et al., 2018), and it is often characterized by conditions that inhibit rather than support higher-level scientific sense-making by learners (Minner et al., 2010). Consequently, learners in South African rural schools are at a greater risk of failing due to poor meaningful learning experiences or of dropping out due to repeated failures (Hardy, 2019). Learners in South African rural schools are highly predisposed to becoming school dropouts, and their opportunities to participate in higher education are limited due to their poor performances (Abotsi et al., 2018; Imoro, 2009). In addition, learners often matriculate from high school with no long-term retention of what they learned and less interest in additional interests in science (Duncan, 2011).

It has been observed that many schools in rural areas are exposed to teaching and learning challenges that can be mitigated by technology (Nkula & Krauss, 2014; Salinas, & Sánchez, 2009). However, the question is, how are teachers going to be persuaded to integrate technology into their routine instruction to provide meaningful learning experiences for their learners? Teachers need to be responsive, in light of the evidence highlighting the efficacy and potential of technology in order to mitigate the perennial challenges that continue to plague the quality, equality and equity in rural schools (Lubin, 2018). There is evidence associating specific uses of digital technologies in teaching and learning with positive impacts on student outcomes (Tamim et al., 2011; Underwood, 2009). Therefore, teachers must pay attention to the current research. They need to be adaptive and responsive to the stimuli, adopting technology to transform their instructional practices. Collective responsiveness is necessary to improve teaching that has prioritizes learners at the heart of professional learning. Collective responsiveness requires teachers with a willingness and responsibility to reinvent themselves via classroom inquiry and knowledge production.

Teachers in rural areas are not inclined to integrate digital technology into teaching and learning (Bo et al. 2018). This situation seems to mirror the digital divide between urban and rural areas (Salinas & Sanchez, 2009). A number of reasons have been suggested as to why teachers do not integrate digital technology into their routine instruction, such as teachers' attitudes (Gilakjani & Leong, 2012), lack of technological skills to integrate technology into practice (Bang & Luft 2013), and lack of effective/adequate professional development (Walan, 2020). As a result of these issues, this study sought to narrate the responsiveness of one particular science teacher in a South African rural school who used digital technology in spite of the barriers at his school. For the purposes of this study, digital technology refers to the use of computer simulations (CS).

There is a dearth of studies in emerging market and developing economies (International Monetary Fund, 2015[1]) especially in rural areas that have reported teachers reflecting on their use of specific digital technology in situ. Whilst the term rural may refer to a geographical location, it is the economic and historical connotation that makes the term/context, an influencing factor in this study. Historical settlement policies of the apartheid government created homelands or bantustans where Africans after being disposed from their productive land, were resettled. Because of the legacy of apartheid, these contexts have a low socio-economic status characterized by poor/dysfunctional family structure, high unemployment and reliance on government social grants, high illiteracy levels, lack of basic services such as running water, electricity, sanitation, health and educational facilities, and inadequate physical and information, communication technologies infrastructure(Gardiner, 2008; Hlalele,2014;Mosimege et al, 2015). In many of the schools, where the national school nutrition program is being implemented, the food is prepared, cooked outside over fires and served outside or in classrooms that are used for learning and teaching. None of the schools have eating facilities. Many learners commute long distances to and from school every day. While some of the schools have been (re)built in recent years from brick, others still use mud structures and containers as school classrooms (Mosimege et al., 2015). As a result of the government no-fee policy on all schools in the quintile 1-3 category, of which most schools in rural areas fall, the classrooms are overcrowded with most schools having more than 45 learners per classroom (Hlalele, 2014; Gardiner, 2008). When it rains, some learners are not able to come to school

1. World economic and financial surveys-October 2015/ www.imf.org/eternal/pubs/ft/weo/2015/02/weodata/groups.htm#cc

because there are no bridges to cross when rivers are flooded. Unfortunately, these conditions have a bearing on rural education and their influence on schooling provision can never be underestimated. While the rural areas will always be a unique set-up, there is need for discourses/research that will not pathologize rurality. The "rural" conversation in South Africa is currently presented with deficiency scripts (Ebersöhn & Ferreira 2012), conceptualized on the basis of what rural areas "do not possess" and in many cases "will never possess" (Hlalele, 2014).

Not many studies tend to recognize rural public schools and their teachers as places and people of innovation and alternative pedagogical effectiveness (Tembrevilla, 2020). Hence, little attention is paid to the potentially positive aspects of rural teaching and the potentially positive experiences of rural teachers that may impact learning (Buckler, 2011). There is need to reject deficit discourses that are often portrayed and fail to go beyond recognizing schools in rural areas as disadvantaged. Teachers working in rural areas are individuals who should be considered to have free will to create their own world and not to have their fate determined by their social context (Elder, 1994). The debate within the education circle (irrespective of context) has shifted from *whether* to *how* teachers should integrate technology in their routine instruction in order to meet the challenges of the 21st century and make education relevant, responsive, and effective for anyone, anywhere, anytime (Haddad & Draxler, 2002). Hence, how teachers are responsive to this phenomenon in rural context is worth researching and is the focus of this study.

Teaching with digital technology is wisdom of practice (Shulman, 1987) which is developed during integration in the real-world messiness of everyday classroom practice. Smart (2016) refers to it as technological pedagogical reasoning (TPR). The argument of this study is that teachers with developed TPR are inclined to successfully integrate digital technology seamlessly into their instructional practice. Increasing experience of teaching with technology makes science teachers feel more self-efficacious for using digital technology in their classrooms (Yerdelen-Damar et al., 2017). With a developed TPR, teachers are able to make decisions on the appropriate combination of instructional design and classroom orchestration (Magana et al., 2021). For the purposes of this study, TPR is a process where teachers make use of the identified affordances of digital technology as they carry out instructional activities for the purposes of facilitating learning. It is a robust nascent concept that continues to evolve due to the ever-changing face of technology, a concept that distinguishes the teacher from other professionals. TPR is both a creative and idiosyncratic process intended to potentially transform content as prescribed in the curriculum policy document into formats that are readily accessible to specific learners in their contexts. Also related to this goal is the idea that curriculum materials are seldom packaged to be intrinsically motivating, nor presented in any way to be particularly meaningful or relevant to the learners' daily lives or purposes (Ryan & Deci, 2017). In this transformation process, digital technology is expected to plays a mediatory role to enhance content transformation. Research on TPR helps to understand teachers' actions (both seen and unseen) and how these mediated actions support learning. There is no universal approach to teaching with technology, and in most contexts, the practical implementation of technology in teaching is largely left to individual teachers (Tallvid, 2015). Through TPR, a teacher's knowledge, skills, judgements and analysis in decision-making processes are manifested and can be studied (Holmberg, Fransson & Fors, 2017). This makes the process amenable to theorization.

Therefore, this study seeks to answer the question: How does a South African rural teacher's experience technological pedagogical reasoning (TPR)?

Computer simulations (CS) are interactive computer programs that are designed to represent or model a particular scientific phenomenon. Computer simulations are emerging learning technologies that research has evinced their efficacy in the teaching and learning of science (Bo et al., 2018). They have the potential to transform teaching practices and afford learners the opportunity to learn physical sciences in an inquiry-oriented approach (Minner et al., 2010). Their potential is realized when they are used with others to achieve a pedagogical purpose (Milner-Bolotin, 2016). These simulations can be used as a medium for communication, inquiry or for motivation purposes (Gonczi et al., 2016; Plass et al., 2012). They present content-as-animated pictures (CAP), visual representations of dynamic theoretical entities that are critical for understanding why matter behaves as observed (Ardac & Akaygun, 2004; Honey & Hilton, 2011). However, their use within schools in rural areas is to a large extent minimal and without clearly defined purpose (Bo et al., 2018). To properly design learning interventions using CS, and more importantly, how to actually adopt, adapt and integrate them in instructional practice for specific audiences and contexts, is a complex task (Kriek & Coetzee, 2021).

As a result of the pervasiveness of digital technology inside and outside the school, teaching with technology is the sine qua non for the 21st century teacher. However, TPR is a new phenomenon that has been triggered by the invasion of digital technology into the education landscape. It is thus a nascent phenomenon that involves the teachers' use of technology to leverage curriculum adaptation, planning and enactment. This integration is a positive departure from the kind of teaching and learning that has typified physical science education in rural South Africa. It is intended to enhance the quality of learning experiences to make science lessons more meaningful and appealing to learners.

Technological Pedagogical Reasoning (TPR)

This study employed Smart's (2016) model of technological reasoning as both a theoretical and analytical framework (Figure 1). This framework was deemed applicable as it guides the novice teacher on which actions/aspects of teaching to execute using the potential affordances of digital technology. It thus can serve as a model for self-directed professional development. The framework also identifies components of the knowledge base for teaching which influences and guides TPR.

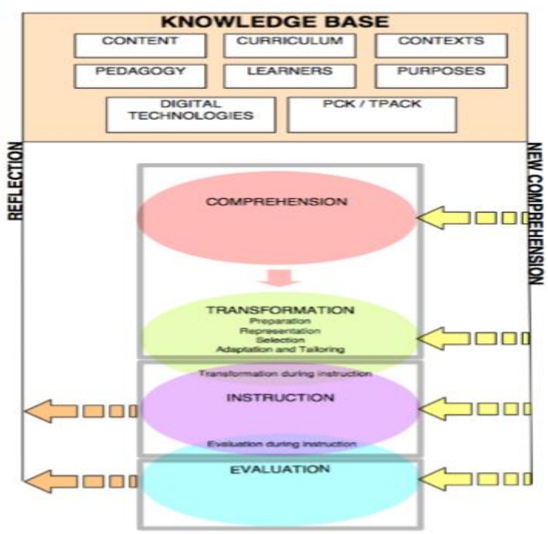

Figure 1: *Smart's Model of Technological Pedagogical Reasoning* (2016, p. 300)

Shulman (1987) refers to pedagogical reasoning as a set of cognitive sub-process undertaken by teachers when they transform the content into formats that are accessible to learners. The sub-processes are: comprehension; transformation; instruction; evaluation; reflection and new comprehension. There are overlapping processes that have also been identified by Smart (2016) namely: transformation-during-instruction and evaluation-during-instruction. Therefore, TPR is the integration of technology to carry out these sub-processes.

Comprehension

As argued by Shulman (1987), to teach is to understand the content as outlined in the curriculum statement (syllabus). Previously, this process involved searching for content in the textbooks since books were the major teaching tool to access scientific material (Moreno et al., 2001). However, web-based resources are increasingly becoming popular and readily accessible for retrieving information useful for teaching purposes. Thus, the digital resources that teachers can access and select for inclusion in a learning environment are becoming enormous. The search for content is no longer restricted to only textbooks, but it involves the search for relevant and appropriate virtual simulations on the internet to address the content as prescribed in the curriculum document. Computer simulation visuals present teachers with the opportunity to understand new content developments when compared to textbook presentation. As a South African rural teacher who is writing his experience with the digital technology, CS presents teachers with an opportunity to engage with content/ideas in an interactive way which opens epistemic agency in learners.

Transformation

In the transformation process, the disciplinary content is to be "educationally reconstructed" (Duit et al., 1996, p. 36) or what is called contextual reconstruction a critical process necessary for teaching. The process of contextual reconstruction is concerned with *contextualization of content*, transforming the content as prescribed in the curriculum statement into a format suitable for teaching and learning in that context. Shulman (1987) conceptualized transformation as four sub-processes: critical interpretation (preparation), representation, selection and adaptation and tailoring. Today, some of the sub-processes of transformation have been eliminated by the use of technology. The selection of suitable computer simulations is one way to transform the content as well as adapting and tailoring it to the needs of the learners. This selection of computer simulation refers to the action of the teacher in purposefully choosing and adopting computer simulations from diverse websites in order to accomplish the lesson objectives. Also, the process of selecting computer simulations is an attempt to "scrutinize" the teaching material in order to decide whether it is fit to be taught and if it is not, to decide how it could be "made more suitable for teaching" (Shulman, 1987, p.16).

Transformation-during-Instruction

Initially, Smart (2016) refers to transformation-during-instruction (T-d-I) as occurring when teachers have to adopt contingency plans and change learning activities temporarily or permanently due to failure of working of digital technologies. However, T-d-I occurs even when there is no failure in working of technology. For example, learners can ask questions with ideas which are or are not directly related to the content under consideration. Teachers need to respond to such questions and clarify the ideas that learners would have stated. In other instances, teachers need to link the ideas of the current lesson with ideas from previous or future lessons. These cases are considered as T-d-I

Instruction

In this context, the term "instruction" will simply be defined as all activities (both cognitive and physical) undertaken by teachers and learners which have the intent of learning new information (Beauchamps, 2011). Technology could play a transformative role by enabling teachers to exploit a wide range of interactive opportunities with learners during instruction. It could transform the way the teacher organizes and manages the classroom while enhancing classroom communication and the interaction with learners. During instruction, there are varying levels of CSs that can be used by teachers depending on their experience and skills

Evaluation-During-Instruction

Smart (2016) also identified the overlapping of evaluation and instruction which she terms evaluation-during-instruction (E-d-I). E-d-I occurs when the teacher either probes for prior knowledge or when the teacher moves around the classroom checking for understanding.

Evaluation

The boundary between evaluation and instruction is usually vague and difficult to delineate. An assessment of learning and how the teaching is progressing is usually on-going and not left until the end of instruction. Using CS enables teachers to execute several approaches to evaluate learners' learning. These include asking direct questions to individuals, groups and/or whole class; peer evaluation; and moving around the room and watching over learners (Smart, 2016). These approaches are examples of E-d-I. In contexts where schools have adequate digital technological infrastructure, teachers use these technologies to check learners' assignments and provide feedback, and learners can use digital technologies to prepare and submit assignments. However, in impoverished schools, this ability is not feasible.

Reflection

Reflective reasoning is equivalent to what Schön (1983) called reflection-on-action. In this phase, the teacher looks back at the teaching and learning that has occurred and reconstruct, re-enact and/or recapture the critical events, emotions and accomplishments or failures to derive pedagogical shifts in their planning and instructional phases. Based on the pedagogical shifts gained, the teacher may reconstruct and/or re-enact part of the practice in future cycles (Shulman, 1987). Smart (2016) reports that many experienced teachers' reflections focused on their successes of using new digital technologies or of using new digital technologies in the classroom for the first time. Though teachers have no regular formal processes for recording reflection, reflections can enlighten all aspects of pedagogical reasoning.

New Comprehension

New comprehension is the new insights gained after a successful pedagogical reasoning cycle. The new comprehension now informs the new cycle of pedagogical reasoning. Teacher gains new insights (pedagogical shift) into his teaching through reflecting on the acts of comprehension, transformation, instruction and evaluation. These insights usher in a new understanding of content to be taught, of students, of purposes, of self and of the process of teaching itself (Geddis & Wood, 1997). New comprehensions consist of all that was learned from the cycle of pedagogical reasoning processes and how things might be done differently. Obtaining new comprehension also takes into account the selected approach, environmental situations, emotions experienced by students and by the teacher, and other such internal and external factors (Nyamupangedengu, 2017). This new comprehension usually does not come immediately or after the reflection stage; it normally takes longer (Shulman, 1987).

Methodology

The use of CS was a new phenomenon to the lead author. Therefore, he wanted opportunities to reflect on the use of the technology in real time. The research design used in the study is action research (AR). This study was completed in three iterations over a period of three years with three different classes. In all of the classes, the topic of instruction was electromagnetism. This topic was chosen based on the previous experiences of the lead author and other researchers where they found that learners had challenges with understanding concepts in electromagnetism (Zenda, 2016).

Data sources were the reflective journals of the lead author, classroom observations by external researchers and peer teachers, focus group discussions with learners, and artifacts such as lesson plans and curricular documents. The use of many data sources was to triangulate data for enhanced validity.

The sub-processes of Smart's (2016) model of TPR were used as codes. The use of pre-codes was influenced by the use of technology in teaching, which was a new phenomenon to the lead author; hence, he wanted to reflect on the use of CS on those common aspects of the teacher thinking processes as identified in literature.

Results

Comprehension

The teacher consulted the curriculum document (CAPS) (South Africa Department of Basic Education [DBE], 2011) for the content to be taught and this resulted in formulating the objectives of the lesson because these objectives were not provided to South African teachers. As the lead author interacted with the document, he was disturbed and confused by the significance of DBE assigning only six hours to the teaching of the topic. Many questions came to the teacher's mind that needed answers:

> What did the curriculum planners consider when allocating the topic six hours? Are learners constrained to understand the topic in six hours? Do learners have the same capacity to

understand the topic in six hours? If the learners didn't understand the content in six hours, what's next? Is the six hours also allowing time for preparation?

Whilst the teacher was the one asking these questions, he also felt challenged because he was unable to answer them. If the six hours were the time to cover the described content, it would assume that the teacher was going to be teaching a homogenous class of learners. Furthermore, by stipulating the time, the focus is now on the content and not on the learners. The teacher also inquired from a colleague about his interpretation of the six hours and he did not get a satisfactory response.

Transformation

After getting an understanding of the content to be taught, the teacher was now prepared for the second stage which was the transformation of the content into formats that would be accessible to learners. This process involved a series of actions that included searching the internet for suitable computer simulation suites, planning practical activities to involve learners and how the activities could be sequenced and finally drafting the lesson plan. The selection of computer simulations was a critical process because these computer simulations were not designed for the physical sciences curriculum for South Africa. Teachers' search behaviours and selection practices becomes critical to provide teachers with readily available, and useful, online CS (Burron & Pegg, 2021). The selection of CS was based on a particular criterion. Introducing these criteria supported the teacher in selecting those simulations needed to cover the prescribed content, whilst at the same time adapting and tailoring the content to meet the needs of the learners. The criteria for these simulations are:

- Relate to the electromagnetism concepts prescribed in the CAPS document. This consideration is important for the achievement of the objectives of the lesson and the integration between the animations and the curriculum for the success of the animations (Barak & Dori, 2011).
- Present 3D representations, which promote learners' spatial visualization ability thereby enhancing learners' understanding by "providing a degree of reality unattainable in a traditional two-dimensional interface" (Kim et al., 2001, p. 38). Interactive 3D simulations have the potential to enhance learners' conceptual development of the basic science phenomena (Huang et al., 2015)
- Depict the dynamic, transient and interactive nature of scientific phenomena (Wu & Shah, 2004).
- Link the macro-processes with the micro-processes.
- Provide affordances that enable learners to interact with the animation and manipulate variables and entities (Akpınar 2014; Velazquez-Marcano et al., 2004; Wilkerson-Jerde et al., 2015)
- Link abstract concepts to real-world examples (Kozhevnikov & Thornton 2006; Wang et al., 2014)
- Be suitable for the learners and support the learning experience.

The transformation stage is very important as it ensures that content has been reduced into formats/representations that enables learners to potentially develop an in-depth understanding of that content and develop key skills. Transformation is intended to enhance the learners' process of transformation- how learners make sense of the new information with respect to their prior knowledge, resulting in restructuring it for meaning making.

Transformation-During-Instruction

Among the suites of computer simulations that were selected, none could be found that was suitable to demonstrate the magnetic field around a loop. It was therefore necessary to use the CS that was used earlier to demonstrate the magnetic field around two straight conductors. The reason for using this CS suite as written in this reflective journal was because

> I could not find a suitable computer simulation to demonstrate the magnetic field around a loop and so I decided to use this computer simulation of two parallel lines with current flowing in opposite directions to demonstrate the field around a loop. It really worked because the magnetic fields are the same around a loop and around two parallel wires with current flowing in opposite directions. In this computer simulation changes in the values of current could be made and learners can observe the outcome or feedback and be able to generate a hypothesis, draw conclusions or formulate a model (August 2015).

Transformation-during-Instruction is evidence of the contingent nature of teaching (Forzani, 2014), which requires in-the-moment action/decision-making.

Instruction

During the instructional phase, the computer simulations were projected on a white screen which was at the front of the room, so that they could be used in a whole-class setting. The teacher manipulated the simulations for two reasons. Firstly, learners were not familiar with this learning tool and had no learning experiences with them in previous classes. Secondly, the teacher wanted to guide learners to the important concepts that they had to understand. Through the manipulation of computer simulations, the teacher was able to deliberately change and vary the way of asking questions. Every move/manipulation of the simulation was a source/initiator of a question. Hence, the teacher moved away from the traditional South African practice of dictating notes while learners were passively copying the notes. On the contrary, the ensuing dialogue resulted in a pattern of interaction where the teacher initiated the questions for discussion, the learners responded, and the teacher sought for the confirmation of the response from other learners. The questions required learners to give more elaborate answers. Noted in his reflective journal:

> The discussions I had with the learners gave me an opportunity to elicit their ideas and to understand their thinking. I am particularly excited with the communicative power of computer simulations. They provide an environment for exploration through dialogue and questioning opportunities. When asking a question, I no longer need to evaluate whether the response is correct or wrong myself, other learners are able to confirm if it is wrong or correct**.** This makes the teacher no longer the arbiter, but multiple learner voices are allowed to speak. However, where it was necessary, I was called to correct wrong ideas that learners may have (August, 2015).

While reflecting on the prior reflection (retro-reflection), the lead author realized an interesting approach to questioning[2], which was shaped by the use of computer simulations. This approach was an attempt to move away from a monologue and authoritative discourse to a more inclusive and dialogic discourse. The attempt to open the dialogic space was motivated by the desire to involve learners in knowledge-building processes. From a learner's perspective, dialogic teaching affords them with greater epistemic agency (Ko & Krist, 2018), resulting in authorship, meaning and more equitable opportunities to learn (Resnick, Asterhan & Clarke, 2015).

Evaluation-During-Instruction

The responses by learners to the teacher's questions showed that computer simulations were very helpful as evidenced in the following excerpt. The responses showed learners who were able to read and interpret the computer graphical displays.

> Learners were able to give valid descriptions of the magnetic field around the current-carrying conductors. One learner was able to give a description, which I had not anticipated. He said that the field was non-uniform as evidenced by the fact that the circles were not equidistant, with the field lines near the conductor very close together while those far from the conductor were farther apart. He even suggested that the field was, therefore, stronger near the conductor while weak far away from the conductor. I perceive that computer simulations can provide supportive guides which assist learners against going astray both scientifically and operationally (Reflective journal, August 2015).

It is therefore important to encourage learners to rely on their own experience as opposed to solely depend on the utterances of teachers. This increases learning, creativity, and insight on the part of learners (Barzouka et al., 2015). It is therefore critical to highlight that the role of the teacher when using CS is now skewed towards "highlighting authentic and relevant information, providing sufficient background material and following up by providing novel insights, interpretations and perspectives" (Sitaraman, 2021, p. 2).

New Comprehension

Selection of various CS is an important process of transforming content. It enhances the comprehensibility of content since different CS have different features which can be used to adapt and tailor the content to the requirements of the curriculum. Noted in his reflective journal:

> The various prompts and cues that are found within some computer simulations are intended to adapt and tailor our lessons to the needs of learners. Some of the computer simulations on the internet are meant to be used by learners in high schools as well as students in college or university (August 2015).

2. The following serves as an example. In a lesson on electromagnetic induction, instead of telling them what happens when a magnet is moved towards the solenoid, I asked them what their observations were when the magnet is moved towards the solenoid. It was not only the lighting of the bulb they referred to but also the moving of the electrons. The question does not require a yes/no. Instead, requires the learner to verbalise and express their thoughts in their own words. The role of the teacher, in this case, is to participate in learners' discussion as a peer and to co-construct knowledge with the learners.

The process of searching for new CS is ongoing since there are new CS with new features that are developed and designed. The selected computer simulations used in this lesson had limitations. It was not possible to change some of the variables for learners to observe the effect, for example, on the magnitude of the magnetic field, when the current is varied. Learners were therefore unable to hypothesise the relationship between current and magnetic field on their own.

Computer simulations are not only the medium to display the content but also the medium through which the content is delivered. These simulations provide supportive and engaging multimedia features that permits content to be displayed pictorially and not through the use of abstract text. Thus, computer simulations can display content-as-animated pictures (CAP), a new learning affordance available to learners in schools in South African rural areas. At the same time, CS allow the teacher to engage in dialogic talk with the learners as they explore the various graphical representations caused by changes to the initial state of the computer simulations. It has both pragmatic and epistemic value. The teacher no longer relies on the textbook as the only curricular material when sourcing for content. The lead author found CS graphically illustrated scientific phenomena better than explanations by the teacher, textbook or any other curriculum material. No matter how well a teacher explains scientific phenomena, the effect on student learning is not the same as when learners view it using CS. Other curricular materials do not explicitly demonstrate the dynamic nature of scientific phenomenon in the manner that CS do.

Discussion

Computer simulations are essential curricular materials and epistemic tools that teachers working in unique contexts such as schools in rural areas can adopt and adapt to design tasks of teaching (Ball, 2000), which can engage learners in meaningful learning as opposed to rote learning. Keeping in mind, these rural areas still lack clean running water, classrooms, furniture, electricity, libraries, textbooks, laboratories, computers, and connectivity to the internet. Smart's (2016) model identifies these tasks of teaching. As curricular material, CS has potential affordances to guide/influence teachers' curriculum adaptation, planning, and enactments, because CS are not only the source of content but also the medium through which the same content is made accessible to learners. As a tool that can be used to engage learners in knowledge construction practices, it also qualifies as an epistemic medium (Miettinen & Virkkunen, 2005). The use of the term "medium" is consistent with Romiszowski's (1988) conceptualization of medium as a carrier of messages, from some transmitting source to the receiver of the message (p. 8). The selection of a number of computer simulations provides affordances that assist the teacher in meeting the content requirements of the curriculum while at the same time tailoring the content to the needs of the learners. It is important to note that not all simulations have the same features. It is therefore important for teachers to know how they can manipulate (T-d-I) the available CS in the event that there is no suitable one to demonstrate the concept. The CS leverages the interrogative ability of the teacher in that every move/manipulation of the simulation is an initiator of a question. Engaging learners through dialogue is an intentional attempt of opening up dialogic space in classroom interactions thereby encouraging learners "to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (Engle & Conant, 2002, p. 404). The use of computer simulations "stimulate language use" (Tomlison, 2003, p. 2), namely the language of science. One of the general aims of the CAPS (section 1.3 d) (DBE, 2011), is to develop learners who are able to communicate effectively using visual, symbolic and/or language skills in various modes. Thus, CSs can be used by teachers to engage learners to communicate science ideas using terms/words that are familiar to them. The affordances of CS present teachers with opportunities of opening up aspects of their curriculum (Ko & Krist, 2018), a practice that allow learners to be part of the knowledge- building processes. Learners are then positioned as collaborators in co-constructing knowledge as opposed to passive consumers. This kind of learning is the emphasis of current reforms in science education to support learners' deep sense-making through their participation in science knowledge-building practices (National Research Council, 2012).

TPR is an attempt to make sense of how the affordances of digital technology can be appropriated to leverage tasks of teaching in a particular context. Thus, the manifestation of TPR indexes the conception of teaching/learning that teachers hold. Not a one-off event, it is a process that is negotiated and intricately linked to the qualities of interactions among the teacher, learners, content and CS. The teacher makes sense of the potential affordances of digital technology by reflecting on the use of the digital technology in- and on-action as they interact with the learners and content. It is important that professional development of teachers should enable them to have opportunities to reflect on their actions and how they affect learning. Practical knowledge is developed through a reflection on their accounts of experiences, which are individually, continuous and situated in cultural and social contexts (Han & Feng, 2015). However, teachers, rarely have an opportunity for reflective analysis on their instructional methods (Cohen & Hill, 1998; McLaughlin & Talbert, 2001). As a result, teachers in rural schools lack a deliberate process for developing contextual, practical knowledge to address the challenges they encounter, and at the same time, engaging teachers in learning about teaching with technology.

Finally, TPR is not a phenomenon only focused on teachers but learners as well. There has been criticism of models of pedagogical reasoning as being only teacher centered. This criticism fails to recognize the inherent purpose of TPR, which is to design and create meaningful learning experiences for learners. Thus, TPR results in new comprehensions, a common feature on all models of pedagogical reasoning, in new knowledge, attitudes, and skills (KAS). The intended outcome is the creation learning environments that support learners' understanding of scientific concepts by appropriating the affordances of digital technology. For South African rural teachers, TPR can be conceptualized as having the following phases: Plan, Enact, Review, and New Comprehension. These phases are depicted in Figure 2:

Figure 2: *Model of Technological Pedagogical Reasoning for a South African Rural Teacher*

During the planning phase, the teacher designs the lesson activities as informed by the curriculum policy, which involves searching for the CS that can be used to deliver the prescribed content. The action of designing learning activities is an attempt to transform the prescribed content to be intrinsically motivating and made to be particularly meaningful or relevant to the learners' daily lives or purposes (Ryan & Deci, 2017). For example, a learner commented,

> …we never knew that magnet can induce current and that current can be induced by magnetism, so it really taught us a lot. Now we know that maybe if we want a magnet, and we don't have a magnet we [can] use current to induce magnetism…

Learners become motivated as they can see relevance in the knowledge they are gaining.

The enactment phase involves the teacher interacting with learners using CS to engage with the chosen content. Within the enactment phase are important sub-phases such as transformation-during-enactment and evaluation-during-enactment. Transformation-during-enactment is an instance when the teacher is compelled to makes on-the-spot instructional changes because of unplanned circumstances that might derail the flow of the lesson. Evaluation-during-enactment is when the teacher assesses learners to check their level of comprehension or the difficulties that learners might be encountering to understand the content. The review phase involves the teacher reflecting on what transpired during the enactment phase: what went right or wrong, or areas that can be further improved. The insight gathered from the reflection on the lesson forms the teacher's new comprehensions. Thus, the new comprehensions should include new knowledge, attitudes and skills. This model includes the routine basic tasks of teaching for teachers in South African rural areas.

Conclusion

Mastery experiences are critical to the development of TPR as they provide teachers with the opportunity to identify/discover potential affordances of digital technology they can manipulate for instructional purposes. Such learning experiences are not only professional but also authentic and embedded in subject matter and connected to the teachers' own practice. The ability to identify potential affordances is an active sense-making and problem-solving process during which the teacher interacts with the learners, and the learners interact with the teacher. Thus, TPR is influenced by digital technology, and at the same time, it influences the way that digital technology is used within particular contexts. TPR is idiosyncratic and cannot be cloned. Digital technology is not the silver bullet to all the challenges in teaching; it does not possess inherent instructional value. It is the concerned teacher who ascribes value that digital technology adds to the teaching and learning processes. Successful use depends on what the teachers concerned intend to achieve, even when teaching the same content. The authors suggest that it is here where South African researchers, policy makers and administrators are incorrect. It is not that teachers are recalcitrant to the pedagogical use of digital technology. There is an attempt and inclination by researchers/policy-makers to force teachers to use particular ways of digital technology use that have been reported/suggested to generally work elsewhere in a different context. As a result, there is no consideration to the contexts of the concerned teachers and the instructional value they intend to derive from the use of specific technology. Teachers have different goals for integrating technology in their instructional practices. South African science teachers should be encouraged and supported to design their signature teaching approaches using technology in ways that addresses their concerns and contexts. In this way, South African teachers have learning opportunities to further improve their practice while at the same time developing practical knowledge relevant to their contexts. Despite the challenges that South African rural schools continue to endure, CS is both pedagogical and epistemic tools, a resource that can be used by teachers to leverage curriculum adaptation, planning, and enactment. These curricular materials are at the disposal of teachers in South African rural areas to transform the learning environment/pedagogy from one of vulnerability to one of resilience.

References

Abotsi, A. K., Yaganumah, N., & Obeng, H. E. (2018). Dropouts issues and its economic implications: Evidence from rural communities in Ghana. *Journal of Economics and Economic Education Research, 19*(1), 1-13.

Akpınar, E. (2014). The use of interactive computer animations based on POE as a presentation tool in primary science teaching. *Journal of Science and Technology Education, 23*, 527-537.

Ardac, D., & Akaygun, S. (2004). Effectiveness of multimedia-based instruction that emphasizes molecular representations on students' understanding of chemical change. *Journal of Research in Science and Teaching, 41*, 317–337.

Ball, D. L. (2000). Bridging practices: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education, 51*, 3-21.

Bang, E., & Luft, J. A. (2013). Secondary science teachers' use of technology in the classroom during their first 5 years. *Journal of Digital Learning in Teacher Education, 29*(4), 118-126.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). *Report of the 2018 NSSME+*. Chapel Hill, NC: Horizon Research, Inc.

Barak, M., & Dori, Y. J. (2011) Science education in primary schools: Is an animation worth a thousand pictures? *Journal of Science Education & Technology, 20*: 608-620.

Barzouka, K., Sotiropoulos, K., & Kioumourtzoglou, E. (2015). The effect of feedback through an expert model observation on performance and learning the pass skill in volleyball and motivation. *Journal of Physical Education and Sport, 15*, 407-416. doi:10.7752/jpes.2015.03061

Beauchamp G (2011) Interactivity and ICT in the primary school: Categories of learner interactions with and without ICT. *Technology, Pedagogy and Education, 20*(2), 175-190.

Bo, W. V., Fulmer, G. W., Lee, C. K., & Chen, V. D. (2018). How do secondary science teachers perceive the use of interactive simulations? The affordance in Singapore context. *Journal of Science Education and Technology, 27*, 550–565. https://doi.org/10.1007/s10956-018-9744-2

Buckler, A. (2011). Reconsidering the evidence base, considering the rural: Aiming for a better understanding of the educational and training needs of sub-Saharan African teachers. *International Journal of Educational Development, 31*(3), 244-50.

Burron, G., & Pegg, J. (2021). Elementary pre-service teachers' search, evaluation, and selection of online science education resources. *Journal of Science Education and Technology, 30*, 471–483.

Cohen, D. K., & Hill, H. C. (1998). *State policy and classroom performance: Mathematics reform in California*. PA: Consortium for Policy Research in Education.
Department of Basic Education [DBE]. (2011). *Curriculum and Assessment Policy Statement Grades 10–12 Physical Sciences.* Pretoria, South Africa: Government Printing Works.
Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of Educational Reconstruction- A framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.) *Science Education Research and Practice in Europe: Retrospective and Prospective* (pp. 13-37). Rotterdam, Netherlands: Brill.
Duncan, A. (2011, March 25). Arne Duncan on American education: We have a crisis on multiple levels. Retrieved from PBS: http://www.pbs.org/wnet/need-to-know/video/video
Ebersöhn, L., & Ferreira, R. (2012). Rurality and resilience in education: place-based partnerships and agency to moderate time and space constraints. *Perspectives in Education, 30*(1), 30-42.
Elder, G. H. (1994). Time, human agency, and social change: Perspectives on the life course. *Social Psychology Quarterly, 57*(1), 4–15.
Engle, R. A., & Conant, F. R. (2002) Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction 20*(4), 399-483.
Forzani, F. M. (2014). Understanding "core practices" and "practice-based" teacher education: Learning from the past. *Journal of Teacher Education, 65*(4), 357–368.
Gardiner, M. (2008). *Education in rural areas: Issues in Education Policy Number 4*. Johannesburg South Africa: Centre for Education Policy Development.
Geddis, A. N., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education, 13*(6), 611-626.
Gilakjani, A. P., & Leong, L.-M. (2012.) EFL teachers' attitudes toward using computer technology in English language teaching. *Theory and Practice in Language Studies, 2*(3), 630-636.
Gonczi, A. L., Chiu, J. L., Maeng, J. L., & Bell, R. L. (2016). Instructional support and implementation structure during elementary teachers' science education simulation use. *International Journal of Science Education*, *38*(11), 1800–1824. https://doi.org/10.1080/09500693.2016.1217363
Haddad, W., & Draxler, A. (2002.) The dynamics of technologies for education. In Haddad and Draxler (Eds). *Technologies for Education: Potentials, Parameters and Prospects* (pp.3-17). Washington, DC: UNESCO and the Academy for Educational Development.
Han, X., & Feng, Z. (2015). Chapter 24: School-based Instructional Research (SBIR): An approach to teacher professional development in China In C. Craig, P. C. Meijer, & J. Broeckmans (Eds.) *From teacher thinking to teachers and teaching: The evolution of a research community* (pp. 503-525). Bingley, UK: Emerald Group Publishing Limited. http://dx.doi.org/10.1108/S1479-3687(2013)0000019027
Hardy, A. (2019). *Capability approach and teacher quality: An analysis of female teacher experience in a rural, Malawian community*. (Paper No. 3527). Electronic Theses and Dissertations. https://dc.etsu.edu/etd/3527
Hlalele, D. (2014). Rural education in South Africa: Concepts and practices. *Mediterranean Journal of Social Sciences 5*(4), 462-469.

Holmberg, J., Fransson, G., & Fors, U. (2018). Teachers' pedagogical reasoning and reframing of practice in digital contexts. *The International Journal of Information and Learning Technology 35*(2), 130-142. https://doi.org/10.1108/IJILT-09-2017-0084

Honey, M. A., & Hilton, M. (2011). *Learning science through computer games and simulations*. Washington, DC: National Academies Press.

Huang, S., Mejia, J. A., Becker, K., & Drew, N. (2015). High school Physics: An interactive instructional approach that meets the Next Generation Science Standards. *Journal of STEM Education: Innovations & Research. 16*(1), 31-40.

Imoro, B. (2009). Dimensions of basic school dropouts in rural Ghana: The case of Asutifi district. *Journal of Science and Technology, 29*(3), 72–85.

Kim, J. H., Park, S. T., Lee, H., Yuk, K. C., & Lee, H. (2001). Virtual reality simulations in physics education. *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning*. Retrieved from http://imej.wfu.edu/articles/2001/2/02/index.asp

Ko, M. L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education. 103*, 979–1010. https://doi.org /10.1002/sce.21511

Kozhevnikov, M., & Thornton, R. (2006). Real-time data display, spatial visualisation ability and learning force and motion concepts. *Journal of Science Education & Technology 15*(1), 111-129.

Kriek, J., & Coetzee, A. (2021). Exploring the intricacies of lecturer and student beliefs when using different technology tools in a tertiary context. *International Journal of Technology Enhanced Learning, 13*(2), 121-138 https://doi.org/10.1504/IJTEL.2021.114049

Magana, A. J., Chiu, J., Seah, Y. Y., Bywater, J. P., Schimpf, C., Karabiyik, T., Rebello, S., & Xie, C. (2021) Classroom orchestration of computer simulations for science and engineering learning: a multiple case study approach, *International Journal of Science Education, 43*:7, 1140-117.1

McLaughlin, M., & Talbert, J. E. (2001). *Professional communities and the work of high school teaching*. Chicago: The University of Chicago Press

Miettinen, R., & Virkkunen, J. (2005). Epistemic objects, artefacts and organizational change. *Organization, 12*(3), 437–456.

Milner-Bolotin, M. (2016). Rethinking technology-enhanced physics teacher education: From theory to practice. *Canadian Journal of Science, Mathematics and Technology Education, 16*(3), 284-295.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474–496. https://doi.org/10.1002/tea.20347`

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents?, *Cognition and Instruction*, *19*(2), 177 213.doi:10.1207/S1532690X CI1902_02

Mosimege, M.,Wiebesiek, L., Makgamatha, M., Moodley, M., & Winnaar, L. (2021). *Multiple technologies in rural contexts: Lessons from school environments in Eastern Cape province*. Pretoria, South Africa: Human Sciences Research Council.

National Education Infrastructure Management System [NEIMS]. (2020). *School infrastructure report 2020*. Pretoria, South Africa: Department of Basic Education.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Nkula, K., & Krauss, E. M. (2014). The integration of ICTs in marginalised schools in South Africa: Considerations for understanding the perceptions on in-service teachers and the role of training. In J. Steyn & D. Greunen (Eds.) *ICTs for inclusive communities in developing societies: Proceedings of the 8th International Development Infomatics Association Conference* (pp. 218-237). Port Elizabeth, South Africa.

Nyamupangedengu, E. (2017.) Investigating factors that impact the success of students in a higher education classroom: A case study. *Journal of Education 68*(2), 113-130.

Plass, J. L., Milne, C., Homer, B. D., Schwartz, R. N., Hayward, E. O., Verkuilen, J., Jordan, T., Ng, F., Wang, Y., & Barrientos, J. (2012). Investigating the effectiveness of computer simulations for chemistry learning. *Journal of Research in Science Teaching, 49*(3), 394-419.

Resnick, L., Asterhan, C., & Clarke, S. (2015). *Socializing intelligence through academic talk and dialogue*. Washington, DC: American Education Research Association.

Romiszowski, A. J. (1988). *The selection and use of instructional media.* New York: Nichols Publishing.

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. New York: Guilford Publications.

Sanchez, J., & Salinas, A. (2009). Digital inclusion in Chile: Internet in rural schools. *International Journal of Educational Development*, *29*, 573-582.

Schön, D. (1983). *The reflective practitioner*. San Franscisco, CA: Jossey-Bass.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23. doi:10.17763/haer.57.1j463w79r56455411

Sitaraman, R. (2021). Avoiding lessening lessons: Proctored online open-book examinations for post-graduate molecular biology courses using office forms. *Academia Letters* (Article 3264). https://doi.org/10.20935/AL3264.

Smart, V. (2016). *Technological pedagogical reasoning. The development of teachers pedagogical reasoning with technology over multiple stage careers*. [Unpublished doctoral thesis]. Griffith University, South East Queensland, Australia

Tallvid, M. (2015). Understanding teachers' reluctance to the pedagogical use of ICT in the 1:1 classroom. *Education and Information Technologies*, *21*, 503-519.

Tamim, R., Bernard, R. M., Borokhovski, E., Abrami, P. C., & Schmid, R. F. (2011). What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study. *Review of Educational Research, 81*(1), 4–28. http://dx.doi.org/10.3102/0034654310393361

Tembrevilla, G.G. (2020). *Examining ICT and FoK integration in rural public junior high schools with the Philippines' new K-12 curriculum: A case study* [Unpublished doctoral thesis]. University of British. Columbia. Retrieved from htt://open.library.ubc.ca/collectiions/ubstheses/24/items/1.0392683

Tomlison, B. (2001). *Developing materials for language teaching*. NY: Continuum.

Underwood, J. (2009). *The impact of digital technology: a review of the evidence of the impact of digital technologies on formal education,* Coventry, UK: Becta

Velazquez-Marcano, A., Williamson, V. M., Ashkenazi, G., Tasker, R., & Williamson, K. C. (2004). The use of video demonstration and particulate animation in general chemistry. *Journal of Science Education & Technology, 13*(3), 315-323.

Walan, S. (2020). Embracing digital technology in Science classrooms: Secondary school teachers' enacted teaching and reflections on practice. *Journal of Science Education and Technology, 29,* 431–441. https://doi.org/10.1007/s10956-020-09828-6

Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2014). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research 1*(2), 1-13.

Wilkerson-Jerde, M. H., & Wilensky, U. J. (2015). Patterns, probabilities and people: Making sense of quantitative change in complex systems. *Journal of Learning Sciences 24*(2), 204-251.

Wu, H.-K., & Shah, P. (2004) Exploring visuospatial thinking in chemistry learning. *Science Education, 88*(3), 465-492.

Yerdelen-Damar, S., Boz, Y., & Aydın-Günbatar, S. (2017). Mediated effects of technology competencies and experiences on relations among attitudes towards technology use, technology ownership, and self-efficacy about technological pedagogical content knowledge. *Journal of Science Education and Technology*, *26*(4), 394-405.

Zenda, R. (2017). Essential teaching methods to enhance learner academic achievement in physical sciences in rural secondary schools: A South African case study. *Information and Learning Science, 118*(3/4), 170-184.

Dr. Maxwell Tsoka is a lecturer at the University of Venda, Department of Professional & Curriculum Studies. He has over 20 years of experience as a high school science teacher interested in physics education, using computer simulations in teaching, professional development, autoethnography, and rural education.

Professor Jeanne Kriek is a professor in the Department of Physics at the University of South Africa. Her research interest is physics education more focusing on the use of technology in teaching and learning physics. She has considerable international recognition for the high quality and impact of her recent research outputs.

Dr. Byung-In Seo is a professor at Chicago State University, Department of Advanced Studies in Education. There, she has taught courses from freshman-level Introduction to Teaching to doctoral-level Curriculum and Instructional Theory. Her research interests focus on improving instructional methods at the secondary, undergraduate, and graduate levels.