Teaching and learning Physics using interactive simulation: A guided inquiry practice

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The research reported here examined the outcome of using interactive simulation technology (IST) as a guided-inquiry approach to enhance learners' conceptual knowledge of electrostatics in physics. Participants were Grade 11 physical sciences learners ($n = 60$) and a teacher from a rural school in South Africa. Learners were randomly assigned to an experimental group ($n = 30$) that took part in the intervention lesson using the integration of IST in the science classroom, and a control group ($n = 30$) that continued with the conventional teaching method. We adopted a mixed-method approach for this research. Data were collected through a pre-post achievement instrument, classroom observations, and focus group interviews. Data were analysed using the Mann-Whitney U-test, the Wilcoxon signed-rank test, and content analysis. It was found that the mean rank rating of the pre-test results for learners in both groups was not significantly different. However, the Mann-Whitney U-test indicated that learners' conceptual understanding measured in the post-test result was greater for the experimental group (mean rank gain score = 38.83) compared to the control group (mean rank gain score = 22.17), $U = 200.0$, $p = 0.000185$. This finding indicates that integrating IST into inquiry-based activities can be used efficiently to improve learners' in-depth knowledge of science concepts.

Keywords: electrostatics; inquiry; instructional pedagogy; interactive simulation; physics; technology

Introduction

Physical science is a diverse and substantial subject that has facilitated the advancement of technological inventions in the modern world. However, many South African learners still struggle with learning physical science as evidenced by the low quality of learners' achievement in national assessments (final matriculation examination) and international examination Trends in International Mathematics and Science Study (TIMSS). Although South Africa is considered a multi-ethnic coastal country with good infrastructure, the country faces similar challenges in science education as those faced by other developing countries. Some of these challenges include teachers' low level of competencies in the use of information communication technology in teaching and learning, as well as values and teaching attitudes which affect their selection of instructional strategies and contributes to the low quality of learners' achievement in physical science (Jarosievitz, 2017; Ramnarain & Hlatswayo, 2018). Research suggests that laboratory activities in many science classrooms are inadequately designed, uncreative, unclear, and enforced (Kind, Kind, Hofstein & Wilson, 2011; Lekhu, 2016). Therefore, South African learners' comparatively low achievement in physical sciences could also be attributed to the inappropriate execution of laboratory activities.

It is mostly believed that understanding specific physics ideas seems to be very difficult due to their abstract nature. Learners' perception of the abstract nature of the subject remains a long-term problem from both objective and socio-economic perspectives (DeWitt, Archer & Moote, 2019). For instance, learners are reported as often answering questions on electrostatics, introduced as static electricity to learners in lower grades, and an important concept in understanding the forces between charges incorrectly (Department of Basic Education [DBE], Republic of South Africa [RSA], 2012, 2018). Learners' responses to individual questions in Physical Science Paper 1 (physics) show that many learners cannot differentiate between an electric and a magnetic field, between a charge creating an electric field and a charge experiencing the electric field; they confuse the formulae for Coulomb's law with Newton's law of Universal Gravitation, have problems with drawing electric field lines around a charged sphere or using the formulae for $F = k\ q/r^2$ and $E = k\ q_1q_2/r^2$ and are unable to correctly recognise or show the direction of field lines (DBE, RSA, 2018). Issues such as teachers' use of conventional teaching methods, perceptions on learners' difficulties, values, and absence of technological skills also contribute to the variables inhibiting the learners' learning experiences and academic achievement (American Association of Physics Teachers [AAPT], 2013; DBE, RSA, 2018; Hoye, 2017; Marušić & Sliško, 2012). In light of this, literature refers to conventional teaching as a teaching method that involves teachers' exclusive focus on textbooks and engagement in teacher-centred discussion during classroom teaching, as learners become passive recipients of knowledge in the learning process and possibly memorise content for examination purposes (Li, 2016). One way to improve the quality of learners' achievement is to use contemporary teaching strategies to model scientific theories and abstract concepts during instructional practices. This, in turn, expands the development of learners' cognitive and conceptual knowledge of physical sciences – physics in particular.

The Fourth Industrial Revolution has seen trending technologies brought into the education system. Equipping learners with necessary 21st-century skills requires that the teaching and learning of physical sciences should be accomplished through technological enhanced inquiry methods that validate science ideas taught in the classroom. However, it is argued that most physical sciences teachers either underuse or do not learn innovative instructional strategies that can be used to complement their teaching and improve learners' intellectual

development in terms of skills and knowledge of the 21st century (Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013; Ferlazzo, 2018; Mupa & Chinooneka, 2015). In the face of all-encompassing global digital transformation, the science education community emphasises technology integration as a resourceful instrument that can be used to improve learners' conceptual knowledge, help learners master the essential abilities required to flourish in the changing world, and provide leaders who transform education (Stošić, 2015; United States Department of Education, 2017).

Research claims that technology integration in education has progressed beyond its implementation for school leadership and administration purposes, to the development of system designs like simulation, visualisation and modelling used to encourage a meaningful and profound learning experience in the classroom (Davies & West, 2014; Tan, Yang, Yoshida & Takakuwa, 2019). The use of online technology tools like simulations allows learners to participate in inquiry-based learning, thus enhancing learners' representation of real-world scientific ideas (Park, 2019). Recognising the relevance of technology integration in developing learners' cognitive knowledge and abilities for global success, the South African education sector is presently targeting the use of digital technologies to prepare learners for the future world of work. With this study, we seek to investigate the effectiveness of using interactive physics simulation technology, manipulated by the teacher as a demonstration tool, on learners' achievement and understanding of electrostatics. We addressed two inquiries:

1)   Are there substantial variations in the learning outcome of learners instructed using IST teaching compared to those instructed using conventional teaching only?
2)   What do learners in the experimental group think about using IST to learn physics?

Literature Review
Teaching and learning electrostatics
Electrostatics is one of the topics assessed in South Africa's matriculation examination, a departure point for the country's 3-year Further Education and Training (FET) education scheme. Electrostatics at senior high school level includes conceptual areas such as static electricity, conductors and insulators, electric fields, field-line representations, electric charges, inverse square law, electric potential, and Coulomb's law. The principles of electrostatics have proven useful in many modern gadgets used for daily undertakings like the generation of high voltages in the Van de Graaff generator, the production of computer-generated text and graphics in printers, the copying of images in most photocopy machines through the xerography process, and in smoke precipitators and air cleaners (Ling, Sanny & Moebs, 2016). It is a universal problem that learners struggle to understand concepts of electrostatics due

to the intricacy and intertwined constructs of the topic and teachers' difficulties in representing electrostatics ideas (Byford & Chahal, 2018; Furió, Guisasola & Almudi, 2004). Most American learners find it difficult to explain the distribution of charges on insulators and conductors (Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2001). Many learners struggle to comprehend and interpret the mathematical applications and representations of Coulomb's law, illogically confuse Coulomb's law with the magnetic effect of a moving charge, determine the direction of the force and electric fields and apply the inverse laws to electric fields (Maloney et al., 2001; Moynihan, Van Kampen, Finlayson & McLoughlin, 2018). This implies that learners' difficulties with electrostatics are not only linked to the abstract and complex nature of physics as a subject but could also be due to learners' memorisation of algorithms and tools without understanding the underlying concepts. In light of these problems, studies have suggested various approaches that could be used to enhance learners' understanding of electrostatics (Buncick, Betts & Horgan, 2001; Furió et al., 2004). One such approach is encouraging activities providing learners with opportunities to collaboratively solve problems in pairs or groups, thereby enhancing learners' recognition and application of the algorithm in understanding the electric field (Furió et al., 2004).

According to Furió et al. (2004), instructional sequences in teaching can help in facilitating learners' understanding of electrostatics and allow teachers to link the cognitive demand of a concept like the electric field to learners' conceptions. Similarly, Buncick et al., (2001) point out that using road-map demonstrations as a framework could also help in explaining ideas/concepts in a lesson or course perceived to be difficult. They recommend the use of road-map demonstrations that apply to real-life illustrations or simulated activities in explaining scientific principles. Besides, learners have to be given enough time for the continuous practicing of concepts to improve a deeper understanding of complex concepts and create opportunities for comparing relationships between associated concepts/ideas.

Simulations
The University of New South Wales (Sydney, Australia) defines simulations as instructional programmes allowing learners to interact with the reality defined by their teacher (UNSW, 2018). According to Wieman, Adams, Loeblein and Perkins (2010:225) "simulations are learning tools that can be used to complement instructional methods like lectures, individual or small group inquiry activities, homework, and lab." The physics education community has committed to well-created simulations to improve the instructional value and

effectiveness of science teaching and to boost learners' understanding of science (Steinhauser, 2013), allowing teachers to test learners' understanding and improve their engagement in the learning process.

Simulations can be used for learning purposes in both complex and simple experiments, by modelling real-world situations in an artificial environment within a social context (DBE, RSA, 2018; Gilbert, 2011; Zulfiqar, Zhou, Asmi & Yasin, 2018). Simulations are assumed to assist in carrying out thought experiments, encourage inquiry-based educational methods and increase the value of learners' visual representation, cooperation, and conceptual comprehension of basic physics concepts (Fan, 2015; Steinhauser, 2013; Zulfiqar et al., 2018). Utilising simulation as an inquiry tool helps in bridging the gap between theoretical knowledge and practice. Simulations link analytical theory and experiment to test theories while also being used as an exploratory instrument under circumstances that would be unworkable, too costly, or too harmful for an actual laboratory practical (Steinhauser, 2013). Simulations integrated into current and growing online platforms allow learners to engage in interactive learning activities within and outside the classroom, fostering inquiry, allowing deep interaction with lesson content, and providing access to laboratories committed to observing and exploring scientific principles. This improves learners' comprehension, achievement, and conceptual understanding, allowing learners to acquire a variety of skills needed for the world of work in the Fourth Industrial Revolution (Rutten, Van Joolingen & Van der Veen, 2012; Srisawasdi & Kroothkeaw, 2014). Peffer, Beckler, Schunn, Renken and Revak (2015) remind teachers that simulations should also be used as a powerful assessment tool for evaluating complex science learning.

Theoretical Framework
This research is based on the social constructivist theory. The philosophical underpinning of the constructivist paradigm emphasises that learners should not only gather information but also link such information with their previous knowledge to enable them to develop a better understanding of the learning process (Huang, Rauch & Liaw, 2010). As a foundation assumption of constructivism, Vygotsky (1978) thinks that creating new knowledge depends on an individual's ability to interact socially with others, implying that learning involves communication, and it can only be done in collaboration with others. This could be achieved with a small amount of collaboration between peers or with help from teachers. For this study, simulation activities demonstrated by the teacher were used to explain the concept of electric forces and fields, as well as Coulomb's law. This simulation system

allowed learners to interact socially with their teacher and peers in the group, discuss their observations, and construct their understanding of the lesson meaningfully. The simulation activities also enabled the teacher to implement a self-guided inquiry practice that challenged learners' cognitive thinking.

Method
A mixed-method design (Flick, 2018) was employed in this research. The quantitative aspect of the study employed a pre-test-post-test quasi-experimental approach to determine the efficacy of using simulation as a teaching strategy to enhance learners' performance. For the qualitative aspect we employed an interpretive approach to explore participants' experiences and perceptions of the use of IST in teaching and learning physics. Participants in this study were selected from a public secondary school in a rural community in the North West province with inadequate laboratory resources and minimal technology access. From the school's 114 Grade 11 physical science learners two classes consisting of 60 physical science learners and their teacher were purposefully and randomly chosen to take part in this study. Learners from each class were assigned to control and experimental groups respectively. The experimental group ($n = 30$) participated in the intervention lesson that allowed the integration of IST during the teaching of electrostatics, while the control group ($n = 30$) continued with the conventional teaching method. The same duration, sequence, and depth of topic content as prescribed by the DBE were taught to each group using the same textbook and lesson plan. Data were collected through a pre-post achievement instrument, classroom observations, and focus group interviews.

The female physical science teacher, with a bachelor's degree in Agricultural Sciences and 17 years of teaching experience, has always believed that most learners struggled with physical sciences, particularly in physics, because they could not visualise the concepts covered in the subject.

Instructional Intervention
Grade 11 learners were taught the concept of electrostatics over 6 hours during 2 weeks of class time. Both groups were given a preliminary assessment, designed to assess learners' prior knowledge and understanding of basic electrostatics concepts, during the first class period of the lesson. Afterwards, the experimental group was taught the target lesson in the school's computer laboratory using the IST, while the control group was taught in their classroom using the conventional teaching method. Both groups received a brief revision of the Grade 10 content on electrostatics and an introduction to electrostatic force and electric fields, with class time allowing learners to engage in

problem-solving and interaction with the teacher's guidance afterwards. As learning aids, the control group used class notes, photocopied pages from a textbook shared by learners and homework in the learners' notebooks.

The lesson for the experimental group applied teacher-guided inquiry activities using simulations from the physics classroom in addition to the conventional teaching methods that used class notes and learners' workbooks. Three lessons were observed using a modified technology integration observation rubric designed to assess the quality of IST regarding teaching physics. During the lesson on field distribution of charges, the teacher illustrated how learners could determine the strength, direction and magnitude of an electric field for a specific charge or several charges using the interactive simulation application downloaded from the physics classroom website. The teacher explained the concept of electric field distribution of charges and virtually manipulated the objects as learners observed and predict the effects of the changes on the variables. During the lesson, the teacher dragged the positive and negative electric charges onto the workspace area in the simulation model. This action allowed learners to visualise the pattern of electric field lines for different charge configurations and interpreted the activities indicating that "*field lines which are also called lines of force become more spread out as they move further from a point charge. The dark part indicates the closeness of the lines of force and at this point, we experience a stronger electric field or greater force, while the magnitude of the charge will also increase. Thus, if the lines of force are closer together i.e. darker as seen on the screen, we say the electric field is closer to the charge and if the lines of force are weaker i.e. further separated, then the electric field is weaker than the charge.*" Figure 1 depicts the demonstration using simulation.
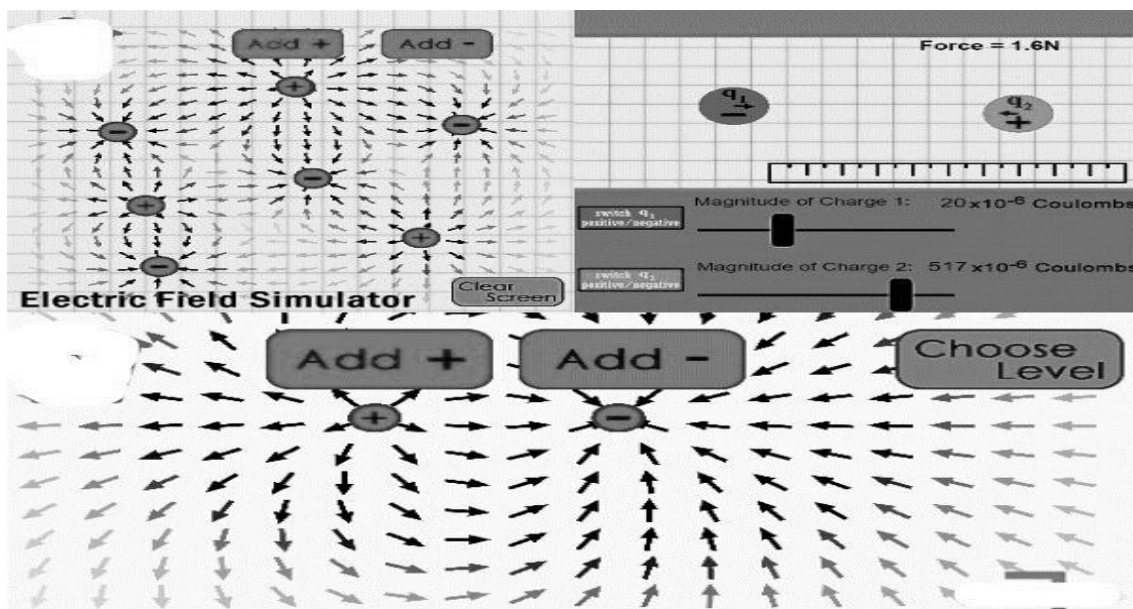
Figure 1 Screenshot of simulation activities demonstrated by Teacher A

The teacher created a configuration of several charges and virtually constructed the electric field lines using various situations in the model. Learners were allowed to work in small groups as they compared the various diagrams and discussed how the number of charges in each location affected the electric field line in the space surrounding the charge. Afterwards, representatives of each group elaborated on their observations, and the teacher explained the conceptualisation of the problems that could assist during the problem-solving task. This activity allowed learners to visualise the connection between the force of attraction or repulsion between two charges, the strength of the force, and the effect of the magnitude of the charges as well as the distance between charged objects. Subsequently, both groups were assigned the same set of questions in their workbooks to assess learners' overall gains in terms of conceptual knowledge of electric fields and Coulomb's law. The pre and post-tests consisted of structured questions that were adapted and modified from past National Senior Certificate examination questions on physical science Paper 1. This achievement test was designed by the sampled teacher and given to two different physical science teachers and a subject advisor for content and construct validation purposes. Data from the pre-post-test were analysed using quantitative measures.

Data Analysis and Results

Data obtained in this study were not uniformly distributed due to reported normality test values of (learners' preliminary score = 0.001, final assessment = 0.093, and paired of differences = 0.07). Since the p-value of one of the variables was less than 0.05, non-parametric approaches like the Mann-Whitney U-test and Wilcoxon Signed Ranks were employed as statistical approaches to determining the variation between the preliminary and final assessment results for both groups in the study. However, the qualitative data collected were analysed using content analysis (Krippendorff, 2019).

Research Question 1: Are there Substantial Variations in the Achievement Outcome of Learners Instructed Using IST Teaching as Compared to Those Instructed Using Conventional Teaching Only?

Table 1 Mean rank and Mann Whitney test of preliminary and final results for both groups

		N	Mean rank	U	p
Preliminary assessment	Conventional teaching group	30	30.75	442.500	.910
	Simulation group	30	30.25		
Final assessment	Conventional teaching group	30	22.17	200.000	0.000185
	Simulation group	30	38.83		

Table 1 displays the mean rank results of learners in both groups and a summary of the Mann-Whitney U-test checking for the difference between the final test results of learners in both groups controlling for their preliminary test results. Although the preliminary tests of both groups showed no significant differences, the differences appeared to be more marked in the results of the final test. The U-value of the preliminary test score was 442.500 at a p-value of 0.910, which was greater than 0.05. Hence, there was no statistically significant difference between the performance of learners in the control group and the experimental group before the intervention. However, the use of simulation in support of the interactive teaching method was found to meaningfully affect learners' final test results at $U = 200$ and p-value of 0.000185, which was less than 0.05. The result indicates a statistically significant difference in the performance of learners taught using conventional teaching methods supported by interactive simulations compared with those taught using only conventional teaching. The result indicates that incorporating simulation into conventional teaching methods could enhance the teaching of electrostatics concepts and learners' outcomes.

Since there was a significant difference, the effect size of the difference was calculated using the following formula:

$$r = z \div \sqrt{N} \text{ where N was the total number of participants.}$$
$$r = 3.739 \div \sqrt{60} = 0.48$$

The calculated effect size above can be compared with Cohen's (1988) criteria of 0.1 = small effect, 0.3 = medium effect and 0.5 = large effect. The effect size of difference at a value of 0.48 suggests that the use of IST with the lesson presentation had a large effect on learners' outcomes as measured by their final assessment outcome.

Table 2 Ranking of the final test and preliminary test results of both groups based on gender

	Control				Experimental		
		Pre-test	Post test			Pre-test	Post test
	N	Mean rank	Mean rank	N	Mean rank	Mean rank
Male	13	16.08	16.12	16	14.94	14.03
Female	17	15.06	15.03	14	16.14	17.18
Total	30			30		

Table 2 shows that the mean rank for females in the preliminary and final tests conducted for the control group was lower (initial = 15.06 and final = 15.03) than for males (initial = 16.08 and final = 16.12). Females performed lower than males since a lower mean rank is associated with lower results in the data, where a ranking of 1 is considered as the lowest score and a ranking of 10 as the highest score. In the experimental group, the mean rank for males in both the pre- and the post-achievement test was lower (initial = 14.94 and final = 14.03) than for females (initial = 16.14 and final = 17.18) which indicates that females performed better than males using the same ranking value. However, the calculated p-value for the test parameters (initial test $_{control}$ = 0.755; final test $_{control}$ = 0.745; initial test $_{experimental}$ = 0.711; final test $_{experimental}$ = 0.333) was greater than 0.05. This implies that there was no significant difference between the preliminary test score and the final test score of learners in both the control and experimental groups based on gender. Thus, the performance of male and female learners in both groups was not statistically different before and after teaching electrostatics using both instructional methods.

Nevertheless, further analysis using the Wilcoxon signed-ranks test was conducted to examine the difference between the preliminary and

final test scores of learners taught using IST compared to those taught using the conventional teaching method.

Table 3 Difference between pre-post treatment based on group

		Control group			Experimental group		
		N	Mean rank	*SS*	*N*	Mean rank	*SS*
Post-test – Pre-test	Negative ranks	1[a]	21.50	21.50	0[a]	.00	.00
	Positive ranks	23[b]	12.11	278.50	30[b]	15.50	465.00
	Ties	6[c]			0[c]		
	Total	30			30		
	z		- 3.728[b]			-4.823[b]	
	Asymptotic Sig. (2-tailed)		.000193			0.000001	

Note. [a]Post < Pre, [b]Post > Pre, [c]Post = Pre, Sig is the significance probability which is also called the *p*-value.

Table 3 shows the Wilcoxon signed-rank test used to check the difference in the preliminary and final test taken by learners in both groups. Analysis of the result using the negative ranks with a mean rank value of 21.50 shows that the performance of one of the learners in the control group had decreased from the preliminary to the final test. On the other hand, the positive ranks with a mean rank value of 12.11 indicate that the performance of 23 learners in the control group had increased from their preliminary test to final test, which was a desirable change in the number of learners that understood the concepts of electrostatics using conventional teaching method. Finally, the result shows that learners in the control group had six ties, i.e. the performance of six learners in the control group remained the same in the preliminary-final test despite the teaching on electrostatics. However, results in the experimental group show that all 30 learners had positive ranks with a mean rank value of 15.50, indicating that their performance had increased from the preliminary test to the final test.

Analysing the difference between the preliminary and final test taken by both groups, the *p*-values for both control and experimental group as reflected in Table 3.0 were 0.000193 and 0.000001 respectively; both were less than 0.05. Therefore, it can be concluded that there was a statistically significant difference between the preliminary, and final test of learners taught using the conventional teaching method and those taught using IST as measured by their respective results. The magnitude of this difference was determined using ($r = z \div \sqrt{N}$); for the control group $r = 0.68$ and for the experimental group $r = 0.88$. This implies that both methods had a large effect on learners' performance. Looking at the increased learning gain and consistency in the performance of learners in the experimental group compared to the control group, it can be concluded from the result of this study that using simulations to support the teaching and learning of electrostatics seems to be more effective in improving learners' understanding and outcomes compared to using conventional teaching methods only (Widiyatmoko, 2018).

Research Question 2: What Do Learners in the Experimental Group Think about Using IST to Learn Physics?

A focus group discussion was held with the teacher and some of the learners after the lesson intervention. During the focus group discussion, learners were asked to "*share their views and experience gained during the lesson presentation*." The learners acknowledged that using simulations during the physics lesson was a new experience for them and provided them with the opportunity to visualise the abstract concept of the topic being taught.

> *The pictures displayed and the questions that were asked during the simulation scenario helped to be able to refine my understanding as to how charges are being distributed and it also made some abstract concepts accessible in the class* (Learner C).
> *Seeing how those lines 'fields' are created at every point when the teacher moves the test charge and she said those lines are electric fields. Besides, we could actually see the direction in which the fields were being created. That was awesome, I say.* (Learner B)

This finding was confirmed during the classroom observation as learners became very engaged in the class activities, as they became motivated to ask questions and engaged in collaborative work, as the teacher was guiding the activities. During the interview, one of the learners indicated that the visual representation of the simulated activity presented her with the opportunity to observe how field lines were being created, thereby creating an environment for reflection on how learners learn. Participants' responses also resonated with the findings of Fan (2015), who claims that simulation activities broaden teachers' conceptual teaching, enables learners to visualise abstract concepts and encourage their conceptual understanding. After the teacher's initial perception of learners' negative attitudes towards physics, she indicated during the discussion that the visual model provided by IST

made physics learning more fun and easier for the learners to comprehend, saying:

> *You know it amazed me to see how these learners were so quiet and focused while teaching especially this aspect of electroscope charging. I guess the visual representations of the activity caught their interest and they were really engaged throughout the lesson.* (Teacher)

An analysis of the teacher's response implies that the simulation activities increased learners' attentiveness and involvement in the lesson, thereby enhancing a positive attitude towards the lesson. The teacher also indicated that using the simulations enabled her to guide the learners' inquiry practice.

> *I believe the content in the simulation would have been too difficult for the learners to understand at first, but I think being able to ask them questions based on how to move the test charge, their observation, and reaction to the values displayed on the screen also made the class more interactive.* (Teacher)

The teacher's response also implies that using IST allowed her to integrate modern teaching methods such as guided instruction and the experiential learning approach in her classroom. Teacher A displayed a positive view on the use of simulations as a technology-enhanced inquiry tool for improving science learning. This agrees with studies claiming that using a teacher-directed approach in simulation-based learning encourages metacognitive scaffoldings that help in enhancing learners' conceptual understanding (Dukeman, Caglar, Shekhar, Kinnebrew, Biswas, Fisher & Gokhale, 2013; Wieman et al., 2010).

Conclusion and Recommendations

The teacher-directed approach in this study did not allow learners to operate the material directly. However, the learners interacted with the teacher on how the simulated activities could be manipulated, modelled and recorded. Through the teacher's planned instruction, integrated use of simulation, and guidance, learners were able to observe relations between charge distribution and electric field lines, asked questions, engaged in team discussions and scientific argumentations, contributed to the activity, and got feedback from the teacher. The psychological mechanism employed during the teacher-directed simulation activity provided a learning environment where learners exercised their reflective thinking and evaluated their understanding through class activities and homework. Using the teacher-directed approach during the simulation activity enabled the teacher to attract the learners' attention, especially when moving the variables on the electric field. The teacher-directed approach also allowed learners to explore ideas from one another as they discussed what they observed in the simulation. The teacher was able to engage learners in class activities and discussions that enhanced their critical,

computational and evaluative thinking skills, thus improving learners' outcomes on electrostatics as measured in the post-test. These findings show the effectiveness of using interactive simulation technology as a teacher-guided instructional method in enhancing learners' learning outcomes, supporting the findings of Dervić, Glamočić, Gazibegović-Busuladžić and Mešić (2018).

This study contributes to the body of knowledge on how using simulation-based technology as a teaching tool may support experiential and inquiry-based learning in physical sciences classrooms, especially in rural South African schools. Findings from the study show that the use of simulation technology during the lesson provided learning opportunities that influenced learners' development of metacognitive skills and transfer of knowledge. This was evident in the evaluation of instructional effectiveness in terms of learners' outcomes which was higher in the IST than the conventional teaching method group. Notwithstanding the shortfalls of the approach used, the teacher's perceived usefulness and ease in using the simulation technology shifted her position from that of an exclusive content provider to a learning facilitator, as observed during an informal conversation and classroom teaching. This study also indicates that the selected simulation-based activities enhanced learners' thinking abilities, which is an essential skill for thriving in the changing world of work.

In rural schools where technology integration remains a challenge, teachers must find ways to address the confines of the conventional teaching method to facilitate the learning of physics concepts and improve learners' positive attitudes towards physical sciences in South Africa. We, therefore, recommend that school stakeholders are actively involved in empowering and encouraging teachers to teach with interactive modelling and simulation tools that are also accessible on mobile platforms. This may contribute to a teacher's practical technological knowledge and ability to support learners' experiential and inquiry learning practices in South African science classrooms.

Authors' Contributions
AO provided data for the study and wrote the first draft. UR contributed to the data interpretation. Both authors reviewed the final manuscript.

Notes

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