Teachers' use of computer-based simulations in teaching electrolysis: A case study in Eswatini

Nkhululeko Lungile Nxumalo-Dlamini* and Estelle Gaigher

University of Pretoria, South Africa

Corresponding author: Nkhululeko Nxumalo email nkhululekonxumalo@gmail.com

Abstract

This study aimed to understand teachers' classroom practices using Computer-Based Simulations (CBS) when teaching electrolysis. The study was framed by the Consensus Model of Pedagogical Content Knowledge. Convenience and purposive sampling were used to select three experienced chemistry teachers from three schools in Eswatini (Swaziland). Semi-structured interviews, questionnaires, and classroom observations were used in the data collection. The data were analysed using a qualitative content analysis in terms of six emergent themes. The findings of this study reveal how the teachers' views and knowledge about CBS and electrolysis relate to the way in which they integrate CBS into their lessons while teaching this topic. The teachers all believed that CBS enhances learners' understanding of electrolysis because it enables learners to visualise abstract processes, and because the simulations raise learners' interest and enhance critical thinking. Two of the teachers valued learners' involvement in the manipulation of the CBS, while the remaining teacher believed that it was adequate for learners to 'see' the movement of ions and electrons. During the classroom discussions following the simulations, the teachers sometimes displayed poor content knowledge, thus reducing the value of the learning experience. All of the teachers were concerned that the shortage of equipment, large class sizes, and the poor socio-economic background of the learners may affect the effective use of CBS. Although the schools participating in this study had computers, the computers were reserved for use by the ICT departments, adding to the obstacles faced by the teachers. It is recommended that teachers be educated more on the pedagogy of using CBS, and that teachers' content knowledge should be prioritised during their training to enhance the effective use of CBS.

Keywords: *Computer-based simulations, electrolysis, computer access, visualization*

Introduction

Computer-Based Simulations (CBS) have the potential to enhance learners' understanding of abstract concepts in science education (Rutten, van Jooligen & van der Veen, 2012). In Eswatini, electrolysis is one of the abstract topics in which learner understanding is very poor (Examination Council of Eswatini, 2016). Hence, it can be argued that CBS may be introduced in Eswatini to improve the understanding of the topic of electrolysis. However, the success of such an undertaking depends on the preparedness of teachers to use CBS. Therefore, this study was undertaken, attempting to answer the following question: How does the integration of CBS into the teaching of electrolysis relate to the teacher's views and knowledge about CBS and electrolysis? The following sub questions were investigated:

1. How do teachers integrate CBS into teaching electrolysis?
2. What are teachers' views and knowledge about CBS and electrolysis?

The sub-questions have to be answered first and then the main question can be answered by finding a relationship between the answers to the two sub questions. It is envisaged that knowing how teachers use CBS in the teaching of electrolysis and understanding their pedagogical choices may lead the way towards implementing CBS efficiently to enhance learners' understanding of the topic.

Computer simulations as a strategy to teach electrolysis

Studies in Physics and Chemistry Education show that learners' understanding of abstract concepts is enhanced by interactive computer simulations as compared to traditional pedagogical approaches (Jaakkola & Nurmi, 2008; Kotoka & Kriek, 2014; Lindgren & Schwartz, 2009). Scheurs and Dumbraveanu (2018) propose that a learner-centred approach should be promoted and implemented because it stimulates curiosity, imagination and critical thinking, making lessons interesting for learners. As learners become actively involved, they develop the ability to manipulate complicated systems when conducting their autonomous investigations (Minner, Levy & Century, 2010). Furthermore, CBS supports learners' use of scientific concepts to communicate, while motivating learners to acquire new knowledge (Minner et al., 2010). Trey and Khan (2008) argue that CBS enhances learning by enabling learners to visualise unobservable phenomena. Visualisation may aid learners' understanding of the sub-microscopic processes in electrochemistry (Doymus, Karacop & Simsek, 2010). These advantages of CBS may improve learners' understanding of scientific concepts and thus motivate learners to learn topics that are considered to be difficult. However, there has also been arguments that CBS provides limited conceptual understanding because of its lack of real world experience and interactions (Mustafa & Altay, 2014).

Electrolysis is a difficult topic for learners as well as for teachers (Bong & Lee, 2016; Rollnick & Mavhunga, 2014). According to Bong and Lee, learners have challenges with distinguishing between the anode and the cathode, with analysing the reaction in the electrolysis and with writing chemical equations. They further point out that teachers' lack of subject matter knowledge, language barriers and rote learning are factors that contribute to learners' challenges. Terminology used in electrolysis is unfamiliar to learners, thus the topic is not related to their everyday life, making it abstract and requiring them to imagine concepts and processes that are not visible (de Jong & Taber, 2014). When teachers cannot explain abstract concepts effectively, that is, with understanding, learners then opt to memorise (Taner, Osman & Sami, 2012).

It is expected that learners studying electrolysis operate on three levels of thinking: the macroscopic, microscopic and the symbolic level (Mbajiorgu & Reid, 2006). However, learners have a challenge in operating at these three chemical representational levels because they often cannot see a connection between these levels (de Jong & Taber, 2014, Dumon & MzoughiKhadhraoui, 2014; Halim, Ali, Yahaya & Haruzuan, 2013). Despite these challenges in learning electrolysis, it is an important topic because of its applications as well as it being the synthesis of the principles of physics and chemistry. It is related to thermodynamics, reaction rate, oxidation and reduction reactions, and chemical equilibrium.

Rollnick and Mavhunga (2014) found that teachers who show moderate content knowledge in electrolysis do not necessarily show similar levels of topic-specific Pedagogical Content Knowledge (PCK). CBS may therefore support teachers in teaching electrolysis. Kaheru and Kriek (2016) found that some teachers were eager to use computer simulations, while others had to be supported in the use thereof. Teachers' beliefs and orientations in science education determine the success of the lesson delivery strategy that they use (Grossman, 1990; Magnusson, Krajcik & Borko, 1999). This implies that the effective use of computer simulations in schools depends on the preparedness of teachers to use CBS in the delivery of lessons in class. It may also depend on whether or not teachers understand the importance of using CBS to facilitate the teaching and learning process in schools.

The importance of the topic of electrolysis in learning chemistry, together with reports that many teachers lack content knowledge and pedagogical content knowledge in this topic, pose a challenge to teaching. This challenge may be addressed by integrating CBS in lessons. However, the success of using CBS in teaching electrolysis will depend on how teachers integrate the CBS in their lessons. It is therefore important to explore how teachers use CBS and to understand the reasons why they use it in particular ways when teaching electrochemistry in order to make research informed suggestions which may improve practice.

Conceptual framework

The way in which a teacher uses and integrates CBS into teaching can be regarded as a manifestation of his/her PCK which is a result of his/her views and knowledge about CBS and electrolysis. We argue that teachers are expected to utilize CBS to transform subject content in an understandable form for learners, echoing Shulman's description of the construct PCK (Shulman, 1986). Numerous PCK models and studies were reported following the introduction of the concept. In an effort to find a common understanding of the construct, scholars developed the Consensus Model at the PCK Summit in Colorado Springs (Gess-Newsome, 2015). This model, represented in Figure 1, was selected as the basis for the conceptual framework of the current study in an attempt to understand how teachers' classroom practice relates to their views and knowledge about CBS and electrolysis. Their views and knowledge about CBS and electrolysis influence their actual implementation of CBS while teaching the topic. This model was preferred above the well-known Technological and Pedagogical Content Knowledge (TPACK) model (Koehler and Mishra, 2009) as the latter does not provide for the role of teachers' views on their practices.

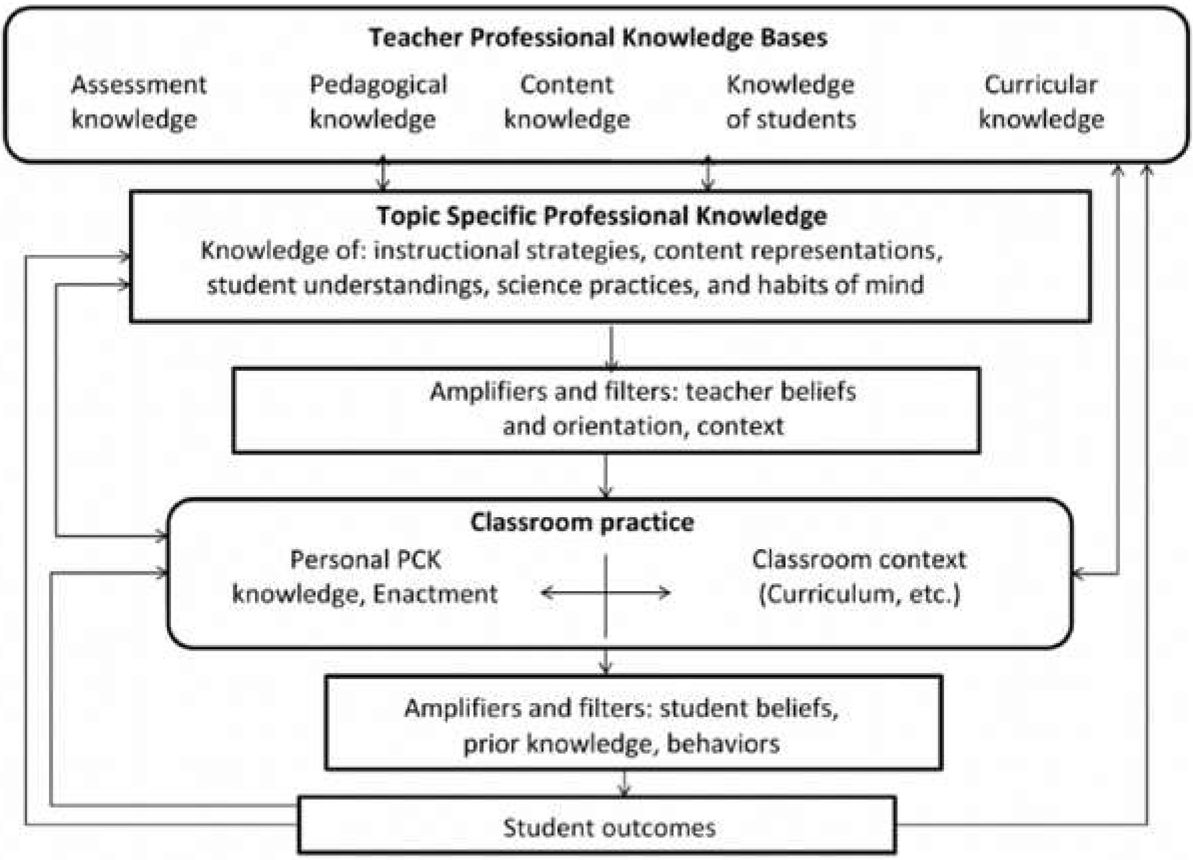

Figure 1. Theoretical framework: The Consensus Model of PCK (Gess-Newsome, 2015, p. 31).

The clear descriptions of PCK components according to the Consensus Model enabled the researchers to identify indicators thereof during the data collection and analysis. The Consensus Model (see Figure 1) describes different levels of teacher knowledge that are ultimately transformed into learner outcomes. The first level assumes the existence of a broad Teacher Professional Knowledge Base, which includes the components of knowledge of assessment, pedagogy, content, learners and the curriculum. The next level is Topic Specific Professional Knowledge, which includes knowledge of teaching strategies, content representations, learners' understanding, scientific practices, and habits of mind related to a specific topic. This level of topic-specific knowledge is manifested in classroom practice, which is amplified and filtered through the beliefs, orientations and contexts of the teachers. These amplifiers and filters, including teacher beliefs and their orientation to science teaching together with the school context, represent the teachers' views which are central to this study. Classroom practice involves the enactment of personal PCK within the specific classroom context. Teachers' classroom practice provides the basis of learner outcomes, amplified and filtered by student behavior, their beliefs and previous knowledge.

In this study, levels two, three and four were selected as the conceptual framework, as these levels represent the issue addressed by the research question. It models the transformation of teachers' professional knowledge in the topic of electrolysis, amplified and filtered by their views and beliefs about using CBS, into classroom practice. The first level, which represents broad teachers professional knowledge bases, and the the last two levels, involving learning amplifiers and filters as well as learner outcomes, were excluded from the conceptual framework as these lie outside the focus of the study. Importantly, the Consensus Model does not propose a simple linear process: teachers also learn from their own experiences and student outcomes. Thus, each part of the model has a direct or indirect impact on the other parts and offers opportunities for professional development.

The narratives taken from the classroom observations, which are placed in Level 4 of the conceptual framework, address the first research question which is on how teachers integrate CBS into teaching electrolysis. While the remainder of each case addresses the second research question which is on how the integration of CBS into the teaching of electrolysis relate to the teachers' views and knowledge about CBS and electrolysis, which fit in Level 2 and 3 in the conceptual framework.

Methodology

The study is located within the interpretive paradigm to understand teachers' use of CBS in teaching electrolysis. A qualitative case study research design was adopted. The sampling procedure was purposive and convenient and three experienced chemistry teachers (who had not previously used CBS) from three different schools with computer laboratories were selected as participants. The backgrounds of the teachers who participated are summarised in Table 1.

Table 1. Background of the participating teachers.

Teacher	Gender	Teacher's qualifictions	Experience (Years)	Location of school	Number of learners
A	Male	BSc and PGCE	24	Semi-urban	44
B	Female	BSc and PGCE	15	Semi-urban	53
C	Female	BSc with Education	14	Urban	45

Three computer simulations were given to each participant to integrate into their teaching of electrolysis during the study. The topics prescribed in the syllabus on electrolysis were addressed by these three CBS. The first simulation modeled the migration of electrons and ions, and the formation of products, representing the basic principles of electrolysis. Learners were expected to understand at which electrode reduction/oxidation occurred and to learn how to write the relevant half reactions based on the decomposition of a solute, or the purification of an impure metal. This particular CBS could be manipulated to select different solutions or metals. The second CBS was on electrolysis of acidified water simulating the formation of hydrogen and oxygen at the electrodes. Learners were expected to understand in terms of reactivity that in this case the water itself rather than the solute was decomposed. The third CBS was on the electrolysis of brine, using carbon electrodes and concentrated sodium chloride solution as electrolyte. Learners were expected to understand that this process represents an important industrial use of electrolysis, producing not only the gases hydrogen and chlorine, but also producing sodium hydroxide as a by-product.

Three consecutive lessons were observed for each teacher. Besides the observations, two interviews were conducted and two questionnaires were completed per teacher capturing teachers' views prior to using CBS as well as their reflections after the completion of the sequence of three lessons.The questionnaires and interviews were open ended to gain insight into teachers' perceptions on the use of CBS and to explore teachers' views and knowledge related to their practice.

The data were analyzed qualitatively using content analysis. The information obtained from the different instruments were classified to capture emerging themes. The categorization was guided by the research questions. Trustworthiness was enhanced by employing several data collection strategies: the observation of three lessons per teacher as well as questionnaires and interviews before and after using CBS. The project was approved by the ethics committee of the University prior to the data collection to ensure that the research was ethically conducted.

Results

Six themes emerged from the data analysis: the advantages of CBS; learners' difficulties in learning electrolysis; challenges in using CBS; teaching strategies; teachers' curricular knowledge; and teachers' attitudes. In this section, the emerging themes are first presented in relation to the theoretical framework, as shown in Table 2. The results are then discussed per teacher, first presenting a narrative of classroom observations, followed by data analysis according to the emergent themes. Finally the teachers' use of CBS in the classroom is linked to their views and knowledge about CBS and electrolysis.

Table 2. Correspondence between the emerging themes and the theoretical framework.

Levels from the theoretical framework	Themes identified from the data	Examples from the data
2. Topic-specific professional knowledge		
(a) Instructional strategies	Theme 4: Teaching strategies.	Facilitating the use of CBS Discussion linking to previous concepts Questioning to engage and assess
(b) Content representations	Theme 5: Teachers' curricular knowledge	Use of symbols Writing half reactions
(c) Students' understanding	Theme 2: Learners' difficulties in electrolysis	Identifying oxidation/reduction at electrodes
3. Amplifiers and filters		
(a) Teachers' beliefs and orientation	(i) Theme 3: Challenges in using CBS (ii) Theme 6: Teachers' attitude	(iii) Belief that examination is more important than understanding (iv) Willingness to change
(b) Context	Theme 3: Challenges in using CBS	Shortage of equipment and overcrowded classrooms
4. Classroom practice		
(a) Personal pedagogical content knowledge	(i) Theme 4: Teaching strategies (ii) Theme 6: Teachers' attitude	(iii) Integrating CBS with other teaching methods (iv) Willingness to use CBS
(b) Knowledge of curriculum	Theme 5: Teachers' curricular knowledge	Understanding the topic of electrolysis

Teacher A

Lesson observations

The first lesson taught by teacher A was during a double period. He started by questioning learners about the conducting properties of ionic solutions, followed up by practical work in small groups, investigating the electrolysis of copper chloride using carbon electrodes. Then he conducted a classroom discussion and finally, towards the end of the lesson, the learners had the opportunity to use the first CBS. He instructed them to select solutions and electrodes and make observations. The teacher moved amongst the groups without giving any instructions or suggestions. The lesson ended without opportunity for discussion. During the second lesson, he presented a theoretical lesson, discussing and summarizing the previous lesson, referring to the practical work as well as to the CBS. The third lesson was a traditional content driven lesson, in which he discussed the second and third curriculum topics, namely the electrolysis of acidified water and then the electrolysis of brine. He did not use CBS during the second and third lessons. He explained the applications of electrolysis according to the syllabus, involving learners in discussions and writing important points on the chalkboard. Furthermore, it seemed that his understanding of redox reactions was limited, as he sometimes contradicted himself when explaining the half reactions. Also, when he referred to the reactivity series and "*preferred*" reactions, as relating to the electrolysis of acidified water, he became confused and ended the discussion abruptly by giving homework. The next day, he did not clarify the issue, and he did not discuss the homework.

Data analysis

Advantages of CBS: In both interviews and in the questionnaire completed after using CBS, teacher A indicated that CBS enables learners to visualise the migration of ions, which they cannot do in a practical: "*... with computer simulation they can see the migration of ions and also what is formed when the bonding takes place"*. He added that practical investigations mainly show the end product, not the process. He also believed that CBS improves learners' interest, motivates them to learn, and increases learners' participation, suggesting that learners pay more attention when they are using CBS.

Learners' difficulties in electrolysis: In both interviews, Teacher A noted that learners seemed to think that electrolysis takes place only in a solution, not realising that molten substances also conduct electricity.

Challenges in using CBS: Teacher A believed that CBS is suitable for a small number of learners, which was difficult in his class where 44 learners shared 4 computers. He further noted that it may be expensive for schools to buy the equipment required to use CBS. He suggested that it would be ideal if the school could afford a big screen and speakers: "... *if a big screen can be used and also where the students are watching there can be more speakers, so that all the students can be able to hear what is being said in the computer simulation."*

Teaching strategies: During interviews, teacher A explained that his teaching involved the full participation of the learners. He reported that he used practical experiments to enable learners to be hands-on, and he held discussions to elaborate on the results of experiments. He further used the question and answer method to link new lessons with previous lessons, and to allow learners to express themselves. He emphasised that CBS should be used together with practical experiments, which actually occurred during the first lesson. In the remaining two lessons that were observed, he resorted to teacher centred strategies without using the CBS that were provided.

Teachers' curricular knowledge: In the first questionnaire, teacher A correctly answered questions requiring basic content knowledge about electrolysis. Also, he correctly indicated the properties of ionic compounds, solubility and conduction as essential pre-knowledge, and mentioned the importance of the industrial applications of electrolysis. However, he became confused during the second lesson when explaining how the reactivity series determined which half reactions would occur, indicating some gaps in his content knowledge.

Teachers' attitudes: Teacher A used CBS in only one of the three lessons that were observed. This may indicate some reluctance to use CBS. His idea about using a big screen suggests that he recognised the value of visualising the movement of ions and electrons, but that he did not appreciate learning by manipulating CBS. Ironically, he mentioned that learners should be involved in lessons, doing practical experiments, yet he overlooked the value of learner involvement in manipulating the CBS.

Relating the use of CBS to the views and knowledge of the teacher

.

By using only one of the CBS provided,, teacher A revealed that he did not consider CBS to be very useful in teaching electrolysis. However, using it together with practical work indicates that he valued the macroscopic and microscopic levels for understanding. In fact he mentioned that seeing the migration of ions on the CBS may support learners' understanding. However, his teaching on the symbolic level was inadequate as he became confused when explaining the redox reactions. Ironically he understood the value of learners' involvement in the practical activity, but not in the use of CBS, as he did not allow the learners to manipulate the simulation. This may be because he prefers the traditional methods indicating that he was not comfortable with CBS. It seems that lacking content knowledge as well as pedagogical knowledge limited his use of CBS to a mere demonstration of microscopic processes.

Teacher B

Lesson observation

Teacher B used the three simulations that were provided, one per lesson, following examples prescribed by the syllabus: the purification of copper, the electrolysis of acidified water, and the electrolysis of brine. She started all lessons by relevant questions to test pre-knowledge and link it to the new lesson before learners were allowed to use the simulations. While learners were working in groups she moved around checking that all learners were engaged. All lessons were completed by classroom discussions during which she summarized main points and wrote equations on the blackboard. During the lessons, she sometimes made mistakes and was then challenged by learners, but it seemed that she was not upset by this.

Data analysis

Advantages of CBS: Teacher B believed that using CBS to teach electrolysis holds many advantages. During the first interview, she explained that CBS may enhance learners' understanding of electrolysis because "*… it can bring manipulation because certain style of learners that need to manipulate and also there are visuals, they can visualise better"*. She expected that the CBS would enhance learning as the new generation is eager to use technology:

> I *think that can be a perfect idea because from my personal experience, pupils are shifting ... technologically, they are now interested in gadgets. So if you can use them I think you can just get their hearts. I think you can just get their hearts* (Teacher B, first interview, L98).

In the second interview, she mentioned that learners understood the topic much better than in previous years and that the CBS enabled learners to be self-driven, to work independently, assisting each other and requiring minimum guidance from her. They were able to manipulate the CBS themselves and to "*rewind*", therefore being responsible for their own learning. She also mentioned that learners asked many questions about oxidation and reduction, which helped her to realise her own misunderstandings. This remark showed that she realised that CBS promotes critical thinking, not only for learners but also for the teacher.

Learners' difficulties in electrolysis: She mentioned learners' difficulties in the first questionnaire as well as in both interviews. She pointed out that learners struggled to distinguish between the cathode and anode, and in being able to tell the direction of the migration of ions during electrolysis: "*... polarity is still an issue and identifying the ions. And they cannot imagine that ions move, you know theoretically but they don't understand. They don't show understanding that ions they do move"*. She also said that some learners lacked the knowledge of physics required to understand electrolysis and would simply "*shut down"* when learning about electrolysis.

Challenges to using CBS: Teacher B indicated in both questionnaires and interviews that the large number of learners in her class was a challenge. The groups were too big and difficult to monitor, having about ten learners in a group, making it difficult to guide the different groups. Consequently, some learners may be left behind, losing the opportunity to manipulate the CBS themselves. However, she said that using CBS with large groups would be better than not using it at all. The shortage of equipment was another challenge that she mentioned. Of interest, however, is that school B had a computer laboratory. Nevertheless, she regarded learners' socio-economic background as a challenge as some of the learners had not been exposed to computers at home. However, to overcome that challenge, Teacher B suggested that learners could assist each other.

Teaching strategies: According to the first interview and questionnaire, Teacher B used questioning, practical work, and discussions as teaching strategies. She said that the question and answer method linked the lesson with the previous lesson to provoke learners' thinking, and that it engaged them in the lesson. During each of the lesson observations, she indeed integrated questioning and discussions with CBS, although no practical work or demonstrations were conducted. She was satisfied with the learners' abilities to use the simulations:

L31 Interviewer: *Ok. So how did you assist the learners during, when using the computer simulation?*

L32 Teacher B: *Actually, I am surprised. During a normal day I usually have to assist them, but this time around not expected, they assisted each other. It was quite amazing and interesting. Yes, those who were able to follow were able to manipulate and in fact to change this, eh, what can I say, to reverse a bit because I am unable to rewind myself but the learners each time I asked a question would just go back a bit, and find things on their own.*

It seems that some of the learners knew better than the teacher how to manipulate the simulations. She was also impressed by the way in which the learners enjoyed working on their own and that they were able to assist each other. She clearly regarded the CBS as a great help and indicated that she may stop doing practical work altogether.

Teachers' curricular knowledge: Teacher B's responses in the questionnaire and interview showed an understanding of how electrolysis links to other curriculum topics. However, there were clear gaps in her content knowledge. In the questionnaire, she gave incorrect answers to some content related questions and in the lesson plans, she did not indicate the chemical processes as important outcomes. Furthermore, she mentioned that the learners had difficulties with oxidation and reduction, however she did not explain these during the lessons. During the classroom discussions following the CBS, she referred to the reactivity series but did not give adequate explanations of how to use it, for example, to understand why hydrogen gas rather than sodium would form at the cathode in the electrolysis of brine. She asked learners which ion would be "*preferred*" and said that it is "*different*" from the reaction of metals without explaining what was meant by "*preferred*". This lack of explanation suggests that she did not have a clear understanding of it herself. Teacher B realised that she had challenges with her subject matter knowledge in electrolysis, and in the second interview, she acknowledged that CBS assisted her in understanding the topic better:

L19 Interviewer: *So now, how have the use of computer simulations improved your understanding of electrolysis?*

L20 Teacher B: *Eh. Especially the second, second lesson, I discovered that in fact, I had issues as well, which I, after using the simulation, we, the learners they understood better and they started correcting me and I felt it was a little bit, it was some havoc because the learners, they kept on assisting me and I was not aware that I did not know the concepts, but after the learners asked a lot of questions, it was then that I gave myself time to revisit the simulation and yes, I was always wrong.*

Teachers' attitudes: Teacher B revealed a positive attitude to CBS during the first interview: "*I'm even excited already because I can imagine my students saying "wow". Yes, I think it can help a great deal.* She confessed that some years back she had used the traditional methods of teaching, mostly the chalkboard. She later realised that the traditional methods were not good enough because the learners complained, "*We can't imagine, we do not even form a picture of* *what you are trying to say"*. She then changed her teaching and began to include practical work, after which she reported that the learners' performance had improved. These remarks show that teacher B was eager and willing to learn, change and improve her teaching.

Relating the use of CBS to the views and knowledge of the teacher

Teacher B used all three CBS that were provided. She allowed learners to be hands-on, she even tried to assist learners. This maybe because she believed that CBS enhance understanding and promote critical thinking. She acknowledged that she had limited knowledge of electrolysis and thus had a challenge of using the appropriate teaching methods. She was concerned about issues raised by the learners. She thus believed that CBS would assist her to make the topic understandable to learners. Allowing the learners to work on their own and assisting each other, minimised the burden of explaining concepts which she herself could not understand well. She did not mind being corrected by the learners and appreciated that CBS enhanced learners understanding of electrolysis, something she had failed to do with the other teaching methods. She also believed that her content knowledge would to improve with the use of CBS. Her admitting to having limited content knowledge and her willingness to learn by using CBS allowed her to let the learners to work independently. She allowed learners to ask questions because she understood that in the process learners internalise what they are learning.

Teacher C

Lesson observation

Teacher C used all three CBS that were provided. She started her lessons by questioning on relevant prior knowledge and then proceeded to discuss the content that that learners would encounter in the simulations. During the lesson, teacher C moved amongst the groups, checking that all learners participated and assisting where needed. After the learners used the simulations she asked questions and summarized the content. During two of the lessons she made some content related mistakes when explaining and writing on the chalkboard. It seemed that the learners did not notice these mistakes.

Data analysis

Advantages of CBS: During the first interview, Teachers C indicated that CBS may enhance the understanding of electrolysis because "*... the kids see using a computer what is happening when we say probably an electron moving from this place to this place…"*, and that this would be better than learning electrolysis theoretically. In the second interview, she indicated that CBS also improved her own understanding:

> *It even helped me to some extent because, uhm, before as well it was theoretically shown. I learnt it theoretically, and was teaching it theoretically. It was fascinating to see how the process of electrolysis go, uhm, how it was happening. And was quite interesting, it led me to really think even deeper about the topic of electrolysis than I ever done before*.

She also acknowledged that the lessons with CBS were more interesting, and learners participated more, asking more questions as compared to previous lessons.

Learners' difficulties in electrolysis: She mentioned that the learners found it hard to distinguish between the two electrodes:

> *"Generally, it's when they have to decide which one has been oxidised, which one has been reduced. Like if you give them the electrode, you have to determine where the electrons are from and where they are going to"*.

Challenges in using CBS: Teacher C explained that she was concerned that using CBS may take a lot of teaching time:

> *It is time consuming because to do one or more concepts you need time, which according to our syllabus we won't be able to complete the syllabus, and students are tested on the assumption that they have completed the syllabus. The only problem I could see is that it takes a lot of time.*

She also mentioned that there was a shortage of computers as those in the computer laboratory were not accessible. She was also concerned that the socio-economic background of the learners could make it impossible for learners to use CBS as some did not have their own laptops.

Teaching strategies: During the first interview, Teacher C mentioned that she mainly used the question and answer method to link the new lesson with the previous, and then used discussions in the new lesson. During the three lesson observations, she started each lesson by discussing the concept to be learnt and she wrote the important points on the chalkboard. After that, she allowed the learners to work independently in groups, using the CBS while she moved around, assisting them when needed. Before the end of each lesson, she again had discussions with the whole class. She also made use of the chalkboard during the discussions, where she wrote important points, such as the chemical equations at the electrodes. She did not do any practical work during the lessons and only mentioned practical work in the first questionnaire, writing that the school lacked the "*equipment to carry out a simple electrolysis technique*".

Teachers' curricular knowledge: She noted in the interviews that ionic bonding and the reactivity series were some of the topics that needed to be covered before electrolysis. This was an indication that she was aware of the concepts that linked to electrolysis. She indeed started the first lesson by recapping the concept of ionic bonding. However, she revealed inadequate content knowledge during the classroom discussions about the reactivity series. In the second lesson, she did not use the reactivity series when explaining which ions would be "*preferred*" at each electrode, instead she gave an incorrect explanation using concentration. She also made a number of conceptual errors in predicting the products formed at the electrodes, which showed that she had a limited understanding of the half reactions in the process of electrolysis. In terms of why it was important for learners to learn about electrolysis, she mentioned understanding the process of electrolysis and also its industrial applications in the questionnaire after using the CBS.

Teachers' attitudes: Her remarks during the first interview indicated that she was more concerned about good results in the examinations rather than understanding chemistry. Initially, she was sceptical about the use of CBS as she believed that it would take up too much time and negatively impact learners' performance in the examinations. After using the CBS, she changed her attitude towards it and mentioned that through proper guidance, CBS could be used to improve the teaching and learning process.

Relating the use of CBS to the views and knowledge of the teacher

Teacher C allowed the learners to work independently and availed herself to assist them. This is an indication that she embraced using CBS as a teaching strategy that would enhance learners' understanding. However, at first she was sceptical about its use as noted in an interview when she said that it would take a lot of teaching time. The experience of using CBS changed her views, afterwards she indicated that it can indeed be valuable, if used with proper guidance. Teacher C also had limited content knowledge, this was observed when she made a number of mistakes when predicting the products of the half-reactions. Using CBS inspired her to think deeply about the topic and actually improved her own understanding.

Discussion and conclusions

The study showed how the participants' use of CBS in teaching electrolysis can be understood in terms of their knowledge and views about CBS in electrolysis. All three teachers believed that CBS enhances learning by enabling learners to visualise the sub microscopic processes, such as the movement of ions and electrons, in agreement with Doymus et al. (2010).They also believed that using the latest computer technology would capture learners' interest and therefore enhance the understanding of the topic in agreement with Scheurs and Dumbraveanu (2018). Teacher B and C allowed the learners to work on their own and manipulate the CBS indicating that they understood that CBS should be used with a learner-centred approach. Both teacher B and C mentioned that the active involvement of learners in manipulating the CBS was crucial for learning. These two teachers utilised the CBS in each of the lesson observations, facilitating the various groups in class. Both conducted classroom discussions after the CBS, asking learners what they had observed. Contrarily, teacher A used only one of the three CBS that were provided. He did involve learners in a practical experiment, thereby engaging them with the macroscopic reality. However, he used the CBS after they had completed the experiment, and used it in isolation, that is, without referring to it during the lesson or in the follow up lessons. It seems that he believed that seeing the movement of ions during the first lesson would be sufficient to understand the process in the other applications of electrolysis. Furthermore, Teacher A indicated that he would prefer a big screen with speakers, so that learners could see and hear, which indicates that he did not understand that manipulating the CBS enhances the understanding of sub-microscopic processes. In contrast, Teacher B and C both believed that learners had to manipulate the CBS and that the teacher was expected to lead discussions after learners used the CBS to enhance learners' understanding.

The results indicate that a lack of pedagogical knowledge about the appropriate use of CBS may lead to its ineffective use, as pointed out previously by Rutten et al. (2012). To be used appropriately, learners have to manipulate the CBS, and teachers have to allow learners to work on their own but guide them by asking relevant questions in the form of discussions or questioning teaching methods. Furthermore, teachers' lack of content knowledge can seriously impede potential learning offered by CBS. In particular, the teachers' lack of content knowledge obstructed the opportunity to help learners make sense of the chemical reactions modelled in the CBS. Though the CBS enabled learners to visualise the process on sub microscopic level, it was not linked with the symbolic level. Nevertheless, CBS may also help teachers to realise their own inadequate knowledge and it thus has long-term benefits. The teachers' attitudes towards CBS acted as amplifiers and filters for their use of CBS. Initially, Teacher B was particularly enthusiastic and she was also the one who had the most success in her use of CBS as she was willing to learn from her content related mistakes. Another factor that may contribute to teachers not using CBS is that teachers in the various departments in schools work in isolation. Thus, the computers in these schools are underutilised. There is a need for schools to review their policies so as to allow teachers in the respective departments to have access to the computers to support learning in all subjects.

This study supports existing literature in that CBS enhances learners' understanding of abstract concepts such as electrolysis (Kotoka & Kriek, 2014; Lindgren & Schwartz, 2009). The main conclusion is that teachers' views about CBS largely influences the way they use CBS in the classroom. Furthermore, the study revealed that teachers' PCK and SMK are important factors in the optimizing the learning experience offered by CBS. The results concur with Sarabando, Cravino and Soares (2014) who noted that learners' gain depends on teachers' pedagogy when using CBS. Thus teachers have to be educated on the appropriate use of CBS to ensure effective use of CBS

The results of this study should not be generalised, as it was a case study conducted in a small, developing country. Also, the study was limited to teachers using CBS for the first time. However, despite the small scale of this study, it opens up questions for further research about how teachers should be educated to utilise CBS effectively.

References

Bong, A. & Lee, T. (2016). Form four students' misconceptions in electrolysis of molten compounds and aqueous solutions. *Asia-Pacific Forum on Science Learning and Teaching,* 17(1), article 8.

de Jong, O. & Taber, K. S. (2014). The many faces of high school chemistry. In N.G Lederman and R. Schwartz (Eds.), *Handbook of Research in Science Education vol. 2* (pp. 457-480). New York: Routledge.

Doymus, K., Karacop, A. & Simsek, U. (2010). Effects of jigsaw and animation techniques on students' understanding of concepts and subjects in electrochemistry. *Educational Technology Research and Development,* 58, 671-691.

Dumon, A. & MzoughiKhadhraoui, I. (2014). Teaching chemical change modelling to Tunisian students: an expanded chemistry triplet for analysing teachers' discourse. *Chemistry Education Research and Practice,* 15(1), 70.

Examination Council of Eswatini (2016). *Swaziland General Certificate of Secondary Education (SGCSE) Physical Science Examination Reports*. Ezulwini, Eswatini: Apollo Printers.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK Summit. In A. Berry, P. Friedrichsen & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 28-42). New York: Routledge.

Grossman, P. (1990). *The Making of a Teacher: Teacher Knowledge and Teacher Education.* New York: Macmillan.

Halim, N. A., Ali, M. Yahaya, N. & Haruzuan, M. (2013). Mental models in learning chemical bonding: A preliminary study. *Procedia-Social and Behavioral Science,* 97, 224-228.

Jaakkola, T. & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning*, 24(4), 271-283.

Kaheru, S., & Kriek, J. (2016). The effect of computer simulations on acquisition of knowledge and cognitive load: a gender perspective. *African Journal of Research in Mathematics, Science and Technology Education*, *20*(1), 67-79.

Koehler, M.J. & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.

Kotoka, J. & Kriek, J. (2014). The impact of computer simulations as interactive demonstration tools on the performance of grade 11 learners in electromagnetism. *African Journal of Research in Mathematics, Science and Technology Education*, 18(1), 100-110.

Lindgren, R. & Schwartz, D. (2009). Spatial learning and computer simulations in science. *International Journal of Science Education,* (31), 419-438.

Magnusson, S., Krajcik, L. & Borko, N. (1999). *Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching: PCK and Science Education.* Dordrecht, Netherlands: Kluwer Academic Publishers.

Mbajiorgu, N. & Reid, N. (2006). *Factors Influencing Curriculum Development in Chemistry*. Retrieved from https://www.heacademy.ac.uk/knowledge-hub/factors-influencing-curriculum-development-chemistry.

Minner, D. D., Levy, A. & 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.

Mustafa, Y, & Altay, E. (2014). Teaching the Topic of Simple Electric Circuits through Simulation and Laboratory Practice Techniques to Prospective Primary School Teachers. *Trakya University Journal of Education 4(2), 84-99.*

Rollnick, M. & Mavhunga, E. (2014). PCK of teaching electrochemistry in chemistry teachers: A case in Johannesburg, Gauteng Province, South Africa. *Educación Química,* 25(3), 354-362.

Rutten, N., van Jooligen, W.R. & van der Veen, J.T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, 58, 136–153.

Sarabando, C., Cravino, J.P. & Soares, A. (2014). Contribution of a computer simulation to students' learning of the physics concepts of weight and mass. *Procedia Technology,* 13, 112-121.

Scheurs, J. & Dumbraveanu, R. (2018). A shift from the teacher centered to learner centered approach. *International Journal of Engineering Pedagogy,* 4(3), 36-41.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.

Taner, O., Osman, Y. & Sami, O. (2012). Determination of university freshman students' misconceptions and alternative conceptions about mitosis and meiosis. *Procedia Social and Behavioural Science,* 46, 3677-3680

Trey, L., & Khan, S. (2008). How science students can learn about unobservable phenomena using computer-based analogies. *Computers and Education*, 51(2), 519-529.