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Computer simulations and animations in the teaching and learning of chemical kinetics, equilibrium, and energetics: Assessing teachers' pedagogical skills in Tanzania secondary schools

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Abstract

This paper presents changes on teachers' pedagogical skills in using computer simulations and animations to support the teaching and learning of chemistry concepts. It draws on the data that were collected using a mixed-method research approach coupled with pre- and post-assessment of 20 level three chemistry teachers. The data from classroom observation were quantitatively analyzed using means, standard deviations, and a sample paired t-test. Thematic analysis was used for the qualitative data. The results showed that teachers' pedagogical skills in using computer simulations and animations in teaching and learning chemical kinetics, equilibrium, and energetics were low in pre-instruction, with an overall mean of 1.3 ± 0.1. In post-instruction, the findings indicate that teachers have improved pedagogical skills, with an overall mean of 3.9 ± 0.06 and p-value of 0.000. Therefore, teachers need improved pedagogical strategies to use computer simulations and animations as viable instructional resources for teaching and learning of chemistry concepts.

Keywords: computer simulations, animations, pedagogical skills, science process skills

INTRODUCTION

Chemistry plays an important role in everyday life because it equips learners with scientific knowledge and skills in particular science process skills (UNESCO, 2009). Learners need to understand the world around them and solve problems. Development of such competences makes it a necessary requirement for learners to learn through practical or hands-on activities (Bete, 2020). They ought to engage in inquiry activities such as problem identification, formulation of hypothesis, conducting experiments, collecting data, and making conclusions from evidence. However, in Tanzania, teaching and learning of chemistry are dominated by teacher centeredness and most often theoretically (Mkimbili et al., 2017; Semali & Mehita, 2012). The lack of adequate laboratory resources and equipment costs and safety issues are among the factors that limit teachers' ability to engage students in hands-on activities. While some chemicals for experiments are dangerous, others are difficult to realize in physical laboratories thus making teachers resort to theoretical teaching (Kinyota, 2020).

Moore et al. (2014) explained how information communications technology (ICT) could be a panacea to the shortage of resources like the situation in Tanzania through the use of computer simulations and animations. They confirm that the technique has the potential to greatly impact the teaching and learning of chemistry concepts and science process skills. According to Nkemakolam et al. (2018), computer simulations are computer representations of actual or hypothetical events or natural phenomena that allow users to experiment with the effects of changing or altering parameters. On the other hand, animations are dynamic displays of graphics, images, and colors that are placed

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Contribution to the literature

- The present study sheds light on the changes in teachers' pedagogical skills in using computer simulations and animations in pre-instruction and post-instruction of chemical kinetics, equilibrium, and energetics in Tanzanian secondary schools.
- Pedagogical strategies in formulating instructional objectives focusing on both content and science process skills as well as active interactive strategies are important for teachers use computer simulations and animations in teaching and learning.
- Equally, the study reveals the significance of computer simulations and animations as viable instructional materials in the teaching and learning of chemistry concepts.

in successive frames to achieve certain visual effects (Trindade et al., 2002). Plass et al. (2012) show that students can use computer simulations and animations to examine processes and participate in hands-on activities while learning.

The use of ICT in education, including computer simulations, has been one of the strategies adopted by several governments to meet the educational demands of the 21st century in chemistry. In Kenya, the curriculum recommends for the integration of ICT, including computer simulations and animations, as one of the innovations in teaching to ensure effective learning in schools (Murithi et al., 2013). In Tanzania, there have been many education reforms and the use of ICT in teaching and learning is one of them. After the introduction of the competency-based curriculum in Tanzania in 2005, teachers were encouraged to use ICT to facilitate the teaching and learning process (MoEVT, 2007; MoEST, 2019a). This reform sought to integrate ICT, including computer simulations, into teaching to guarantee seamless teaching and learning while also providing learners with real-world experience (MoEST, 2015), although its implementation as a pedagogical tool remains problematic.

Several strategies have been adopted to address the issue of teachers' pedagogical skills in incorporating ICT into the teaching and learning process. One of these strategies is in-service teacher training, which is designed to help teachers improve their fundamental computer skills, technical skills, and theoretical knowledge of ICT tools in general (Kihoza et al., 2016; Tsai & Chai, 2012). Despite the introduction of these strategies in Tanzania, a majority of teachers still struggle to put the theory into practice by using computer simulations to facilitate learners' learning through inquiry activities (Kafyulilo & Keengwe, 2013; Kihoza et al., 2016). Consequently, classroom teaching is dominated by teacher talk, lacking hands-on activities for inquiry learning (Kinyota, 2020).

Studies in science education indicate that teachers lack appropriate pedagogical skills in using computer simulations in inquiry-based teaching and learning process (Bingimlas, 2009; Kafyulilo & Keengwe, 2013; Kihoza et al., 2016). Apart from technological barriers associated with computer simulations and animations, non-technological issues for example lesson planning, task selection, instructional procedures for inquiry, content knowledge and assessment techniques are among the pedagogical barriers to using computer simulations and animations (Jamil & Isiaq, 2019; Kelly et al., 2016; Nxumalo-Dlamini & Gaigher, 2019; Smetana & Bell, 2012). As a result, this has hindered the development of science process skills among learners vital for application in life (Kinyota, 2020). Therefore, this mixed-methods pre-test and post-test study involving chemistry teachers seek to address the following research question. What are the changes in teachers' pedagogical skills in using computer simulations and animations in pre-instruction and post-instruction of chemical kinetics, equilibrium, and energetics because of the training program?

LITERATURE REVIEW

Computer Simulations and Animations in Teaching and Learning of Chemistry

One of the ICT tools that may engage learners in hands-on activities for inquiry learning is computer simulations. The usefulness of computer simulations for chemistry teaching lies in their ability to allow students to visualize aspects of chemistry that are either too complex or too small to see through virtual laboratories, scenarios, and visualization of phenomena (Moore et al., 2014). Simulations can also be used to carry out experiments that would otherwise be difficult or dangerous to carry out in physical laboratories. They can also use simulations autonomously to practice repeating or extending classroom experiments for further clarity (Plass et al., 2012; Watson et al., 2020). As students interact with computer simulations have opportunity to engage into inquiry activities such as scientific problem formulation, hypothesizing, collecting data, making interpretations and conclusion (Moore et al., 2014).

In addition, the appropriate use of computer simulations and animations can transform the whole teaching and learning process leading to paradigm shift in both contents, teaching approaches and strategies (Das, 2019; Plass et al., 2012). Computer simulation improves students' acquisition of science process skills (Beichumila et al., 2022), however, with appropriate use of teaching methods (Çelik, 2022). Moreover, students improve their understanding and confidence of chemistry concepts (Watson et al., 2020). Hence computer simulations are powerful learning tools in engaging students in active learning to construct knowledge as scientists do.

Develaki (2019) and Khan (2011) point that computer simulations as a single unit cannot transform learning, but an important matter is how they are used by teachers in the classroom. The effectiveness of computer simulations depends on how they help teachers and learners to achieve the intended instructional objectives (Smetana & Bell, 2012). Teachers need to let students work on their own while using guiding questions through worksheets, small groups, or the whole class discussions instead of presenting students with facts and conclusions (Khan, 2011; Kunnath & Kriek, 2018). Furthermore, guiding learners to conduct practical works through computer simulations together with a follow-up interpretation and discussion contribute to meaningful learning and acquisition of higher order skills including science process skills for problem solving (Develaki, 2019).

Teacher Pedagogical Skills and the Use of Computer Simulations in Chemistry Teaching and Learning

Pedagogical skills refer to teaching skills and knowledge of using relevant instructional materials and teaching strategies to facilitate knowledge or content of the subject matter (Shulman, 1987). It includes teaching-learning related skills such as planning the lesson, choosing an appropriate strategy for instruction, using instructional materials, content mastery and supporting students in their learning process (Choy et al., 2013). This encompasses the pedagogical content knowledge (PCK) in which Shulman (1986) expects teachers to understand how different instructional materials facilitate the teaching and learning of different types of content. With these skills, teachers develop the ability to support learner-centered, collaborative learning and scientific explanations, making the learning meaningful rather than transmitting the knowledge (Rahman et al., 2020). This viewpoint contrasts with a less contextualized and more rationalist approach to teachers' knowledge, as exemplified by the TPACK framework (technological PCK) construct that is too vague or large on PCK for inquiry learning (Brantley-Dias & Ertmer, 2013).

The main goal of computer-based educational simulations is to aid scientific exploration and investigation through hands-on activities. Consequently, teachers' and learners' roles move from director to facilitator, and from passive to active (Moore et al., 2014). Teachers require pedagogical approaches in guiding, questioning, and facilitating to help learners find their own answers and construct their own knowledge using computer simulation affordances (Doerr et al., 2013; Kunnath & Kriek, 2018). In this regard, learner-centered strategies in guiding students to develop broader skills as well as engage in classroom discourse are encouraged (Law, 2009; Rutten et al., 2015). The level of guidance from teachers influences the way students interact and engage with simulations to learn (Kunnath & Kriek, 2018). For example, Khan (2011) and Sarabando et al. (2014) revealed that total students' learning gains obtained depend on teacher pedagogy when using computer simulations. These include teachers' role in selecting appropriate resources, sequencing, and structuring the learning activities, guiding students' experimentation, generation of hypothesis and critical reflection discussion upon outcomes.

In a similar vein, Kunnath and Kriek (2018) noted that the ability of a teacher to manipulate computer simulations in the classroom influences students' learning. These include skills in interpreting visuals and graphics to help make explicit the phenomena and reactions that simulations tend to explain. Learners may have misconceptions about science if they are misguided or if the teacher does not manipulate the simulations properly. In addition, Nxumalo-Dilamin and Gaigher (2019) explains that the effectiveness of computer simulations in the classroom depends on teachers' content knowledge of the subject matter in delivering the lesson in the classroom.

Regarding on important role of pedagogical skills in using computer simulations to facilitate students' inquiry learning, Lee et al. (2021) and Smetana and Bell (2012) advocate professional development programs and teaching practices that include specific technology instruction, which is integrated into the classroom teaching process to provide teachers with real practice in their pedagogies and foreground learner-centeredness. Through this kind of professional development, teachers learn and develop strategies to teach with computer simulations. Teachers understand their role and useful instructional strategies with computer simulations (Doerr et al., 2013). It is another way to foster teachers' attitudes towards the use of computer simulations and their usefulness in the teaching and learning process (Lee et al., 2021).

THEORETICAL FRAMEWORK

The research employed the social constructivism theory proposed by Vygotsky (1978). The theory views knowledge and skills construction as a result of an active process that occurs through social interaction between learners and teachers. Thus, teachers are facilitators, and any use of instructional materials such as computer simulations or animations requires the teacher to provide the required scaffolding for students to interact and learn in a learner-centered approach. From this point, teachers' pedagogical skills play a greater role in facilitating students' learning through active learning

Table 1. Pedagogical skills

Item	Focused on pedagogical skills	Classroom implications
1	Planning lessons with clear learning objectives & learning activities to be supported & archived with relevant computer simulations	Relevant learning objectives & computer simulations/animations
2	Setting teaching & learning activities to support the lesson supported with relevant computer simulations	Relevant learning activities to support the achievement of lesson objectives through inquiry activities
3	Use of inquiry activities supported with computer simulations/animations	Engaging learners in learning by doing using computer simulations to perform hands-on activities, discussions, & presentations on what they found
4	Use of active learning strategies such as guiding learners to make predictions, plan experiments, observations, interpret, make conclusions, group works, & discussions as means for classroom interaction	Classroom interaction activities/as a means of constructing knowledge to make sense of chemistry concepts
5	Guidance strategies to manipulate computer simulations & animations during hands-on activities to scaffold learning through inquiry activities	Scaffolding learners to conduct hands-on activities, correct interpretation of any results from computer simulations, & correcting any misconceptions
6	Content mastery, e.g., use of prior knowledge & connecting the lesson concepts with real life experiences or activities	Examples from the environment & daily life experiences
7	Use of probing questions, worksheets, learners' pair sharing, & written reports as assessment strategies supported by computer simulations	Assessing content knowledge & science process skills

processes and social interaction environments with computer simulations and animations. Teachers' pedagogies engage learners in inquiry activities such as formulating hypotheses and predictions, planning experiments, performing, and collecting data and interpreting and drawing their own conclusions. This is one way to promote classroom interaction. Again, involving learners in small groups, discussions, and presentations of what they explored is important for promoting learner-centered learning in the classroom (Pritchard, 2010). Demirci (2009) adds that teachers should engage learners in practical activities rather than merely listening to their lectures.

Social constructivism theory informed this research to develop and explore how teachers employed pedagogical skills by using computer simulations and animations to facilitate the teaching and learning of chemical kinetics, equilibrium, and energetics. **Table 1** indicates the focused on pedagogical skills.

Moreover, all of these pedagogies, as indicated in **Table 1**, are categorized into six themes, which are selecting computer simulations and planning instructional objectives, teaching, and learning activities, classroom interaction strategies, guidance strategies to manipulate computer simulations and assessment strategies, and content mastery.

METHODOLOGY

Sample Participants

The current study involved level three secondary education chemistry teachers from Dodoma and Singida regions, in the central part of Tanzania. The mentioned area has a severe lack of chemistry laboratories in secondary schools (MoEST, 2020). They are also ranked poorly in form four national examinations, particularly, in chemistry subject (MoEST, 2018, 2019b, 2020). Teachers with pedagogical skills in the use of computer simulations in the teaching and learning of chemistry concepts were expected to help teachers and students use this technology as instructional resources in the teaching and learning process. A total of 20 chemistry teachers were sampled from four secondary schools with computer laboratories: five teachers from each school. Participants were purposively selected following the availability of teachers in schools (Cohen et al., 2011). The sample of teachers was considered adequate as the study involved one-to-one observation of teachers' pedagogical skills development and changes through classroom observation in a naturally occurring social context (Cohen et al., 2011).

Research Design, Data Collection Procedures, and Study Generalizability

The study used a mixed-method research approach, using pre and post assessment designs with both quantitative and qualitative methods (Creswell, 2012). The use of pre and post assessment helped to ascertain the changes and development of pedagogical skills during the intervention among teachers over the use of computer animation and simulations. The settings in the pre-assessment were similar to those in the post-assessment and established a similar environment for comparable results. In addition, similar participants, in particular teachers, were involved in the pre-assessment and post-assessment using the same classroom observation checklist (Robson, 2002). Each teacher was observed three times by three different observers (Creswell, 2013). Moreover, the use of interviews with teachers helped to ascertain teachers' views and insights into their pedagogical practices when using computer simulations. The use of both interviews and observation checklist was considered as triangulation of information (Cohen et al., 2011). The study employed an explanatory research design where quantitative data were first collected and analyzed followed with a qualitative data (Creswell & Clark, 2018). The following steps explain the design and procedures during data collection.

Stage 1: Pre-intervention

Before the interventions (the training program), teachers participated in microteaching activities, where they collaborated to prepare lessons focusing on chemical kinetics, equilibrium, and energetics. At least each teacher prepared a lesson of 40 or 80 minutes and then observed in the actual classroom during microteaching. These lessons were termed "pre-instruction" (pre-assessment) of the pedagogical skills of teachers during instruction while using computer simulations and animations. At this stage, data were collected using a prepared observation checklist of pedagogical skills (**Appendix A**). Classroom observation was deemed the appropriate method since it gives firsthand proof of what the teacher and learners do in the classroom rather than utilizing questionnaires (Atkinson & Bolt, 2010). Three observers of a research team who were science teacher educators observed and rated the lessons. This was followed by reflection and discussion among teachers and researchers. The majority of teachers were unfamiliar with the inquiry activities and opportunities of computer simulations and animations in teaching and learning chemistry for inquiry learning. Moreover, interview was conducted with 20 teachers to ascertain their views and insights on supporting learners learn chemistry concepts using computer simulations and animations (**Appendix B**). The interview lasts for 40 to 50 minutes.

Stage 2: Intervention

This stage involved researchers in a hands-on training program to help the participating teachers acquire the pedagogical skills regarding the use of computer simulation and animations in the teaching and learning chemical kinetics, equilibrium, and energetics concepts. Based on pedagogical weaknesses identifies during pre-intervention stage, teachers developed alternative approaches under social-constructivism theory to integrate computer simulations and animations in teaching chemistry concepts. A total of 20 teachers participated in the training program that involved teachers in various collaboration activities such as lesson planning, lesson design, and lesson teaching through microteaching and reflection. During microteaching teachers assumed the same role as that of actual classroom teaching such as delivering lessons, asking questions, and fostering classroom interactions interacting (Kilic, 2010). In addition, teachers taught in level three classrooms. Teachers focused on the topic of chemical kinetics, equilibrium, and energetics for level 3 (form 3) (MoEVT, 2010). This was due to the fact that teachers and learners face difficulty in teaching and understanding of chemical kinetics, equilibrium, and energetics concepts (Gegios et al., 2017; Lati et al., 2012). This is aided by a scarcity of teaching and learning materials, as well as teacher-centered techniques that do not engage learners in inquiry learning (Kinyota, 2020).

In particular, during the intervention, teachers used computer simulations and animations of the concept of rate, the effect of temperature on the rate of reaction, the effect of concentration on the rate of reaction, effect of surface area on the rate of reaction, the effect of catalyst on the rate of reaction, reversible reactions, irreversible reactions, effect of temperature on the position of chemical equilibrium, endothermic and exothermic reactions accessed https://www.yenka.com/en/Yenka_Chemistry. Users can conduct experiments in a virtual lab with the help of Yenka. A user could select from a variety of ready-made models or design their own. Also, PhET simulations were used https://phet.colorado.edu/en/simulations/reactions-and-rates. The features and design of these computer simulations are based on school curriculum relevance and the level of learners (Çelik, 2022; Zendler & Greiner, 2020). Most of the activities in intervention focused on **Table 1** pedagogies and as indicated in **Table 2**.

The reflection activity during the intervention helped teachers to get feedback from peers and researchers on the weakness and strengths of their pedagogical practices under social-constructivism approach, the process that helped to improve the lessons and teaching practice via alternative approaches. The intervention lasted for three weeks.

Stage 3: Post-intervention

At the end of the program 20 chemistry teachers were observed again for post assessment through microteaching in the classroom context (**Appendix A**). At this stage, data were collected using the same prepared observation checklist of pedagogical skills. The same three observers of the research team who were science teacher educators observed and rated the lessons. In addition, interviews were conducted with 20 teachers to get their views on pedagogical practices during their instruction (**Appendix C**). The interview lasts for 40 to 50 minutes per teacher. This helped to understand their pedagogical changes from pre- to post-instruction.

Study Generalizability

The current study has limited generalizability as it is mainly focused on public secondary schools and chemistry teachers only. Therefore, the current methods and findings under the present study should be limited to contexts involving teachers' pedagogical skills in

Table 2. Intervention activities

Item	Content of the training program	Learning strategies by teachers
1	Introduction in the use of computer simulations/animations added features & advantages of computer simulations in the teaching & learning of chemical kinetics, equilibrium, & energetics for scientific investigation	Lecture & collaboration
2	Selecting relevant computer simulations & animations from available resources; conducting experiments, appropriate interpretations of experiment results, & graphs generated from computer simulations	Collaboration
3	Using inquiry activities focusing on science process skills, its facilitation through inquiry process with computer simulations	Collaboration
4	Development of instructional objectives, setting of teaching & learning activities to support learning of chemistry concepts with relevant computer simulations	Learning by designing
5	Development of guidance strategies to manipulate computer simulations & animations, assessment strategies to support learning of chemistry concepts with relevant computer simulations	Learning by designing
6	Use of prior knowledge & examples from the real environment for students to transfer knowledge & skills	Learning by designing
7	Teaching of own lessons to colleagues through microteaching & in real classroom context	Putting learning into practice in classroom context
8	Reflection on the developed & taught lessons	Feedback from peers & researchers

using computer simulations involving the teaching of chemical kinetics, equilibrium, and energetics and the use of computer simulations and animations as viable instructional materials.

Validity and Reliability of Data Collection Tools

Observational checklist

Teachers' pedagogical practices were captured using an observational checklist that included pedagogical skills indicators during the lesson preparation, teaching, and learning process (**Appendix A**). The observation checklist on teachers' pedagogical skills in the chemistry classroom documented aspects of pedagogical practices which were adapted and developed from different existing literature including de Jong and Njoo (1992), Khan (2011), and Rahman et al. (2020).

Six main aspects were identified: selecting computer simulations and planning instructional objectives, teaching, and learning activities, classroom interaction strategies, guidance strategies to manipulate computer simulations, assessment strategies, and content mastery. The six aspects had 27 items observed and rated. The observation checklist was validated by three science teacher educators for content and relevance of the items (Creswell, 2013).

To ensure reliability, the interrater reliability, or inter-observer reliability, between three observers was calculated during the pilot study using Cohen's kappa coefficient (Cohen, 1988) since an observer's agreement occurs by chance. Inter-observer reliability is a measure of consistency between two or more observers of the same construct (Cohen, 1988). The value of the kappa coefficient (ka) across three observer pairs was found to be 0.76, 0.78, and 0.79. According to Cohen (1988), kappa values range from 0-1, where above 0.75 is considered an acceptable agreement. In addition, use of three observers (the researcher and two assistant researchers) independently during classroom observation helped to improve internal reliability of the findings from classroom observation (Creswell, 2013).

Interview guide

Researchers and science educators reviewed the validity of the content of the interview guide questions. Pilot study was undertaken for the purpose of estimating the duration of interviews and identify irrelevant and inaccurate interview questions (Cohen et al., 2011). As the result irrelevant questions were eliminated while unclear or inaccurate questions were refined. The questions focused on teachers' experiences with their pedagogical practices with computer simulations and their experiences.

Data Analysis

The data gathered were coded and transcribed. For quantitative data, descriptive statistics were produced, such as means and standard deviations, and were utilized to compare changes in teachers' pedagogical skills in pre- and post-instruction (Pallant, 2020). Moreover, inferential statistics for a paired sample t-test were calculated. This helped the researcher to understand the significant difference in teachers' pedagogical skills in using computer simulations and animations in pre and post instruction of chemical kinetics, equilibrium, and energetics concepts. The observational checklist data were analyzed using mean scores on a 0-4 scale ranging from 0: not evidenced to frequently evidenced. The observation checklist had 27 items; hence, the mean and standard deviation were calculated independently from each item. Thereafter, the overall average mean and standard deviation were obtained. The analysis was done using SPSS version 23.0 software. Furthermore, themes were developed from the data for qualitative data analysis from interviews, and thematic analysis by Braun and Clarke (2012) was used. Teachers' interviews were transcribed in order to facilitate the visual and coding process (Mutch, 2013).

Thereafter, a copy of transcribed information was provided to the research team for them to review, amend and improve. Finally, the agreed themes were used to conclude in relation to teachers' experiences and feelings about their pedagogical practices with computer simulations. As the result, peer review and checking of the data improved the credible of the research outcomes (Creswell, 2013).

RESULTS

Teachers' Pedagogical Skills in Pre- and Post-Instruction

The study's overall findings show that teachers' pedagogical abilities in using computer simulations and animations in teaching and learning chemical kinetics, equilibrium, and energetics were inadequate with mean scores ranging from 0 to 2 in pre-instruction. The overall mean was 1.3±0.1 (**Table 3**). In post-instruction, the findings indicate that teachers have high pedagogical skills with an overall mean of 3.9±0.06 (**Table 3**). The results indicated that there was a statistically significant difference between the pre- and post-instruction with $p<0.05$. This implies that there was improvement of pedagogical skills in pre-instruction to post-instruction as the result of the training program engaged teachers in real practice of using computer simulations and animations in teaching and learning chemical kinetics, equilibrium, and energetics.

The findings indicate that majority of teachers use computer simulations and animations to plan instructional objectives to be archived in the learning process (with the mean of 1.8±0.2) in **Table 4**. However, the instructional objectives lacked specific scientific skills such as science process skills that can be enhanced

Table 3. The overall changes of teachers' pedagogical skills indicators in pre- and post-instruction

S/No	Pedagogical skills indicators	n	Items on the checklist	Mean±SD in pre-instruction	Mean±SD in post-instruction	t-value	p-value
1	Selecting CSA & planning instructional objectives	20	1-3	1.8±0.2	4.0±0.0	37	0.000
2	Teaching and learning activities	20	4-6	1.3±0.2	3.8±0.1	29	0.000
3	Classroom interaction strategies	20	7-14	0.9±0.1	3.9±0.09	56	0.000
4	Guidance strategies in manipulating CSA	20	15-18	1.3±0.1	3.9±0.09	62	0.000
5	Assessment strategies	20	19-23	0.8±0.2	3.8±0.1	45	0.000
6	Content mastery	20	24-27	2.0±0.3	3.8±0.1	25	0.000
	Overall	20		1.3±0.1	3.9±0.06		

Table 4. The overall changes in specific items levels of teachers' pedagogical skills indicators in pre- & post-instruction

S/No	Pedagogical skills indicators	n	Mean±SD in pre-instruction	Mean±SD in post-instruction
1	The teacher selects relevant computer simulations/animation to the lesson	20	1.6±0.7	4.0±0.0
2	Teacher frames objectives of the lesson correctly	20	4.0±0.0	4.0±0.0
3	Lesson objectives includes specific scientific skills, i.e., science process skills	20	0.0±0.0	4.0±0.0
4	The teacher sets strategies to explore the content through inquiry activities, i.e., use of worksheets	20	1.2±0.4	3.8±0.4
5	The teacher sets strategies to develop process skills i.e., using hypothesizing, experimenting, observing, measuring, communicating results, etc. as activities	20	0.2±0.4	3.9±0.3
6	The teacher sets strategies involving learners in collaboration into the lesson, i.e., group works, discussion, etc.	20	2.6±0.4	3.9±0.3
7	The teacher guides learners to identify scientific procedures & variables before investigation	20	0.0±0.0	3.8±0.41
8	The teacher guides learners to make simple predictions or hypothesis	20	0.0±0.0	4.0±0.0
9	The teacher guides learners to conduct simple experiments	20	1.6±0.4	3.9±0.3
10	The teacher encourages learners to perform lesson activities in groups with a minimum support	20	2.6±0.6	3.95±0.2
11	The teacher observes & listens to learners as they interact within their groups	20	1.6±0.6	3.9±0.3
12	The teacher encourages learners to present/report the results to the class	20	0.0±0.0	3.9±0.3
13	The teacher prompts discussion & probing learners' understanding/thinking	20	1.4±0.5	3.8±0.3
14	The teacher provide opportunity for learners to draw reasonable conclusion on their own from evidence	20	0.0±0.0	3.95±0.2
15	The teacher manipulates computer simulations/animations to clarify concepts, misconceptions where necessary, and know when to use it	20	0.2±0.4	4.0±0.0
16	The teacher assists learners to make proper observations, taking accurate measurements	20	3.4±0.5	4.0±0.0
17	The teacher guide in correctly interpreting results from experiments including graphs generated	20	1.1±0.3	3.8±0.3
18	The teacher is confident with use of technology in guiding hands-on activities	20	0.4±0.5	4.0±0.0

Table 4 (continued). The overall changes in specific items levels of teachers' pedagogical skills indicators in pre- & post-instruction

S/No	Pedagogical skills indicators	n	Mean±SD in pre-instruction	Mean±SD in post-instruction
19	The teacher uses verbal probing questions that appeal to learners understanding of learned concepts & science process skills	20	1.1±0.5	3.7±0.4
20	The teacher asks learners to write a minimum of two & a maximum of five sentences to summarize the topics	20	0.0±0.0	3.8±0.3
21	The teacher triggers learner critical thinking through learners' pair sharing	20	0.2±0.4	3.8±0.41
22	The teacher examines the written reports of learners participated in computer simulations-based experiments	20	1.3±0.5	3.9±0.3
23	The teacher assesses the concepts of the learners' using worksheets	20	1.7±0.4	3.9±0.3
24	The teacher gives clear clarification of the concepts	20	2.7±0.5	3.9±0.2
25	The teacher answer/respond to learners' questions correctly	20	2.6±0.5	3.8±0.3
26	The teacher uses examples to relate the lesson, activities, & real-life experiences	20	0.3±0.4	3.7±0.4
27	The teacher appears confident in lesson content	20	2.5±0.5	4.0±0.0

with computer simulations affordances. As for item 2, (4.0±0.0) teachers correctly framed the learning objectives, however, item 3 (0.0±0.0) scientific skills to be attained in the teaching and learning process lacked. In post-instruction, the findings indicate that a majority of teachers improved their pedagogies in planning instructional objectives by focusing on both the content knowledge and scientific skills with mean 4.0±0.0 (**Table 4**). Science process skills such as the ability of learners to make predictions/hypothesis, planning experiments, observations, recording data, correct interpretations, concluding based on evidence as learning outcomes was part of instructional objectives. The findings from the interviews with teachers revealed the same. For example, teacher 1 said:

> "Now I understand, it is critical to consider that a lesson begins with what you plan to achieve during lesson preparation. I used to set instructional objectives that required students to explain, define, and mention things. Along with these, I understand how to include science process skills as learning outcomes."

Teacher 6 explained:

> "I have realized that scientific skills should be part of instructional objectives. For example, ability of students to formulate hypotheses, make correct observations, interpret, communicate, and make conclusions, etc. based on the nature of the lesson. Also, teaching and learning activities should be supported with computer simulations at various stages and involve learners to gain these skills."

Furthermore, a majority of teachers exhibited low classroom interaction strategies that engage learners in learning interaction as they construct knowledge using computer simulations in pre-instruction (mean 0.9±0.1 in **Table 3**). The analysis revealed that most of strategies were not used. The strategies which were not used are as presented in **Table 4** item 7 (0.0±0.0) devising scientific procedures, item 8 (0.0±0.0) formulating hypothesis, presenting, or reporting the results to the class (0.0±0.0), learners drawing their conclusion from evidence (0.0±0.0). This implies that teaching is teacher centered. On the other side, teachers showed to use group work and discussion, however putting learners in groups is not enough. What makes learning meaningful is the ways through which learners engage in learning as they interact. The findings in the post-intervention indicate that teachers' pedagogical skills in enhancing classroom interaction have improved up to a mean of 3.9±0.09. Teachers were observed to be capable of involving learners in small groups, developing hypotheses, thinking about, and developing a plan for testing their hypotheses, making observations, and classroom discourse. The interview quotes below from teachers demonstrates their feelings.

> "After this program, I know how to engage learners in learning with computer simulations using simple activities like making simple hypothesis or prediction, identifying variables, and thinking the plan to test their hypothesis. These activities are the means through which learners can discover new knowledge and construct new knowledge."

Another teacher said:

> "Through this program, I have realized that learners can think on their own once they are given such opportunity during the teaching and learning process, instead of explaining everything as a teacher."

Another teacher added,

> "I have realized that, as a teacher, I need to give room for learners to discuss and present what they find from exploration with computer simulations instead of direct giving answers. This helps to

> identify misconceptions within learners but improves communication skills."

Moreover, with regard to guidance strategies in manipulating computer simulations for hands-on activities, the findings indicate that in pre-instruction majority of teachers had inadequate pedagogical abilities in manipulating computer simulations as teaching and learning resources which was 1.3±0.1 (**Table 3**). On the contrary, teachers' guidance to learners in making proper observations of hand-on activities such as color changes, reactions and taking accurate measurements of chemicals was good (3.4±0.5).

However, a majority of teachers were unable to properly use computer simulations and animations to clarify misconceptions to meet the lesson's stated objectives where it was necessary. Consequently, teachers' confidence in guiding hands-on activities through computer simulations (0.4±0.5), correctly guiding interpretation of results from experiments including graphs generated in experiments was low (1±0.3) in **Table 4**. On the other hand, the findings from post-interventions indicate that this skill was improved by a mean of 3.9±0.09 (**Table 3**). These findings are confirmed by the findings of the qualitative information obtained from teachers as the quotes below explain:

> "It was my first time using a computer and performing the experiment on rates of reactions between hydrochloric acid and calcium carbonate. It was easier for me to take measurements of substances and mix the required amount of chemicals such as hydrochloric acid and Calcium carbonate into the test tube and conducting experiments."

Another teacher said:

> "I was not able to make a clear interpretation of the graphs in relation to rate concepts. Through this training, it became simple for me to use computer simulations to perform simple experiments and I can easily make interpretations of generated results."

Another teacher explained:

> "I have developed techniques that allow me to decide when to pause the simulation to clarify a concept, ask a question, aid learners in making predictions, or assist students in properly interpreting experimental results, all of which are key strategies for improving the learning process."

In addition, the findings from the pre-instruction indicate that a majority of teachers had low pedagogies in the assessment of scientific skills during the teaching and learning process, with a mean of 0.8±0.2. The study revealed that a majority of teachers face some difficulties in asking questions about science process skills in order to elicit critical thinking during formative assessments. The vast of the questions assessed content knowledge rather than scientific process skills. The findings from the post-intervention show that teachers' pedagogical skills in assessment improved to a mean of 3.8±0.1, indicating that teachers' use of probing questions, worksheets, learners' pair sharing, written reports as assessment strategies supported with computer simulations were important for learners' sense and learn science process skills. Similar findings were revealed through qualitative data from teachers. The following are statements from teachers:

> "It is not enough to ask learners to define or mention rate concepts, factors affecting the rate of reaction. It is important for the leaner to also understand how to plan investigations, make predictions, test them, making proper interpretations and conclusions."

> "Through this program, I see the importance of assessing these science process skills along the teaching and learning process through simple probing questions because the teacher needs to know if the formulated hypothesis or prediction is correct or if the student real makes a good conclusion."

> "Now I understand that computer simulations can save in performance tasks to assess science process skills as directly you see what a leaner can do and what he fails to do through observation. For example, through generated graphs, the teacher can know if the learner can make correct interpretations or not. In addition, it is easier to identify and understand variables."

Generally, the qualitative information from the teachers' interviews indicates that the training improved the teachers' pedagogy of planning the lessons and assessing learning, focusing on subject knowledge and science process skills. Moreover, the use of active interaction strategies and guidance strategies for manipulating computer simulations during hands-on activities to maximize learning in virtual environment.

DISCUSSION

Instructional Objectives and Assessment in Teaching and Learning Chemistry Concepts

A majority of teachers could develop instructional learning objectives to be achieved with computer simulations. Further, they were unable to include scientific process skills as one of the learning objectives to be met in the teaching and learning process in the pre-instruction. Planning of instructional objectives focuses on students' content knowledge rather than science process skills, which are the means to acquire the content knowledge. One of the reasons is explained by Mkimbili et al. (2017) who found that, in science classrooms, a majority of teachers do not target learners to acquire science process skills. As a result, teachers do not focus on scientific process skills during the teaching and learning process.

Teachers need to balance instructional objectives and learning activities which emphasize subject content and process skills as learning outcomes to be achieved with computer simulations (Rogers & Finlayson, 2004). Therefore, training of teachers helped them to improve their pedagogical abilities for developing lesson objectives and learning activities. Teachers could develop lessons which target learners to formulate hypothesis or make a prediction, observe, measure, interpret, make conclusions, and communicate the results. This is comparable to Voogt's (2009) study, which discovered that after participating in a professional development program, teachers were able to plan the lesson objectives, organize and deliver ICT-supported lessons. Stemata and Bell (2012) recommend clear learning objectives when using computer simulations if the goal is to acquire both knowledge and scientific process skills. However, this current study focused on chemistry teachers and mainly on specific computer simulations and animations that supported lessons.

In addition, as teachers mention science process skills and other affective outcomes in their lesson objectives, they also need to assess them through formative and summative assessment. It was discovered that the majority of teachers ask questions on learned concepts that focus on content knowledge (recall learned concepts and theories) rather than ability to perform scientific process skills. This affects not only students' learning but also their ability to overcome problems in daily life. This is because scientific process skills are used not only in the construction of knowledge during the learning process but are also tools that an individual uses in problem solving (Bete, 2020).

Through intervention (training program), the use of probing questions, worksheets, learners' pair sharing, written reports as assessment strategies supported with computer simulations was emphasized. Through these strategies' teachers assessed learners' ability to make hypotheses, plan experiments, identify variables, make observations, interpretations, and conclusions as science process skills during the teaching and learning process. Gacheri and Ndege (2014) noted the need of assessing science process skills in teaching. Similarly, Yadav and Mishra (2013) suggested that it is through assessment procedures that science process skills can be realized and promoted. Unlike the previous studies focusing on normal laboratory work, the current study focused on computer simulations and animations as viable resources in teaching, learning, and assessment of chemistry concepts.

Classroom Interaction Strategies in Teaching Chemistry Concepts

The findings indicated that teachers were unable to engage their learners in making simple predictions or hypotheses and thinking about the ways to test their hypotheses and give feedback to the class. This research found that teachers dominated in interpreting the results of the activities and drew conclusions instead of letting learners do them. This implies that teachers directly employed teacher-centered methods. This teaching method contradicts the competence-based curriculum, which promotes active learning for students to build knowledge and gain science process abilities (MoEVT, 2010).

During the intervention (training program), the new pedagogical strategies such as guiding learners to make predictions, plan experiments, observations, interpret, make conclusions, group work and discussions as means for classroom interaction helped teachers diminish lesson dominance in the classroom, improved lesson delivery and use of computer simulations affordances. Having learners discuss in groups is not enough, but encouraging learners to construct knowledge through active learning, to present and report what they found in their small groups back to the class is important. This entails what Khan (2011) and Kunnath and Kriek (2018) explained that teachers should reduce direct instruction and allow more student-centered learner activities. Learners should be guided to perform hands-on activities, answer questions, discussion, and presentations. Through these pedagogies, classroom interaction is maximized to facilitate active and meaningful learning (Rahman et al., 2020).

From the social constructivism view, the teacher's role during the learning process is that of a facilitator; the teacher should not be the owner of the knowledge and should not convey it to the students (Vygotsky, 1978). Instead, a teacher must create a social learning environment in the classroom, which he or she can bridge with instructional materials such as computer simulations and animations (Demirci, 2009). Classroom engagement strategies that involve learners in the creation of hypotheses, developing a thinking plan for testing their hypotheses, making observations, producing reports, and engaging in classroom discourse are key for inquiry learning as teachers think of using computer simulations in chemistry.

In addition, teachers' guidance strategies in manipulating computer simulations for hands-on activities is important to maximize students' interaction and exploration in virtual environment. Teachers ought to scaffold learners to conduct hands-on activities, select when to pause the simulation to clarify a concept, ask a question, aid students in making predictions, or assist learners in properly interpreting experimental results. Further, they need to correct any misconceptions, interpret graphs, and emphasize concepts during instruction to meet the lesson's intended objectives. This means that integrating computer simulations and animations in a real-world teaching environment increases the teacher's pedagogy of familiarity and use of instructional resources to scaffold learners' learning. As the result, teachers' and learners' confidence in using computer simulations is a viable resource for conducting hands-on activities to improve teaching and learning process. The findings are supported by (Doerr et al., 2013; Kunnath & Kriek, 2018) that teacher's pedagogy in scaffolding learners to conduct practical works and making correct interpretations of their results through computer simulations is important for effective learning. However, the reviewed studies focused on physics domain and other learning contexts while the current study focused on chemistry teachers and chemistry, in particular, chemical kinetics, equilibrium and energetics.

Content Mastery

Findings indicates that mastery of the content in the pre-intervention was high compared to other pedagogical skills (**Table 3**). This could be because teachers are professional and experienced educators who have mastered their subject matter. A majority of teachers, on the other hand, were unable to use examples that relate or connect the taught lessons to their real-life experiences. Mkimbili et al. (2017) found that teachers could not connect the learned lessons with real life experiences in science classrooms. The results of the post-instruction, majority of teachers improved content mastery as a crucial pedagogy in using examples and prior knowledge from the environment to link the class content with their real-life experiences. Teaching to relate content to real-life events allows learners to see the significance of what they are learning as well as the capacity to apply what they have learned in the classroom to other situations, which can lead to problem-solving abilities in society. The findings are supported by Nxumalo-Dilamin and Gaigher (2019) that teachers need strong content knowledge as they use computer simulations. The key difference is that the current study involved teachers in practical hands-on activities as a means of improving their content knowledge in using computer simulations.

LIMITATION, CONCLUSION, AND RECOMMENDATIONS

The study indicated that teachers significantly improved their pedagogical skills in using computer simulations and animations from pre-to post-instruction. However, during data collection, classroom observation was used as the main data collection technique on teachers' pedagogical practices in using computer simulations and animations in their instruction of chemistry concepts. Transcription of information from classroom observation may cause a threat to validity. To ensure appropriate findings, three observers were involved independently per lesson, per classroom observation, and per teacher or learner (Atkinson & Bolt, 2010). Beyond this scope, a further study may be conducted focusing on investigating the effectiveness of computer simulations and animations on learners' science process skills in the teaching and learning of chemistry concepts. Also, since science process skills depend on the nature of instructional activities, it is important to investigate the computer simulation instructional activities during chemistry teaching and learning.

Furthermore, this study has established that chemistry teachers in secondary schools have low pedagogical skills in using computer simulations and animations in teaching and learning chemistry concepts. However, after exposure to the training program, teachers' pedagogical strategies in formulating instructional objectives focusing on both content and scientific skills as well as active interactive strategies were improved. Therefore, it is recommended that teachers need improved pedagogical strategies in using computer simulations and animations as viable instructional resources for inquiry learning. Furthermore, the Tanzanian Ministry of Education, Science and Technology should ensure adequate training through professional development for teachers to promote their pedagogical skills in using computer simulations and animations as viable instructional materials for inquiry learning.

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APPENDIX A

Teachers' Pedagogical Skills in Using Computer Simulations & Animations in Teaching & Learning

Observational checklist (Microteaching & classroom activities: Pre & Post)

A. Preliminary information

Date: ……..…..…….. Teacher's code: ...……..…...…… Lesson title: …..…….…….… Observer code: …..…..…...………

B. Pedagogical skills

Instructions: **Table A1** comprises statements about events performed by chemistry teacher and learners during teaching and learning process in chemistry lessons. On the right side there are scales 0-4. 0 indicates the listed behavior or skill was not evidenced. 1 indicates the listed behavior was little (less) evidenced. 2 indicates the listed behavior or ability was sometimes evidenced. 3 indicates that the behavior was evidenced, clear but not frequent. 4 indicates the behavior or skill was frequently evidenced. Rate each item according to what you will observe.

Table A1. Teachers' pedagogical skills in using computer simulations & animations in teaching & learning

Item	Pedagogical skills indicators	0	1	2	3	4
Selecting CSA & planning instructional objectives						
1	The teacher selects relevant computer simulations/animation to the lesson					
2	Teacher frames objectives of the lesson correctly					
3	Lesson objectives includes specific scientific skills i.e., science process skills					
Teaching & learning activities						
4	The teacher sets strategies to explore the content through inquiry activities, i.e., use of worksheets					
5	The teacher sets strategies to develop process skills, i.e., using hypothesizing, experimenting, observing, measuring, communicating results, etc. as activities					
6	The teacher sets strategies involving learners in collaboration into the lesson, i.e., group works, discussion					
Classroom interaction strategies						
7	The teacher guides learners to identify scientific procedures, identify variables before investigation					
8	The teacher guides learners to make simple predictions or hypothesis					
9	The teacher guides learners to conduct simple experiments					
10	The teacher encourages learners to perform lesson activities in groups with a minimum support					
11	The teacher observes and listens to learners as they interact within their groups					
12	The teacher encourages learners to present/report the results to the class					
13	The Teacher prompts discussion and probing learners' understanding/thinking					
14	The teacher provide opportunity for learners to draw reasonable conclusion on their own from evidence					
Guidance strategies in manipulating CSA						
15	The teacher manipulates computer simulations/animations to clarify concepts, misconceptions, where necessary, & know when to use it					
16	The teacher assists learners to make proper observations, taking accurate measurements					
17	The teacher guide in correctly interpreting results from experiments including graphs generated					
18	The teacher is confident with the use of technology in guiding hands-on activities					
Assessment strategies						
19	The teacher uses verbal probing questions that appeal to learners understanding of learned concepts & science process skills					
20	The teacher asks learners to write a minimum of two and maximum of five sentences to summarize the topics					
21	The teacher triggers learner critical thinking through learners' pair sharing					
22	The teacher examines the written reports of learners participated in computer simulations-based experiments					
23	The teacher assesses the concepts of the learners' using worksheets					
Content mastery						
24	The teacher gives clear clarification of the concepts					
25	The teacher answer/respond to learners' questions correctly					
26	The teacher uses examples to relate the lesson, activities, & real-life experiences					
27	The teacher appears confident in lesson content					

APPENDIX B

Teachers Interview Guide (For Pre-intervention)

The following questions seek your views on pedagogical skills in using computer simulations and animations in teaching and learning process of chemistry concepts in secondary schools. The given information will only be used for the purpose of the study and not otherwise.

1. What is your experience in teaching with computer simulations and animations as instructional materials?
2. What do you feel are important pedagogical skills for you to properly use computer simulations and animations in facilitating teaching and learning process of chemistry concepts?

APPENDIX C

Teachers Interview Guide (For Post-intervention)

The following questions seek your views on pedagogical skills in using computer simulations and animations in teaching and learning process of chemistry concepts in secondary schools. The given information will only be used for the purpose of the study and not otherwise.

1. From your experience as a teacher through this training arrangement, has the use of computer simulations/animations changed the way teach? Can you explain pedagogical changes you have experienced?
2. How was it easy or difficult for you to use computer simulations e.g., in planning the lesson, learning activities etc.? Explain please.