



Supporting Student Active Engagement in Chemistry Learning with Computer Simulations

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Abstract: This case study is an attempt to investigate how computer simulations can contribute to engaging students' active participation in knowledge creation through chemistry learning. Empirical data were collected through interviews, a survey, and a test on secondary school student performance in Rwanda. The findings reveal four main forms of participating in knowledge construction with computer simulations: self-reliance, peer collaboration-reliance, teacher-guided-reliance, and strategic variation-reliance. The study found no statistical difference between male and female students' preferences while engaging with these forms. There was also no difference in their performance in terms of higher order thinking skills in chemistry learning with computer simulations. Moreover, the findings demonstrated that computer simulations can help students to create multisensory connections enabling them to become actively engaged in chemistry learning through various settings. Consequently, the lines between abstract concepts and their related chemical reactions and processes become closely connected in a virtual reality. Finally, this study suggests a pedagogical strategy that teachers can undertake to support student active engagement in chemistry learning with computer simulations.

Keywords: chemistry learning, computer simulation, knowledge construction, multisensory connection, pedagogy, Rwanda.

Introduction

In most Sub-Saharan African countries, access to education has continuously increased since the implementation of the Education for All global movement in 1990 (Vavrus et al., 2011). Science, technology, engineering and mathematics (STEM) are increasingly and globally considered as the key drivers to national socioeconomic development and welfare (Freedman et al., 2019). The Government of Rwanda identified STEM among the strategic priorities of its Education Sector Strategic Plan 2018/19 – 2023/24 (Ministry of Education, 2018). The use of technology in education has become an issue of critical importance to students, teachers, institutions and governments since the Covid-19 pandemic, when technology widely became the primary means to convey learning (UNESCO, 2020).

Nevertheless, broad criticisms continue to rise pinpointing that, in the context of Rwanda, "teaching methods remain largely teacher-centred", with little open debate and teaching of critical thinking skills (Hilker, 2011, p. 2). For example, according to the study conducted by Byusa et al. (2020), secondary school chemistry teachers experienced challenges to help their students work collaboratively in small task-based groups. They argue that chemistry teachers need to acquire how to



actively engage students in group work. Globally, the reality is that some students complain that chemistry is a difficult subject to study when teachers rely on traditional teaching methods (Nahum et al., 2010; Musengimana et al, 2021).

On the other hand, studies have shown that among the factors contributing to influencing students' positive attitudes towards learning chemistry we can include interactive computer simulations (Rutten et al. 2012; Gambari et al. 2016). Though several reforms have been undertaken to leverage the use of technology to expand access to education, reinforce teachers' professional development and enhance student performance in schools, especially in the context of Rwanda (Mukama, 2009, 2010), issues about how students engage with computer simulations for chemistry learning have remained almost unnoticed, hence, the focus of this study. The aim of this case study, therefore, is to investigate how computer simulations can contribute to engaging students' active participation in knowledge creation through chemistry learning.

Literature Review

Gunter et al. (2011) report that computer simulations can assist students to grasp theoretical issues in chemistry. They also argue that computer simulations may help students engage actively in critical thinking and reflection. According to Landriscina (2013), simulations play different roles depending on specific contexts: either students are involved in building a simulation using, for example, a programming language, or they can use an existing one in order, for example, to conduct and/or visualise a virtual experiment. Williamson (2015) concludes that students, depending on their focus, can attend to visualisations either individually or sequentially or, again, simultaneously. In this connection, Williamson explains that students' attributes and spatial abilities determine the magnitude of their interaction with visualisations. Accordingly, Williamson argues that students form mental models that help them develop conceptual understanding in chemistry.

Some studies reveal that computer simulations are more effective than traditional methods of teaching and learning (Akçay et al., 2003; Koomson et al., 2020). Koomson et al. (2020) add that students who learn collaboratively with computer simulations perform better than those working solo. Accordingly, Gambari et al. (2016) point out that students like to deal with different exercises on balancing chemistry equations with computer simulations on their own, without waiting for the teacher's guidance. Several studies also confirm that good performance in chemistry learning while using computer simulations does not depend on gender (Adesoji & Babatunde, 2005; Fagbemi et al., 2011; Gambari et al., 2016; Uzezi, & Deya, 2020).

Williamson (2015) emphasises that computer simulations convey images and motions which enhance students' problem-solving abilities and understanding in chemistry. Gambari et al. (2016) explain that the features of computer simulations include sound, visual images and moving pictures and text onscreen. They conclude that these features translate chemistry concepts' abstractness into something seemingly concrete through virtual reality.

Sahin (2006) affirms that computer simulations can be used as a pedagogical tool to simulate labs and, therefore, cut the costs of expensive reagents, reduce hazardous chemical waste and permit experiments that would be impractical in normal physical labs. Sahin (2006) and Rutten et al. (2012) explain that student engagement with computer simulations depends to a large extent on how

teachers can support students to do so. Beichumila et al. (2022) recommend that appropriate pedagogical strategies to integrate computer simulations in teaching and learning chemistry should be developed. The present study is therefore an attempt towards this development. The following research questions guided this study:

1. What are the contextual drivers in chemistry learning with computer simulations?
2. How do students strategise knowledge building in chemistry learning with computer simulations?
3. What are the outcomes of chemistry learning with computer simulations?

Methods

This paper draws from a case study. Data were collected in 2020 in a boarding secondary school purposely selected from the Western Province in Rwanda. This school had two science combinations with chemistry as a major subject and a computer lab connected to the internet. The class randomly selected to take part in this study was composed of 40 students (17 males and 23 females). These students followed a session aiming to explain the purpose of the study and to invite them to collaborate. They all agreed to participate voluntarily and signed individual consent forms. A chemistry teacher of this class received training organised by the research team on how to integrate and use computer simulations in teaching and learning chemical bonding. Most simulations used were borrowed from the Khan Academy and YouTube channels. After the training, this teacher taught her students the same content using the same digital tools. Students had access to the computer lab to ensure that they could use simulations at their convenience. These simulations included an audio explaining chemical reactions and processes.

Right after the completion of the chemical bonding unit, six students (three males and three females) were randomly selected to be interviewed on their experience studying chemistry with computer simulations. To ensure the participants' anonymity, they were given pseudonyms. These fictitious names are used in the findings' section. Interviews were conducted in Kinyarwanda, the participants' mother language that they were all conversant with. The interviews were audio-recorded, transcribed verbatim and then translated into English. Each interview lasted approximately 20 minutes.

The data from interviews were analysed qualitatively. The participants' utterances were recorded in a matrix, indicating the questions from the interview guide. Each paragraph was coded and concepts representing central analytical ideas were written in the margins. Afterwards, these concepts were closely scrutinised in terms of their similarities and differences, allowing the grouping of those with similar objects under common themes. These themes were gradually refined and, later, became the headings of the section on findings. Other concepts under each theme were further developed into explanatory descriptors. Memos and diagrams were used to track the comparison of patterns and potential relationships between emerging concepts.

The preliminary interviews' analysis revealed four different forms of participating in knowledge construction with computer simulations, namely: *self-reliance*; *peer collaboration-reliance*; *teacher-guided reliance* and *strategic variation reliance*. Thus, a follow-up survey was conducted with 37 students (17 male and 20 female students who were then present in class) to confirm whether these forms of participating in knowledge construction with computer simulations were consistent. The students

were asked through a questionnaire to identify their preferences in terms of the ways they would like to participate in chemistry learning with computer simulations. Data from the questionnaire were recorded and gender-desegregated in a spreadsheet. Therefore, a chi-square (χ^2) was performed to analyse the differences in preferences for knowledge construction methods using computer simulations between female and male students.

On the other hand, the theme *higher-order learning skills* emerged from the interviews. In order to ascertain whether a significant disparity existed between the performance of male and female students concerning their higher-order thinking skills when using computer simulations, an independent sample *t*-Test was conducted. This time, 35 students (14 males and 21 females) were present in class. To ensure its reliability, the test measuring student performance was initially piloted with students who had completed the chemical bonding class through a traditional teaching method of lecturing. Subsequently, test items were revised accordingly. The pilot revealed a coefficient Cronbach's alpha equivalent to 0.79, which is greater than the standard value of 0.70. Therefore, the calculated Cronbach's alpha indicated a satisfactory internal reliability, which suggests that test items consistently measured student performance. Data from the test were analysed using SPSS 16.0.

Findings

Forms of Participating in Knowledge Construction with Computer Simulations

The findings demonstrated that students adopted different ways to solve chemical bonding problems with computer simulations. Students' arguments during the interviews revealed four different forms of participating in knowledge construction with computer simulations, namely: *self-reliance*; *peer collaboration-reliance*; *teacher-guided reliance* and *strategic variation reliance*.

Is there a difference between male and female students' preferences in terms of the forms of participating in knowledge construction with computer simulations? The students were asked to identify their choices regarding their preferences of active engagement when using computer simulations for learning. The results of the survey are summarised in Table 1.

Table 1: Forms of Participating in Knowledge Construction with Computer Simulations

Observed Frequencies	Self-reliance	Peer collaboration reliance	Teacher-guided reliance	Strategic variation reliance (exploring computer simulations...)				TOTAL
				...sometimes individually and sometimes with peers	...sometimes individually and sometimes with a teacher	...sometimes with peers and sometimes with a teacher	...sometimes individually, sometimes with peers, sometimes with a teacher	
Male students	1	4	4	1	2	2	3	17
Female students	1	4	6	0	0	2	7	20
TOTAL	2	8	10	1	2	4	10	37
Total percentage	5%	22%	27%	3%	5%	11%	27%	100%

The general picture of this table shows that the majority of chemistry students in the context of Rwanda prefer to seek for teacher guidance in order to solve chemical bonding problems with computer simulations. The table shows that 70% of students seek guidance from the teacher in one way or another (11 males and 15 females). These students include *teacher-guided students*, representing 27% and *strategic variation-reliant students* (43%), i.e., those who explored computer simulations either sometimes individually and sometimes with a teacher (5%); or sometimes with peers and sometimes with a teacher (11%); or sometimes individually, sometimes with peers and sometimes with a teacher (27%).

Given that the null hypothesis states that the preference for participating in the different types of participation in knowledge construction with computer simulations was independent of students' gender with $df = 6$, it was noted that $\chi_0^2(4.79) < \chi^2(12.59)$. In other words, the chi square observed (4.79) was smaller than the chi square critical value (12.59). Therefore, the null hypothesis was confirmed: gender and preferences regarding participation in the different types of participating in knowledge construction with computer simulations were independent. There was no relationship between them. This means that the types of participating in knowledge construction with computer simulations do not depend on whether the students are males or females.

The narrations of the six students interviewed have been used to substantiate the meaning embedded in students' preferences, as depicted in Table 1:

- (1) *Self-reliance*: this type includes students who consider computer simulations as interactive, interesting, motivating and presenting well-organised material in a way they could learn with it individually (5%). Tereza put it in these words: "When I was exploring computer simulations individually, I was extremely curious to watch the next step". It appears that this curiosity to delve deeper into the learning material contributed to some students isolating themselves with their computers. In fact, these students were convinced that they were not entirely alone; computer simulations acted as a virtual presence behind the screen which they could actively engage with and revisit at their convenience.
- (2) *Peer collaboration-reliance*: 22% of chemistry students belonged to this type. During the interviews, the students reported that collaboration between peers helped them to push their understanding to a higher-order thinking level beyond what they could achieve alone without support, as Petero pointed out: "My colleagues shared with me what they had learned. Combining their explanations with my own views helped me learn from them and gain a better understanding." Monika stated: "It was a chance to discuss with my colleagues about issues which were difficult for every one of us and then try to understand them better than when I was alone." Mariya argued that collaboration with peers opened an opportunity for her to discuss with them challenges she was facing, unpack them and solve them.
- (3) *Teacher-guided-reliance*: as referred to above, 27% of chemistry students preferred to seek support from their teacher only. Trying to explain the reasons behind this dependence, some students claimed that the teacher helped them to understand most of the difficult issues regarding chemical bonding. Tereza revealed that poor proficiency in English could have been the main reason that prompted many students to continuously request the teacher's assistance: "The teacher provided vital clarification on issues we struggled to comprehend due to our

limited grasp of the English language." The same challenge of language barriers was confirmed by the students' responses to the questions regarding the challenges they faced while learning chemistry with computer simulations. In fact, four out of the six students interviewed affirmed that the language of instruction used in computer simulations was difficult to comprehend and that the speed of the audio was too fast.

(4) *Strategic variation-reliance*: this type of participating in knowledge construction with computer simulations includes 46% of chemistry students, as illustrated in Table 1, i.e., 17 students (eight males and nine females). This type denotes some variations in strategising knowledge construction while exploring computer simulations:

- a) *Exploring computer simulations sometimes individually and sometimes with peers*: this type indicates that individual students did not disappear in a group of peers; they worked individually and asked for peer support when it was really required. Monika explained: "The discussion with my colleagues helped me to catch up missing points that I couldn't grasp while exploring computer simulations alone." This explanation suggests that students who adopt this approach to constructing knowledge typically begin by working diligently on their own. However, when faced with a challenge, they readily participate in group discussions to achieve a shared understanding.
- b) *Exploring computer simulations sometimes individually and sometimes with a teacher*: Based on the interviews, it is evident that students regarded their teacher as the most knowledgeable person. Andereyasi confirmed this by saying, "With the teacher, it was good because I asked her the most difficult questions." This interaction with the teacher highlights how students found it beneficial to delve into the learning material more deeply.
- c) *Exploring computer simulations sometimes with peers and sometimes with a teacher*: 11% of chemistry students, i.e., four students (two males and two females) belonged to this type. During the interviews, students extensively discussed their active participation in collaborative work on chemical bonding using computer simulations, either with their peers or with the teacher. Tomasi reported: "I was learning first with my colleagues and what remained difficult to me was addressed when the teacher intervened". Individual and social active participation in knowledge construction is further elaborated in the next paragraph.
- d) *Exploring computer simulations sometimes individually, sometimes with peers, and sometimes with a teacher*: according to Table 1, this type of participation in knowledge construction with computer simulations is one of the most preferred by students (27%). The students emphasised that increased interaction led to a deeper understanding. Andereyasi stated, "All the strategies employed in learning chemical bonding with computer simulations helped me learn multiple times, and repeated learning enhances your understanding in depth." Tereza depicted the change in understanding with percentages:

I can say that after exploring computer simulations individually I understood the concept of a molecular shape at 50%; after the discussion with my colleagues, my level of understanding shifted to 75%. When the teacher intervened, I got the point at 80%.

Putting this excerpt differently, engaging in discussions with various learning partners, both peers and the teacher, proved beneficial for grasping the subject of study.

In fact, most chemistry students strategically varied the forms of participating in knowledge construction. The *strategic variation-reliance* suggests that learning conditions with computer simulations need to be reorganised in such a way that students are given a chance to actively participate in learning activities that can allow them to collaborate with their peers and their teacher.

Creating Multisensory Connections between Students and the Object of Learning

Most students who participated in the study affirmed that they were excited to learn chemistry with computer simulations. They explained that this enjoyment reflected not only the computer simulations' power to convey the object of learning but also the visible, audio, readable, and motion connections that these tools created.

Visible connections: For example, Monika, one of the female students, voiced how she was able to link abstract concepts with what really happened during chemical reactions in these terms: "After learning with computer simulations, I saw and understood in a concrete way how a transfer of electrons happens during the formation of ionic bonds." Petero explained: "I had some confusion about the molecular shape and geometry. [...] After watching with my own eyes how things happen, I got a clear understanding because when you see with your own eyes you understand better." This excerpt denotes how computer simulations brought the learning material within the students' proximity.

Motion connection: Tomasi, pinpointed *motion connection* as follows: "I liked to see in a concrete way how electrons move around the nucleus and how they jump from one energy level to another and how atoms acquire stability after the formation of a covalent bond". Two more connections emerging from learning chemical bonding with computer simulations were *audio* and *readable*. Mariya asserted: "With simulations, you hear explanations behind what you see, and you read what is written."

The findings showed that the *audio and readable connections* were linked to the language of instruction. Tomasi explained that poor proficiency in English was a serious challenge in learning chemistry with computer simulations: "Many of us are not good at English. Therefore, we faced a language barrier." This implies that if the object of learning was conveyed in a language that the students were more conversant with, their understanding of chemical bonding could be increased.

Learning to solve chemical bonding problems with computer simulations helped students to create multisensory connections with the object of learning. These connections contributed to bringing the object of learning within the students' proximity. Moreover, they enabled students to concentrate on, and actively engage with, the object of learning through various settings, while the lines between abstract concepts and chemical bonding reactions and processes became closely related in a virtual reality.

Shift from First- to Higher-Order Thinking Skills

The findings reveal that the outcomes of chemistry learning with computer simulations can be categorised into two levels of cognitive processes: first- and higher-order thinking skills. *The first order thinking skills* reflected the outcomes of learning created by a simple encounter with computer simulations as interactive pedagogical tools. For example, Mariya expressed her enjoyment in

studying chemistry with computer simulations in these terms: “[Computer simulations] were motivating to all of us. We were very excited to attend chemistry classes”. In addition to increasing commitment to attend class, computer simulations caused students to like chemistry as Petero highlighted: “On my side, learning chemistry with computer simulations encouraged me to like more chemistry courses than I did before.” Moreover, computer simulations increased students’ focus on the learning material. Andereyasi explained: “Learning with computer simulations required much attention and concentration than when I was learning in a traditional way. With simulations, I was motivated to follow everything”.

Most students reported that computer simulations served as an *aide-memoire*. Monika asserted: “The computer simulations helped me to memorise key features of chemical bonding. The images remained in my mind, and I cannot forget them”. Later, with a reflective voice, she advised: “It would be better if what we learn in theory by using the traditional method could be illustrated by a concrete session such as those simulations”. Briefly, the *first order thinking skills* conveyed by the computer simulations included memorisation, enjoyment, motivation and commitment to study chemistry. These findings indicate that these skills were developed mainly through the students’ encounter with computer simulations as technology.

On the other hand, the findings demonstrate that computer simulations can help students to acquire *higher order thinking skills*, including analysing, evaluating, creating, elaborating, changing, comparing, contrasting, critical thinking, problem solving and explaining. For example, Tomasi insisted on his potential to leverage the use of the internet to search for further information: “Our teacher should give us opportunities to explore lessons further by supplementing the traditional methods of teaching with searching other computer simulations on the Internet.” This same student expressed some degree of the autonomy and independence required to conduct research on the internet until he got a response suitable to his needs: “Sometimes, I was not satisfied with answers my teachers gave me in the class. I was only satisfied when I searched and found a response to my questions through the Internet on my own”. In fact, the need to conduct research on the internet and explore other computer simulations beyond indicative content proposed by the teacher was echoed in the majority of the students’ utterances.

Personal and societal fulfilment was another aspect highlighted by students during the interviews. Andereyasi expressed how his experience with computer simulations inspired him and his classmates to create a science club: “After learning with computer simulations, we had an idea to start a science club at school where we can explore further and in-depth various simulations in science. I have seen that girls supported the idea faster than boys.” Thus, chemistry learning with computer simulations became a springboard towards initiating change in science learning. The creation of the science club as something new at school extended learning beyond the boundaries of the school: “It became a culture to discuss what we learned in computer simulations even outside the class”, Petero argued. Mariya illustrated with a concrete example how the science club offered also a friendly environment conducive to peer collaboration and mutual support: “Learning chemistry with computer simulations helped me to gain more literacy skills from boys who trained me about how to manipulate a computer in order to retrieve computer simulations”. This example of Mariya in the hunt for technical support from boys does not mean that the boys were better than the girls at chemistry performance after learning with computer simulations. In fact, most students who participated in the interviews, both

boys and girls, reported that they all performed well in science subjects. Andereyasi explained: "In my class, many students are girls, and they succeed well in science subjects. In this school, many girls are awarded for doing well in science like boys." Tereza affirmed the same statement in different words: "We are all capable except individual differences."

To understand whether there was a significant difference between boys' and girls' performance in terms of higher-order thinking skills, an independent samples *t*-Test was performed. The results of the test showed that there was no statistically significant difference between male ($M = 61.00$; $SD = 14.69$) and female students ($M = 58.57$; $SD = 13.78$) in their scores for a post-test performed after studying chemical bonding with computer simulations, $t(33) = .497$; $p = .62$.

Discussion

The purpose of this case study was to explore the ways in which computer simulations could enhance active student participation in the learning of chemistry. In pursuit of this goal, the study examined the contextual factors influencing chemistry learning with computer simulations, the strategies employed by students to construct knowledge in this context, and the outcomes of chemistry learning through the use of computer simulations. Although chemical bonding is typically viewed as a challenging topic due to its abstract nature, this study demonstrated that computer simulations can serve as an effective pedagogical tool to promote active student engagement in constructing knowledge in this subject. Indeed, the findings of this study illuminate that students' learning is influenced by both the teachers and the computer-based simulations. Consequently, this case study proposes a pedagogical strategy comprised of five specific actions that teachers can take to foster active student engagement in chemistry learning using computer simulations. These actions are detailed below:

- (1) *Action on contextual drivers*: Computer simulations facilitate a distinct and unique mode of learning, diverging from conventional teaching methods. Additionally, this study has shown that students were excited to discuss simulations with their peers or their teacher. Some other students were interested in doing research on their own, because computer simulations were interactive and they had full access to the internet. In other words, *action on contextual drivers* implies that the teacher needs to have a full picture of the learning practice based on expected outcomes of learning and on unit competency, learning objectives, indicative content and assessment criteria, and then organise the learning activities accordingly. The teacher may prepare research questions to guide students' work or formulate hypotheses for validation. Students may be requested to deal with a challenge, a case study or a learning project. This work can be done individually or in small task-based groups. These configurations represent the contextual parameters that the teacher may establish to facilitate chemistry learning with computer simulations. However, contextual drivers may vary depending on the subject matter and specific circumstances.
- (2) *Action on the forms of participating in knowledge construction*: this study revealed four main forms of participating in knowledge construction with computer simulations. These forms were *self-reliance*, *peer collaboration-reliance*, *teacher-guided-reliance*, and *strategic variation-reliance*. The study found no statistical difference between male and female students' preferences to engage in these forms while studying chemistry with computer simulations. The findings indicate that these four

forms can support students in building new knowledge through collaboration and critical reflection around the object of learning and mediating tools (computer simulations). These findings are in concurrence with the sociocultural perspective on knowledge construction (Bates, 2019). *Self-reliance* in computer simulations also involves other people behind the screen since these pedagogical tools are interactive. However, self-reliant students may need the teacher's attention to ensure that they benefit from her/his feedback or from peers. In this connection, *strategic variation-reliance* involving individual and group collaboration with the teacher and peers suggests that learning conditions with computer simulations may be organised in a way that allows students to change strategically the forms of participating in knowledge construction to maximise active engagement with the object of learning.

- (3) *Action on multisensory connections*: Computer simulations can help students to create multisensory connections (*visible, audio, readable, and motion*) with the object of learning. In fact, multisensory connections play a central role in bringing the object of learning within the students' proximity. The findings show that most chemistry students preferred to seek teacher guidance to study chemistry with computer simulations. Students reported that the teacher helped them understand the language conveyed through these pedagogical tools. Thus, since the *audio connection* seems to be at the heart of the interaction between the students and the teacher/computer simulations, this implies that if the object of learning was conveyed in a language that students were more conversant with, then this connection could enhance their understanding in a powerful way. However, Masterson (2020) supports that digital technologies have the potential to enhance students' knowledge construction while learning in languages other than the mother tongue. Finally, through multisensory connections, the relationship between abstract concepts and chemical bonding reactions and processes becomes closely intertwined within a virtual reality setting.
- (4) *Action on higher order thinking skills*: This study suggests that students could construct higher order thinking skills if they were given opportunities to explore computer simulations beyond the indicative content proposed by the curriculum. The findings reveal that students' encounters with computer simulations develops students' first-order thinking skills such as memorisation and capacity to recall, enjoyment and motivation to learn chemistry with simulations. Further, students explained that they created a science club at school on their own initiative to deepen their learning of science. Other students reported that they conducted research on the internet during their free time. These findings suggest that teachers can elevate students' cognitive abilities with computer simulations when granting them some degree of autonomy and independence. For example, the teacher may invite students to see things in different ways, explore new solutions, make connections between concepts, experiment, search evidence and infer from them, analyse chemical reactions and processes, and apply new knowledge in real-world situations.
- (5) *Action on the outcomes of learning*: students' opportunities to demonstrate the outcomes of chemistry learning with computer simulations can determine the way forward for the promotion of effective chemistry learning. According to the findings, students were excited to report their achievements to the teacher and other people outside the class. The science club played a crucial role in engaging the school community and served as a tool for mobilising students in the pursuit

of science learning through technology. Therefore, the teacher's responsibilities extend beyond simply preparing, delivering and assessing lessons; they also encompass ensuring both student and school community fulfilment while considering the outcomes of learning.

Conclusion

The five pedagogical actions that the teacher can perform to support active student engagement in chemistry learning with computer simulations are interdependent. For example, action on contextual drivers and that on outcomes of learning, though placed on opposite ends in the presentation, are interrelated in practice. Outcomes of learning are defined at the beginning of a chemistry learning course to guide the teaching/learning process, which takes place with specific contextual drivers. Action on contextual drivers determines the forms of participating in knowledge construction that are likely to occur. Thus, the teacher can plan how students will be involved in these forms in a way that maximises exploration of the object of learning through multisensory connections. The latter, in turn, bring the object of learning within the students' proximity, which facilitates the development of higher-order thinking skills. These findings can contribute to improving the process of chemistry teaching/learning with computer simulations. On the other hand, they can be transferable to other science subjects, taking into consideration contextual drivers under which computer simulations are implemented. In fact, the interplay between the five pedagogical actions and their integration may contribute to building an effective pedagogy for science education in paving the way towards national sustainable development and innovative socioeconomic transformation.

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