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Effect of Computer Simulation on Senior High School Students' Conceptual Understanding of Chemical Bonding

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Abstract: The purpose of this study was to establish the effectiveness of computer simulation on students' conceptual understanding of chemical bonding. The study utilized pre-test and post-test treatment to come up with results. The sample size for the study was 42 second year students purposively selected out of 286 General Arts students from the T. I. Ahmadiyya Senior High School, Potsin. Tests (pre-test and post-test) and questionnaire were the main research instruments. The data obtained from the tests were analysed using t-test statistics to establish students' achievement levels after the intervention. The study revealed that there was a significant difference in the performance of students after the intervention. More than 80% of the students had sound understanding of the concept after the intervention. This implies that the intervention had positive effect on conceptual understanding of the chemical bonding. The findings would enable curriculum planners as well as policy makers to suggest a more student centered curriculum. It would also prompt school administrators to look into the development and acquisition of appropriate facilities to enhance the teaching of specific concepts in science.

Keywords: Computer Simulation; conceptual understanding; chemical bonding.

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Introduction

Chemistry is one of the most important branches of science; it enables learners to understand things that happen around them. Because chemistry topics are generally related to or based on the structure of matter, chemistry proves to be a difficult subject. Chemistry curricula commonly incorporate many abstract concepts, which are central to further learning in both chemistry and other sciences (Taber, 2002; de Jong and Taber, 2014) These abstract concepts are important because further chemistry/ science concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by students (Coll & Treagust, 2001; Nicoll, 2001). The abstract nature of chemistry along with other content learning difficulties (e.g. the mathematical nature of chemistry) means that chemistry classes require a high-level of skill set (Taber, 2002).

Poor performance in chemistry is a pointer to the fact that students have difficulty in learning, in mastering the subject and in applying the knowledge when they are under examination conditions. The problem is that students have been failing in chemistry in secondary schools at alarming rates for years. West African Examination Council (2017) reported students' general poor performance in chemistry. Whereas performance in Fisheries, Biology and Animal Husbandry saw an improvement, there was a decline in the performance for General Agriculture, Physics, Chemistry, Integrated Science, Forestry and Crop Husbandry and Horticulture (West African Examination Council, 2020). Candidates were reported to have performed woefully in the area of using bond dissociation energies to compare the acidity of HCl and HF (West African Examination Council, 2021).

Despite the efforts made by the various stakeholders to address teaching and learning difficulties in science, some teachers and learners still face challenges in the teaching and learning of science, especially, the chemistry. Chemistry is often regarded as a difficult subject, an observation that sometimes repels learners from continuing with studies in chemistry. One of the essential characteristics of chemistry is the constant interplay between the macroscopic and microscopic levels of matter. It is this aspect of chemistry learning that represents a significant challenge to novices (Bradley & Brand, 1985). A study by Anamuah-Mensah and Apafo (1989) found out that conceptualization of chemistry is indeed difficult for learners of science. The problem areas in the chemistry, from the students' point of view, persisted well into university education, the most difficult topics being the bonding concept, chemical formula and equations, condensations and hydrolysis. Many factors have been suggested as contributing to poor performance of students in Chemistry. Some of these factors include inadequate laboratory equipment for chemistry, poor teaching methods and mathematical nature of chemistry, among others (Eniayeju, 2010).

Chemical bonding is a fundamental concept in chemistry education. It is a central concept in chemistry because most of the concepts in the subject are related to understanding fundamental ideas related to it, hence its understanding is critical to the learning of almost all other topics in chemistry. Chemical bonding is one of the key and basic concepts in chemistry. Clearly, many of the concepts taught in chemistry in both secondary schools and colleges are based on understanding the fundamental ideas related to chemical bonding concept. Nevertheless, the concept is perceived both by teachers as well as by learners as difficult to understand. Taber (2001) indicated that students often lack deep understanding of key concepts such as chemical bonding. A study by Sokmen et al. (2000) revealed that students often confuse covalent and ionic bindings. The most possible reason for the students' misconception that covalent bonding is formed between a metal and a nonmetal atom is that students could not understand exactly what properties of non-metals enable them to form covalent bonding or what properties of metals and non-metals enable them to form the ionic bonding.

Many of these misconceptions result from over-simplified models used in text books by the use of traditional pedagogy that present a rather limited and sometimes incorrect picture of the issues related to chemical bonding and by the nature of the assessment of students' achievement that influence the way the topic is taught.

Studies conducted by Teichert and Tracey (2002) attest to the ineffectiveness of traditional approaches to teaching concepts such as chemical bonding. One of the goals of the chemistry teaching fraternity is to develop strategies to effectively teach high-school students the concept of chemical bonding. This aim is motivated by some studies (Hurst, 2002; Taber & Watts, 2000) that clearly revealed that the traditional approach to teaching bonding is problematic. Typically, covalent and ionic bonds are presented dichotomously, as 'electron sharing' or 'electron transferring' bonds. However, in hetero-atomic systems, bonding is better described in terms of a continuum of a covalent-ionic dimension or scale (Sproul, 2001).

Several studies have noted the benefits of web-based learning and its vast potential to empower learning and teaching in terms of its visualization, accessibility and dynamicity. More specifically, in alignment with the idea of visualization to support students in learning the chemical bonding concept, Linn et al. (2003) noted the importance of integrating computer-based visualizations in learning abstract concepts and phenomena. Molecular models, simulations and animations have the potential to contribute to the learning of chemistry in general and to the better understanding of the chemical bonding concept in particular.

Today, science educators have access to sophisticated multimedia simulations that allow learners to view and interact with models of phenomena and processes. Such simulations can provide learners with visual representations of dynamic theoretical entities that are difficult to represent in the static environments of science textbooks but are critical to understanding why matter behaves as observed (Ardac & Akaygun, 2004; Honey & Hilton, 2011). These simulations may also encourage active learning by giving students opportunities to manipulate complex systems and discern patterns through their own investigation.

While interacting with simulations, learners are engaged in processes of scientific reasoning such as problem definition, hypothesis generation, experimentation, observation and data interpretation (Kim & Hannafin, 2011). As a result, simulations have the potential not only to help learners understand scientific phenomena, but also to foster inquiry and problem-solving skills. There is therefore the need to move away from traditional approach through the integration of Information and Communication Technologies in the teaching and learning processes.

Chemical bonding is an essential concept in chemistry. Its principles are needed in understanding other concepts such as chemical reactions, ion formation, structure of hydrocarbons etc. However, it seems most students of Potsin Ahmadiyya Senior High School find it difficult to visualize and appreciate chemical bond formations. This was evident in the students' inability to classify compounds into ionic compounds and covalent compounds after they were taught. The situation is more serious among General Arts students. An interview with some of the students revealed that chemistry concepts, such as chemical bond formations in particular, are abstract and are remote from everyday life experiences. The interaction also revealed that students have misconceptions about how chemical bonds are formed. They were unable to visualise and distinguish between types of bonds that exist between atoms in compounds. The researcher realised that the students' inability to grasp the concept of chemical bonding might be due to outmoded teaching methods.

Many teachers of science often endeavour to use strategies which are simple and appropriate to help students understand concepts being taught. Teachers are quick to blame students for not doing well in class tests and often times attribute it to the students' inability to learn rather than looking at the problem in a broader perspective by reviewing their own teaching pedagogy. Nevertheless, a large proportion of science teachers still resort to the use of traditional/lecture method rather than the activity-oriented or student-centred strategies such as demonstration, problem-solving and others (Olorukooba, 2001). A number of activity-oriented instructional strategies have been advocated by curriculum designers and science educators to help improve secondary school science students' performance (Eniayeju, 2010). These strategies include guided discovery approach, demonstration, discussion and problem-solving. However, analysis of the WASCE results from 2012 to 2020 shows a downward trend in performance of students in Integrated Science and Chemistry at the Potsin Ahmadiyya Senior High School. Most students, especially females, through interview, unequivocally said they have lost interest and the enthusiasm to study the chemistry aspects of the Integrated Science course due to its abstract nature. This might be the cause of the poor performance of students in the subject over the years. While the traditional approaches adopted by teachers in addressing these challenges have not been helpful, this study serves as a point of departure to integrate computer models into the teaching of chemical bonding.

Methodology

Design

The study employed the quasi-experimental design which aims to establish a cause-and-effect relationship between the independent and dependent variables. However, a quasi-experiment does not rely on random assignment of research subjects. Instead, subjects are assigned based on non-random criteria. A quasi-experiment is useful in situations where true experiment cannot be used for practical reasons.

Population and Sampling

The target population for this study was 286 General Arts students of T. I. Ahmadiyya Senior High Schools, Potsin. The sample size was 42 Form Two General Arts I students selected because the majority of students in the class demonstrated lack of understanding of chemistry topics.

Instruments

Test items and a questionnaire were the main instruments for data collection. The test items consisted of pre-test and post-test. The pre-test was questions administered to the students before the intervention, and the post-test was questions administered after the intervention. The intervention was carried out in three weeks, where students were taken through various learning experiences using computer assisted activities such as animations and videos on chemical bonding concept.

Validity and Reliability

To grant the instruments content validity, the instruments were given to experienced researchers for assessment, constructive criticisms and suggestions for improvement. Modifications were made. The instruments were then pilot tested to confirm their effectiveness. Test-retest method was used to establish the reliability of the questionnaire which was determined through Cronbach's alpha, which yielded the value of 0.73.

Data Collection Procedure

Data collection procedure was divided into three phases; pre-intervention phase, intervention phase and post-intervention phase. The pre-intervention phase involved construction of the pre-test items (based on the demand of the teaching syllabus for Integrated Science in Senior High Schools) and the administration of the test. All the answered test scripts were marked and recorded. This was to get a fair idea about their knowledge and/or performance level to be used as a base-line before the intervention.

The intervention phase dealt with the use of computer modules to teach the structure of chemical bonding. The lessons on the topics were taught using computers and overhead projectors. Students were given the opportunity to watch the animations and videos. Videos, diagrams and textual explanations were thoroughly discussed.

In the post-intervention phase, an equivalent form of the pre-test was administered after the treatment as post-test. A questionnaire was administered to students at this stage to solicit their views about the use of computer modules compared to traditional methods like lecture. The data collected from the students' pre-test and post-test as well as the questionnaire results were subjected to analysis during this period.

Statistical Treatment of Data

Data was analyzed using Microsoft Excel, version 2010. The Microsoft Excel was used to run a t-test which compared the pre-test and the post-test results. Furthermore, students' responses to the questionnaire on a five-point Likert scale were analysed by determining the mean score and standard deviation, using Microsoft Excel, version 2010.

Results and Discussion

This section presents the results and discussions based on research questions that guided the study.

Research Question 1: What were students' conceptions about chemical bonding before the intervention?

The following interpretation scale was used to interpret results for this research question: SU = Sound understanding, PU = Partial understanding, MU = Misunderstanding, NU = No understanding.

IUPAC names

As shown in table 1, only ten percent of the students managed to write IUPAC names of compounds while 19 percent had partial understanding, 45 percent demonstrated misunderstanding and 26 percent had no understanding of the concepts.

Table 1: The percentages of students' responses to the pre-test item

Test item	SU (%)	PU (%)	MU (%)	NU(%)
IUPAC names	10	19	45	26
Atom Species	0	14	69	17
Position of bonding electrons	0	0	0	100
Bond formation	0	2	86	12

Atom Species

None of the students demonstrated sound understanding of the type of atom species that form ionic and covalent bonds. Fourteen percent of the students had partial understanding. They were able to identify the type of bond in the given compounds. They were able to state that covalent bonding in NH_3, CO_2, HCl and O_2, but could not tell the property of the atoms that make them share electrons. They were also able to state that ionic bond existing between the species of $CaCl_2$, $AlCl_3$ and ZnO through complete transfer of valence electrons. However, they failed to point out the species that donate the electrons and the number of electrons donated and the species that accept them. Sixty-nine percent had misunderstanding as they provided answers which were illogical. Seventeen percent of the students had no understanding. These students could not determine the type of bond in the given compounds, let alone offer any explanation.

Position of bonding electrons

None of the students demonstrated sound understanding or even partial understanding of position of bonding electrons in the bonded species. Most of the students did not attempt this question. Even the very few students who attempted it seemed to have lacked knowledge of electro negativities of the bonded species.

Bond formation

None of the students demonstrated sound understanding of chemical bond formation. Only two percent of the students showed partial understanding of chemical bond formation. Eighty-six percent of the students provided incorrect information while twelve percent of the students did not attempt the question at all.

Analysis of the answers given by respondents to the test items in the pre-test questions as presented in Table 1, shows that students had various misunderstandings in four important areas related to chemical bonding. The four important areas were the writing of chemical formulae of compounds, the types or properties of atoms which form a chemical bond (ionic and covalent bonding), how ionic and covalent bonds are formed and the types of covalent bonding (polar covalent or non-polar covalent bonding).

It came out that a greater number of students could not determine the electronegativity or charges of the atoms involved. They could also not get the correct chemical symbols for the elements involved. For example, some students used the first three letters, first two letters or first letter of the names of elements as their chemical symbols. Such as 'Alu' for Aluminium, 'Chl' or 'C' for Chlorine and Sulphur as 'Sul' or 'Su'. These findings were somewhat similar to that obtained by Sokmen *et al* (2000) where it was reported that students used the first letter of the names of elements as the chemical symbol for all the elements. The impression from the two studies show that students continue to have misunderstanding when it comes to writing of chemical symbols.

Another important area where students had misunderstandings was the type of atom or species which form covalent or ionic bond. It was realised that majority of the students had misunderstanding as though covalent bonding was formed between a metal and a non-metal while ionic bonding is formed between two nonmetal atoms. The students were not able to distinguish metals from non-metals. This was evident as almost all the students indicated in their response that ionic bonding is formed in both HCl and NH_3 molecules. These non-scientific ideas held by students appear to indicate that students confused ionic and covalent bonding.

This finding is similar to a previous finding where students found it difficult to differentiate between types of chemical bonding and they had a thinking that covalent bonding is formed between a metal atom and a non-metal atom (Nicoll, 2001). This type of confusion about ionic and covalent bonding was also reported in the study of Sokmen *et al*. (2000) where students confused the concepts about ionic and covalent bonding.

The third area of importance about covalent bonding where students had misconception was about how a covalent bond formed. This was clearly seen as the majority of the students stated that covalent bonding is formed by the transfer of electrons both within hydrogen chloride (HC1) and ammonia (NH_3). These students also indicated that covalent bonding in water molecule is formed by the transfer of electron. These misconceptions about chemical bonding was in line with the findings of other studies which reported that students thought that covalent bonding was formed by a complete transfer of electrons from one atom to the other (Nicoll, 2001).

The last area of misunderstandings about chemical bonding that students had was the position of the bonding electrons within a molecule. It became clear that students could not answer the question in the test item that demanded the determination of the position of bonding electrons within given molecules. Apart from students not being able to determine the position of the bonding electrons in the given molecules, some stated that bonding electrons are placed equidistant to the bonded atoms. They might not have had knowledge about polar and non-polar covalent bonds/molecules. Here students demonstrated complete lack of understanding.

A study by Nicoll (2001) reported that students confuse polar covalent bonding with non-polar covalent bonding. Moreover, the misconception that bonding electrons are equidistant to the atoms which form covalent compounds whether it is formed within the same atom or not was also reported in some studies (Peterson & Treagust, 1989). A possible reason for these misconceptions about the types of covalent bonding might be students' ignorance of the concept of electronegativity of atoms and confusing the term 'polar' with 'non-polar' covalent bonding.

Research Question 2: What impact would computer simulation have on the performance of students in chemical bonding?

This section presents the overall effect of the use of computer simulation as an instructional strategy to improve students' conceptual understanding of chemical bonding. Thus, the mean score and standard deviation of the total scores from the four content areas of the pre-test and post-test were computed and summarized in Table 2 and Table 3.

Table 2: Pre-test and post-test mean scores on chemical bonds

Item	Mean	N	SD
Pre-test Score	9.90	42	3.95
Post-test Score	26.05	42	5.54

Table 3: The t-test for the pre-test and post-test mean scores on chemical bonds

Item	Mean	SD	SE	t	df	Sig.(2-tailed)
Pre and Post-Test Scores	16.17	2.96	0.46	35.37	41	0.000

As observed in Table 2, the pre-test mean score was 9.90 against the post-test mean score of 26.05. The descriptive information shows that there was a 16.17-point average improvement as the result of the application of the intervention strategy. The inferential statistics results obtained from Table 3 shows p-value of 0.000 which suggests a significant difference between the pre-test and the post test results.

Therefore, exposure of students to computer simulation when dealing with chemical bonding enhances students' conceptual understanding of the concepts.

Research Question 3: What were the views of students on the use of computer as a teaching and learning tool?

A survey of students' perceptions about the use of computer animations and videos as teaching and learning materials for chemical bonding was done using a questionnaire as results appear in table 4.

Table 4: Mean Scores (MS) and Standard Deviations of students' Responses on Questionnaire

SN	Item	Mean	SD
1	General level of motivation was derived from the use of computer simulation	3.90	1.01
2	Using computer simulation makes the concept real.	4.10	0.86
3	The use of computer simulation helped retained attention during lesson.	3.71	1.12
4	Computer simulation visualized the position and arrangements of bonding electrons.	4.33	0.77
5	Students recognized the various bonding types.	3.95	0.93
6	It is easy operating the computers.	2.81	1.74
7	Computer simulation helped improve upon students' understanding of chemical bonding.	4.21	0.79
8	The teacher talked less when using computer in teaching.	3.12	1.62
9	Computer animations/videos motivated to ask questions for clarification.	3.60	1.33
10	There was great participation in group discussion when computer animations were used.	3.40	1.47

Legend: MS < 1.5= strongly disagreed; 1.5 ≤ MS < 2.5= disagree; 2.5 ≤ MS < 4.0= agree; MS≥ 4.0 =strongly agree

Table 4 reveals that respondents strongly agreed to the statement that using computer simulation for teaching and learning of chemical bonding makes the concept real with a mean score of 4.10. Furthermore, the mean score of 3.90 shows that the use of computer simulation motivated students to learn better. The respondents acknowledged that the use of computer simulation attracted their interest and retained their attention during lessons, with mean score of 3.71. This confirmed the observation of the study findings by Kara and Kahraman (2008) which showed a significant improvement in favour of those exposed to CAI.

Conclusions

The study revealed that students had misconceptions about the concept of chemical bonding ranging from the type of atoms that form specific chemical bond type, bond length, bond strength and energies. However, computer simulations effectively addressed the students' challenges as there was a significant improvement on their performance after the intervention. Furthermore, the study revealed that computer simulation motivated students to learn better as it helped them to visualize the various components of chemical bonds. Therefore, computer simulation has the potential to address students' challenges in perceived difficult or abstract concepts in chemistry, particularly in chemical bonding.

Recommendations

The study recommends that chemistry teachers must consider incorporating computer simulations into their teaching strategies to address students' challenges of understanding chemical bonding and other abstract concepts. National Council for Curriculum Assessment (NaCCA) of the Ministry of Education could consider introducing computers and computer models in schools to address problems pertaining to perceived difficult or abstract concepts in science.

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