Effects of sequenced experimentation on trainees' understanding of concepts in analytical chemistry

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Abstract

The study involved 12 undergraduate teacher trainees who embarked on several 3-step sequenced laboratory activities to assess how it would affect their conceptual understanding of some analytical chemistry concepts in a conceptual laboratory. A quasi experimental approach was adopted. Results from the study showed that majority of the trainees preferred engaging in virtual activities more than, and before physical activities. There were improved gains in conception with trainees' engagement in sequenced experimentation with a Hake's gain of 0.58.

Key words: chemical phenomena, conceptual laboratory, physical experiment, virtual experiment

Introduction

The use of Information and Communications Technologies (ICT) comprises of animation, video, multimedia, web-based learning and simulation. Information and Communications Technology (ICT), is an extended synonym, an umbrella term which contains both Information Technology (IT) as well as Communications Technology under its fold. In fact, it is a very broad term used to refer to the literally infinite areas of scientific studies and techniques used in the handling of telecommunications; media management and broadcast; intelligent systems; data handling, processing, storage and transmission; network based solutions; as well as audio visual monitoring processes (Case, Johnstone, & Robinson, 2017). ICT has become such an important requirement in all spheres of life such that knowledge of its application determines one's affable capabilities in a work place or education environment. It has become increasingly important for employers, irrespective of the role one is to play in a work place.

The use of ICT in chemistry education provides benefits by enabling users to develop high quality mental models that enhance their conceptual understanding. It allows learners to explore and obtain immediate visual feedback. They are able to visualise and thereby understand abstract concepts such as amount of substance, models of atoms, molecules, and chemical bonds through animation and simulation. Conventional laboratory activities do not allow students to understand some of the mentioned processes of chemical phenomena. The application of ICT, which allows for visualisation, and e-manipulations which are in line with recent modern technological activities of school-age children can improve their investigative skills as they work through virtual practical activities and simulation. ICT can provide the opportunity for the demonstration of microscopic, macroscopic, and symbolic processes of chemical reactions through animation more thoroughly. In a study of the use of ICT in a high school class in Ghana, Ayim (2016) found a significant

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difference in academic performance as regards students who used simulation and conceptual change instruction, vis-à-vis the traditional in their study of chemical bonding. Her findings suggest the feasibility of use of ICT in other areas of chemistry. This current study sought to find out how the integration of ICT into lessons could affect teacher trainees' understanding of some fundamental inorganic chemistry concepts and the best time to introduce it into one's lesson.

Methodology

Series of a three-step designed whole class laboratory exercises were carried out in a conceptual chemistry laboratory (lab) where no special mathematical and algorithmic processes were required. The lab was designed to introduce trainees to basic chemical concepts from a basic conceptual point that did not require knowledge of mathematical formulae or algorithmic processes. Twelve trainees participated in the study. The sequences of activities were such that all trainees completed a pre-lab (pre-test) and participated in a theoretical treatment class for two weeks. This was followed by four laboratory (lab) sessions of two labs per week, where trainees' answered open-ended questions after their activities. In one instance, they saw video (ICT) representations of chemical reactions in microscopic, macroscopic as well as symbolic representations during the first 10 minutes of a lab class. They were then allowed to engage in two lessons involving individual virtual activities after which physical/manual (traditional) activities were carried out. Each exercise was followed by conceptual questions. Responses to worksheet questions were categorised naturally, based on meanings expressed in responses. This laboratory strategy was termed the virtual-physical (or V-P) approach. This approach was followed by two other lab lessons which allowed the trainees to engage in physical activities, followed by virtual activities for reinforcement - herein termed the physical-virtual (or P-V) approach. Trainees were required to make brief descriptions of what they thought happened at the microscopic level in the physical activity (backed by equations). Their responses to the two simple approaches and how they bore on their understanding of immediate conceptual underpinnings were assessed. These were concluded with a post-lab assessment. A framework for the study is presented in Figure 1.

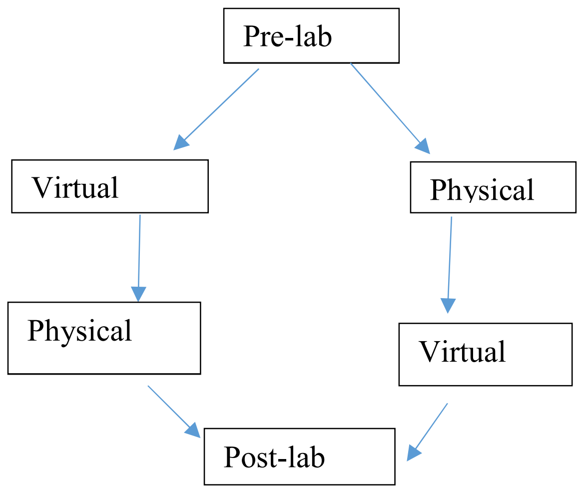

Figure 1: A framework for the V-P/P-V laboratory approach

Data was collected through trainees' pre-/post-lab results, lab reports during the treatment sessions, an observation schedule, and focus group interviews that involved groups of four trainees per set. The pre-test was to assess their entry point in the research while the observation schedule allowed the researcher to assess if the manipulative, process and concept skills expected to be acquired in each activity were mastered. Their exit points were assessed through a terminal post-lab/test. The interview was to seek their opinions about the sequenced approach and for the purposes of corroboration to the observation and gains made- if any. The object of study was the sequenced learning approach followed by trainees. The V-P activity was carried out first as against the P-V in order to arouse students' interest and to observe how that sequence affected their comprehension of activities that were carried out. Trainees were already used to engaging in unplanned e-activities to support the traditional method of teaching in some other courses.

Results

Results of the V-P and P-V lab activities (scored over 20 marks) are presented in Table 1. There is no obvious consistency in the obtained data.

Table 1 V-P and P-V results

V-P Activity	Mean (V)	Mean (P)	P-V Activity	Mean (P)	Mean (V)
1.Solubility of metal sulphates	16	14	1. Analysis of ions/ppm	13	14
2.Amount of substance in solution	17	16	2.Acid-base reaction (stoichiometry)	12	15

A consistent analysis of the effectiveness of the sequenced approach in promoting conceptual understanding was obtained by taking a rough measure of the average normalized gain<g> (the Hake's gain and not Cohen's 'd') because this was a one-group sample study. Hake's gain is defined as the ratio of the actual average gain (%post−%pre) to the maximum possible average gain (100% -pre). Science educators are able get first-hand information on the impact of the use of interactive approaches on students' cognitive learning , social practice and how the phases of the activities used in interactive engagement approaches contribute to their conceptual understanding (Hake, 1998).

Discussion

The effect of sequenced instructional approaches on trainees' understanding of various chemistry concepts was investigated. The benefits and limitations of traditional (physical) and ICT (virtual) activities were also inadvertently studied. Both have advantages and disadvantages, without doubt, as observed by other researchers (Klahr, Triona, & Williams, 2007; Zacharia & Constantinou, 2008). Physical activities could waste students' time as they may have no relevant results at the end of their activity. This could cause loss in time, energy, motivation, and finances. Virtual activities however, are free of the aforementioned loses. Instead, it helps students to visualise problems and their solutions and provide an interactive learning environment. One problem though with simulation in ICT is over-simplification of real world situations (Hofstein & Lunetta, 2004). Regardless this, the use of simulation has been reported to enhance practical skills and conceptual understanding (Finkelstein, et al., 2005). In this study it was observed that the activities generally increased trainee interest and motivation for learning. Besides, there was increased excitement and a lot of collaboration with the virtual activity sessions.

Zacharia, Olympiou and Papaeripidou (2008) also studied physical and virtual manipulations in a lab session, but without taking cognisance of the sequential effect, and found that students who used ICT performed better on a conceptual test. This was because the time required for manipulating each activity might have caused a difference in extension of collaborative associations and increased student learning. However, Carmichael, Chini, Gire and Rebello (2010) after comparing the effects of physical and virtual experimentation sequence on students' understanding of mechanics said that their P-V group performed better than their V-P group. They added that simulation provided high salience on certain concepts and induced blocking of further learning from the physical activity. They intimated, nevertheless, that students learn from whatever experiment that they are first introduced to – whether physical or virtual. Certainly, many exciting innovative activities open up students' desires to acquire new knowledge. Human beings generally get excited when they are introduced to new settings (activities or positively challenging environments). In this current study, it was found that teacher trainees who engaged in the virtual activities before manual activities performed better on those virtual activities than when they first performed the physical activity; which is consistent with Carmichael, Chini, Gire and Rebello's (2010) findings about sequence effect. However, the general academic output with respect to the two approaches differed from their finding.

Furthermore, in this current study, trainees had to perform both qualitative and quantitative chemical analysis virtually and physically, which differed from what other researchers had done. One of each set of activities was a P-V activity while the other was a V-P activity. In each instance trainees' reasoning responses (as this was a conceptual lab session) were more logical and sequential with the V-P activities. For example, in activity 2 of the V-P session, trainees had to find out the percent by mass concentration of Na_2SO4 in a solution made by dissolving 7.6g of the given salt in enough water to give 873g of solution. They were able to do so by simple proportion while hitherto they used formula which they did not understand conceptually and so made various wrong substitutions into given formula. Haider and Al Naqabi (2008) studied Emirati secondary school students' understanding of stoichiometry and the influence of metacognition and found that majority of students relied on algorithmic processes with very little conceptual understanding.

In the focus group interview which centred on the P-V/V-P approach to performing activities, trainees explained that the virtual activities were very helpful in giving them ideas on what the underlying concepts or principles of the chemical phenomena concerned were. The virtual activities also facilitated trainee-trainee interaction or collaboration, which led to personal construction of chemical phenomena. For example, they could see the sizes of atoms (as in the group 2 species) and how they combined with other periodic elements, resulting in their differing solubilities. Such a virtual activity could help learners to engage in fruitful deliberations which foster cognitive growth. They were able to visualise the process and types of chemical bonds that there were. They were able to understand terms such as intra- and intermolecular bonding and appreciated the differences in their bond strengths. Some of the virtual activities were preceded by short video tutorials which presented useful conversion factor relationships, often in a kind of flow diagram. In this way, how concepts were related became very evident and understandable to the trainees and algorithmic processes learned by rote were no longer required. In one such colourful video tutorial a question based on acid-base reactions was:

> What volume, in litres, of a 3.40M KOH is needed to react completely with 0.100L of a 6.72M H_2SO_4 solution according to the equation $2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$?

They first had to interpret the problem as: 0.100L H_2SO_4= ? L KOH. Then the sequence or analytical route below was followed:

Solution A	Molarity →	Moles of A	Equation coefficients →	Ymoles of B	Molarity →	Vol of sol B

The use of dimensional analysis was observed to be more common among the trainees. In a sub – question on the number of grams of NaCl required to add to 375g of water to prepare 2.75% (m/m) solution of NaCl, 10 out of 12 trainees used dimensional analysis that:

> If 97.25g of water, which had been worked out (100g solution – 2.75g NaCl) contained 2.75g NaCl, then 375g of water would contain a certain commensurate amount by simple proportion.

No formulae were required in most of the questions which accompanied the lab activities. The quantitative relation among reactants and products as well as concepts that they hitherto had learned in isolation became more meaningful to them.

There were no obvious differences in performance in trainees' virtual and physical experiments. The reason here could be that, trainees might have formed mental models that they could link with the physical activities for whose ions and true physical combinations could not be observed at a micro level. This helped them to gain scientific process skills such as setting up experiments, observing critically, recording data, analysing data and conceptualizing principles in the abstract. Nevertheless, they could vividly explain the microscopic activities vividly. They intimated in an interview that they had understood the required scientific concepts from their virtual activities and that was the reason for their good performance with the physical activities also. That is true, but the vividness of colourful images formed on their minds accompanied by the said processes would have a part to play. The creation of opportunities for learners to form mental models of chemical activities have been found to be very helpful in their formation of near permanent scientific concepts (Hanson, 2016) as was observed in this current study also. These adult learners became convinced that reactivity of elements do not automatically increase or decrease down a group or across a period but that variations in periodic parameters as well as the nature of combining species were significant factors in chemical reactions. They also learned at first hand that mole ratio was not dependent on concentration as they hitherto thought. Undocumented observation showed that concept and process skills worked together to produce imageries which facilitated concept formation and subsequently conceptual understanding.

In activity 1 of the V-P activity, trainees worked on the solubility of group 2 metal sulphates. They were familiar with some rules on identification of ions and solubility rules, which they applied by route but wrongly. However, the virtual activities enabled them to understand issues and so devised their own understandable logical frameworks which aided them in answering follow up questions in a physical session correctly than they formerly did. This was reflected in good performance in a post-test as indicated by high changed scores or gain in Appendix A. The calculated Hake's gain for the tests was 0.58, which falls between 0.7> (<g>) > 0.3; quite close to an appreciable gain, which implies that trainees' engagement with the sequenced activities enhanced their conceptual understanding of analytical chemistry concepts. In the second V-P activity, trainees had to carry out a virtual activity to determine amounts of substances in solution. The outcome was quite dramatic. It must be noted that a few trainees still held alternative conceptions about principles required for understanding the topic of stoichiometry. The mean score for that activity was quite low, with wide standard deviations among trainees from the central tendency. This implies that though innovative methods may work out for a large population of a sample, a few will still have peculiar problems which may require more intense attention. Nevertheless, this innovative sequenced approach to laboratory work worked especially well when virtual activities were performed before the physico-manual activities.

Feedback from trainees in the focus group interviews indicated that they were excited with the new approach as they gained confidence in carrying out physical activities, were more encouraged to collaborate with colleagues and dissuaded their minds from inherent dangers about certain laboratory procedures. They intimated that virtual activities were safe and appeared easy to go through. They added that the sequenced approach increased their process, concept and manipulative skills as well as enable them to eliminate some initial alternative conceptions. They reiterated that it enhanced teacher-trainee relationship which shifted the teaching –learning process from a teacher-centred one to a learner-centred base.

Conclusion

Reflections on the procedural strategies used in experimentation indicated that for the Ghanaian teacher trainees who participated in this study, the V-P approach was helpful in enhancing their learning processes. This increased their academic achievements. Observations and reports from them indicated that curiosity, collaboration and confidence gained from virtual experiments were a big boost for undertaking and understanding physical experiments. They described the newly introduced virtual activities as easy, fascinating and exciting; and that delighted in the fact that there was no cleaning to do afterwards. They intimated that many more of such activities could be carried out during normal classroom lessons, if topics lent themselves to such procedures.

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Appendix A: Trainees' entry point performance as against their terminal performance

Student No.	Pre-test (50 marks)	Pre-test (100 %)	Post-test (50 marks)	Post-test (100 %)	Changed score (Post-test–Pre-test)	Changed score in %
1	23	46	39	78	16	32
2	29	58	37	74	8	16
3	38	76	45	90	7	14
4	40	80	48	96	8	16
5	41	82	47	96	4	08
6	36	72	44	88	8	16
7	26	52	38	76	12	24
8	31	62	41	82	10	20
9	28	56	39	78	11	22
10	30	60	46	92	16	32
11	38	76	43	86	5	10
12	36	72	46	92	10	20
Mean	33.00	66.00	42.75	85.67	9.75	19.67