USE OF MULTIPLE REPRESENTATIONS TO PROMOTE STUDENTS' UNDERSTANDING OF PHASE CHANGES

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The research in this paper examines the effect of multiple external representations in the promotion of senior school students' understandings about changes in the physical state of matter. Static pictures and dynamic visual representations, as well as students' self generated diagrams were embedded into constructivist pedagogy to challenge students' alternative conceptions of phase changes in molecular substances. Students' change in conceptions and retention was determined through a pre test- post test- delayed post test research design. Data included student generated molecular level diagrams, written explanations, responses to conceptual interviews and researcher's field notes. This paper presents a qualitative analysis of change in students' conceptions and discusses the implications for pedagogy.

INTRODUCTION

Phase change or change in the physical state of a substance is an observable macroscopic property of matter whose scientific explanations are at abstract molecular level. In order to generate scientifically accepted explanations of phase changes, learners need to visualize and imagine entities and processes at molecular level. Learners also need to apply concepts related to bonding, molecular structure and intermolecular forces in order to formulate explanations of phase changes. This paper presents a part of the study in which a series of intervention sessions were conducted by the first author to promote senior secondary school students' understanding of phase changes.

THEORETICAL BACKGROUND

This study is based on the theoretical perspectives of constructivism, both individual and social constructivism. Individual constructivism asserts that learning is the construction of knowledge by the individual through his/ her interaction with the environment. Learner's existing ideas too effect the further construction of knowledge (Taber, 2006). Hence, there can be multiple interpretations of the same event.

Social constructivism emphasises the supporting activity of teachers and more informed peers in learning who communicate ideas through different modes, talk, gestures, visual images etc. to promote individual understanding (Scott, Asoko & Leach, 2008).

The past two decades have seen a large number of studies in the constructivist paradigm exploring students' conceptions in various domains of science. In the recent past, researchers have moved from exploring students' conceptions to addressing students' misconceptions. Calik et al. (2007) used a four step strategy, incorporating the following elements of constructivist pedagogy: eliciting student's prior ideas, focusing on the target concept through small group activities, challenging the idea thorough discussion with peers and teacher, and applying newly constructed ideas to other similar situations, to promote students' scientific understanding of phenomena. According to Baviskar et al. (2009) reflection by the learner on the learning which has taken place, is also an essential feature of constructivist pedagogy. The use of multiple modes of representations (visual, textual etc.) and collaboration in learning was recommended by Driscoll (2000) as important constructivist conditions of learning.

Pictures, concrete models, text etc. are commonly used as instructional materials in the science classroom. These are external representations that are used to communicate scientific ideas. The benefits of using multiple external representations in science learning have been documented in literature (Corrandi et al., 2014; Wu & Puntambekar, 2012). Theories in the information processing approach have explained the learning though multiple representations. According to Mayer's theory, learners select and organize the information from text and visuals, and then build referential connections between the verbal mental representations and visual mental representations (Adadan, 2013; Goldman, 2003; Kozma, 2003).

Wu and Puntambekar (2012) have emphasized the active engagement of students to integrate representations. Group discussions around multiple representations where students share their understanding of representations and concepts, can encourage students to form connections between the different representations and integrate representations with their prior knowledge (Goldman, 2003, Kozma, 2003, Wu and Puntambekar, 2012).

Adadan, Trundle and Irving (2010) used multi representational instruction, with focus on student generated diagrams and reflection on learning, to promote Grade 11 students' learning of particulate nature of matter. Hilton and Nichols (2011) used instructional strategies like animations and simulations using Molecular workbench, and static visual representations along with small group activities to address students' alternative conceptions of bonding.

Wu and Puntambekar (2012) have pointed out the need for further studies on how MER's can be effectively used in the classroom, by embedding MER's in different teaching approaches.

Use of multiple representations is especially significant in the context of phase changes due to the sub microscopic level of explanations.

Students' misconceptions about phase changes reported in literature (Tsai, 1999) are related to change in size of particle, the relative distance between particles and the motion of particles during phase change. Another misconception reported in literature is the conception that intramolecular covalent bonds are broken during phase changes of covalent molecular substances (Treagust et al., 2011).

Successful attempts to promote conceptual understanding of phase changes and related concepts amongst students, through use of different strategies, have also been reported in literature. These include use of representations like concrete models, diagrams and texts (Prain et al., 2009) for evaporation, demonstrations followed by discussion (Treagust et al., 2011) on effect of intermolecular forces on states of matter, and technology enhanced dynamic visualizations (Levy, 2013) for phase changes.

More studies are required, especially in the Indian classroom context, to examine the effects of students' engagement with multiple representations on their understanding of sub - microscopic level processes like phase changes.

THE STUDY

In this study, multiple representations primarily static pictures and dynamic visuals (accompanied by text), were embedded in constructivist pedagogy, to address senior secondary school students' conceptions of phase changes. The participants were 35 Class XI students (21 boys and 14 girls) from an urban private school. The school follows English as the medium of instruction. The students in this school belong to upper middle class families. All participants during the time of the study were of age 16-17 years.

The Research Questions

The research questions which are addressed in this paper are:

What are students' explanations and conceptions of phase changes two months after regular formal instruction (prior to the intervention)?

What are the changes in students' conceptions as they engage with the learning sessions of the intervention based on constructivist approach?

What is the short term and long term impact of intervention sessions based on multiple representations and constructivist pedagogy on students' conceptions of phase changes?

THE METHODOLOGY

The study incorporated a single group quasi experimental (pre test- post test- delayed post test) design. A set of ten conceptual questions (of which four had subparts) was prepared to elicit students' prior conceptions of phase changes in molecular substances, and their conceptions of intermolecular forces. The questions were predominantly open ended and included questions for which students were required to make pictorial representations or diagrams of phenomena at molecular level, along with written explanations. The purpose of the questions was to explore students' conceptions of changes in physical state of substance: melting, vaporization and condensation processes and to understand how students used the concept of 'forces' of attraction between atoms/ molecules, to explain phase changes.

While some of the questions were adapted from previous studies, others were designed by the researcher. The questions were validated by a six chemistry experts, teaching the chemistry courses at the undergraduate level, and a chemistry teacher educator. Two chemistry teachers teaching at the senior secondary school level also validated the questions for their appropriateness to the cognitive level of the participants. The same set of questions served as the pre test and post test.

Students' pre intervention conceptions were determined by administration of the pre-test two months after regular formal instruction in the classroom on phase changes. Semi structured interviews were then conducted with those students who gave their consent to be interviewed. Students' responses to the pre test and conceptual interviews, was examined for their conceptions and their difficulties in understanding phase changes.

A series of seven intervention sessions, each of one hour duration, were designed and conducted with the objective of promoting a more scientific understanding of bonding concepts, intermolecular forces and phase changes. The last two sessions had the specific objective of remediating the most common alternative conception of students about phase changes, that is, 'covalent bonds are broken during phase change in molecular substances'.

These two sessions aimed at developing the understanding that,

i) Change of state is an interplay between thermal energy and strength of intermolecular forces.

ii) When temperature is increased and the state of a substance changes from liquid to gas, weak forces between molecules are overcome and not the strong forces of covalent bond within the molecule.

iii) During condensation of gas at low temperatures the kinetic energy of particles decreases and the intermolecular forces are able to bring the slow moving molecules together, leading to condensation.

External representations that were used in the sessions included static diagrams of processes at macroscopic and molecular level, accompanied by a text, and dynamic visualizations. According to Ploetzner and Lowe (2004), static visuals demand lesser processing requirements than dynamic visualizations. Static visuals are preferred for students who are new or less familiar in dealing with visualizations. Sequencing of MER's also needs to take into account learners' prior competencies with multiple representations (Wu & Putambekar, 2012). In this study, students were first presented with static visuals, accompanied by text. Static visuals selected were depictions of substances in the three states or processes of phase change at atomic/ molecular level. Animations were then used to facilitate the idea of increased motion of particles and its role in changing states of matter.

Static pictures from internationally well-known books were selected and included as a part of the learning experiences of the sessions. An example of a static picture used is that of boiling of pentane, macroscopic view and molecular level representations (from the book Chemistry; the molecular nature of matter and change, fifth edition by M.S. Silberberg et al., 2006). The dynamic visuals were taken from the free resources available on you tube, on the world wide web and also the resources available with the school. These included an animation on the changing states of matter, depicting the increased motion of particles and the increase in distance between the particles on heating. These external representations were also validated by experts for their appropriateness to the learning goals.

In the intervention sessions, the multiple representations were embedded in a *constructivist teaching learning strategy.* The steps of the teaching- learning strategy were *elicitation of prior conceptions, restructuring of ideas, application of new ideas and reflection on learning*. A worksheet was also designed to facilitate the learning process.

For restructuring of ideas, group discussions were woven around the multiple representations. This allowed the students to exchange their perceptions of the static and dynamic representations, listen to others ideas and justify their own. This was followed by whole class discussion. Students were also encouraged to maintain a reflective journal where they recorded their new learning. The first author, that is the researcher who was also the facilitator, recorded her observations and reflections of the classroom interactions immediately after each session.

The post test was administered a day later after the intervention sessions were conducted, and the delayed post test was administered three months later. Both the tests were followed by semi-structured interviews of students who were willing to be interviewed. In all there were 11 students who appeared for all the three interviews at each stage, pre intervention, post intervention and delayed post intervention. While a qualitative analysis of the development of students' understanding was carried out for the whole group, the change in the conceptions of the students who participated in the interviews could be studied in greater depth.

DATA ANALYSIS AND FINDINGS

Prior to the intervention, analysis of the expressed constructs of students in the form of their written responses and molecular level diagrams revealed that none of the students had sound understanding of processes of phase change.

Students' prior conceptions of the change of state during the boiling of water: Most of the students gave partial explanations, mentioning either the increase in KE of water molecules or the overcoming of intermolecular forces, but not the relation between the two to explain the change of state of physical state of water.

The explanations of eight students were limited to the conceptions of change of state learnt in junior classes, that is, the simple explanation that the distance between the molecules increases, with no mention of the role of KE of molecules or intermolecular forces.

Alternative conceptions were noted in seven students, that is twenty percent of students, which was that the covalent bond in liquid water breaks to give H and O atoms, or H_2 and O_2 molecules, when it changes to gaseous state.

Students' prior ideas of the liquefaction of Chlorine gas: Most students gave the simple explanation that the particles would come closer in the liquid state. Amongst these five(about 14 percent of students) had the alternative conception that individual atoms of chlorine and not diatomic molecules are present in both the liquid and gaseous state. One student, S-10 expressed the scientifically unacceptable idea that additional covalent bonds are formed between the atoms of chlorine. He wrote in his explanation,

"Chlorine in gaseous state has weak bond order but long bond length, whereas in liquid chlorine the atoms come closer to each other and form short bond lengths but strong bond order.'

Three students had the notion that chlorine gas cannot be condensed (it had something to do with critical temperatures, they said).

Overall in their explanations, it was found that almost all students were aware of the change in distance between particles in the three states. However, none of the students could give detailed, clear as well as consistent scientific explanations of the phase change processes in molecular substances, in terms of intermolecular forces, kinetic energy and motion of molecules. Even those students, for example, S-26, S-8, who gave partially scientifically accepted explanations in situations like phase change in water and chlorine, expressed alternative ideas in another context that N_2 would have a higher boiling point than Br_2 because the triple bond is N_2 is more difficult to break than the single bond in Br_2.

During the intervention sessions: Students' perceptions of the static pictures and animations included the colour of substances and the relative distance between the molecules in the three states, and the motion of the molecules. S-7 mentioned that the molecules in liquid phase are closer than he thought them to be. For some of the students, the new learning also included other aspects like knowledge of scientific terms like 'deposition'.

S-28, after the session which had static pictures of molecular level representations of bromine in the three states and sublimation of iodine, wrote as his new learning in his reflective journal,

> "Covalent bond is not broken during change of state.
>
> The colour of bromine is orange.
>
> Iodine can easily sublime, it's colour is magenta'.
>
> S-16 wrote in her new learning: "Iodine sublimes to vapours and then condenses and deposits.

Intermolecular and not intramolecular forces have to be compared to find which compound will have more boiling point."

It was evident from their worksheets and their reflective journals that all students could reconstruct or strengthen their idea that the intermolecular forces are involved and not the covalent bonds during the phase change of covalent molecular substances.

During the post test, most students could give consistent scientifically accepted explanations of phase changes in different contexts.

However, in the delayed post test a regression was observed in few students. These students gave explanations in terms of intermolecular forces for liquefaction of X_2 gas, and boiling of water. But while comparing substances for their boiling points, their spontaneous idea was that O_2 will have higher boiling point than Br_2 because the double bond is more difficult to break. Even in such students, when they were asked to make a pictorial representation, they made molecules of O_2 separating from each other. While making the diagram, they connected their ideas to the visual representations that they had seen during the sessions. Most of these students then corrected themselves and said that the intermolecular forces between O_2 molecules would be overcome.

The efficacy of the external representations can be judged in terms of students' reflections about their learning and their feedback about the sessions.

S-14: Earlier I was not knowing the correct procedure of solid changing into liquid. In solid I thought that the particles are at rest. The animation helped me that know that they are vibrating at their mean positions....though the randomness is less but it is still there.

S-16: "Next time when we will read about anything which explains the process at atomic level we will be able to make a picture in our mind. This will enhance our ability to build concepts."

IMPLICATIONS FOR PEDAGOGY AND TEXTBOOK

Molecular level representations related to phase changes need to be included in the current national level textbook, to help students visualise the processes of phase change. However, just incorporating the pictures in the textbook or the animations in the classroom teaching is not enough. Students should be given an opportunity to express their conceptions in different ways, writing, speaking and through their self generated molecular level representations. The nature of questions in our assessments tasks as used currently also needs to undergo a change. Classroom environment should also encourage students to freely express and justify their ideas, to enable them to reconstruct their ideas, and promote meaningful learning.

It was found in the study that prior to the intervention students did not give consistent scientific explanations of phase changes of molecular substances in all situations. Both the scientific framework as well as the alternative conception coexisted in their cognitive structures. While the alternative conception was successfully tackled for the short term, a regression was observed in a few students in the delayed post intervention stage. There was spontaneous use of the alternative framework of breaking of covalent bonds in the phase changes of molecular substances, which shows that this idea is highly resistant to change. This finding stresses the need to practice and revisit the scientific explanations using sub-microscopic level representations various times in the course of the study of physical properties of inorganic as well as organic molecular substances, in order to remediate this strongly held alternative conception.

The molecular level diagrams of a few learners were representations of the scientifically accepted ideas, but were in contradiction of their verbal representations of ideas. This shows that these learners were not able to form a coherent mental model of phase change. Further studies are required on how to help students actively integrate the multiple representations, and how to optimize the results of the integration to promote retention.

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