Strategies to Enhance Teachers’ College Students’ Understanding of Concepts on Matter and Chemical Bonding

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Abstract

This case study was carried out at a teacher training college in Masvingo, Province, Zimbabwe, 2008, to study the prevalence of misconceptions related to matter and chemical bonding by student teachers and suggests ways to enhance conceptualization. Data were collected through pen and paper tests, one-on-one interviews, focus group discussion interviews and observations. Specific questions focused on the nature of matter and chemical bonding to establish misconceptions held by the students and come up with possible intervention strategies. Twenty-one science student teachers aged between 18 and 40 years took part in the study. Purposive sampling technique was used to collect data through case study based on performance in a pen and paper test. Triangulation of data was done to validate the data, get insight into views of the students on effective instructional strategies, and to enhance better conceptualization of concepts. Analysis of the data showed that most participants had misconceptions about the nature of matter and chemical bonding but the extent of the misconceptions was not clear. Subsequent data collection concentrated on the extent of the misconceptions and on how they could be eradicated. Instructional strategies that could enhance understanding of scientific concepts were suggested by the participants at the end of the study.

Key words: Chemical bonding, interviews, focus group discussion, matter, misconceptions, observations, instructional strategies, scientific concepts.

Many student teachers at teachers’ colleges struggle with chemistry topics, the concepts related to matter and chemical bonding appearing to pose great challenges because of their abstract nature. The problem is worsened by the misconceptions the students hold which work against their proper grasping of chemistry concepts (Boo, 1998). Possible intervention strategies have to be employed to enhance proper conceptualization of these important concepts as they are fundamental in the study of chemistry.

Students are introduced to the concept of chemical reactions usually through the students’ carrying out chemical reactions or through demonstrations by the teacher without giving consideration to the reason why the chemical reactions take place. They are only introduced to the nature of chemical bonds later on in high school, but by then, they will have developed their own meanings as a result of their interaction with chemistry, leading to faulty understandings which may hinder conceptualization of scientific concepts.
An insight into the alternative conceptions might assist science educators in their quest to help student teachers understand chemistry. Focus on prospective science teachers’ training in the subject matter is rare (Haider, 1997). In a study of pre-service teachers’ understanding of the particulate nature of matter about 11% were reported as having sound understanding and 62% were reported to have specific misunderstandings. Appropriate strategies of instruction of pre-service student teachers are needed to enhance their effectiveness as teachers at schools and curb development of misconceptions by preventing the student teachers translate the misconceptions to their pupils after graduation (Gabel, Sammuel & Hunn, 1986).

The limited science knowledge and ability of primary school teachers to teach science has been documented and various reports have advocated increasing the knowledge preparation of primary science school teachers (Peterson & Treagust, 1998). Researchers have used several terms interchangeably in connection with students’ understandings about science concepts (Boo, 1998; Novak, 2000). These include preconceptions (Anderson & Smith, 1993), alternative framework (Driver & Easly, 1978; Driver & Erickson, 1983), naïve conceptions (Champagne, Gunstone, & Klopfer, 1983) and misconceptions (Cho, Kahle, & Norland, 1985; Griffiths & Grant, 1985). Boo (1998) suggested the term alternative conception to mean students’ ideas which are at variance with those currently accepted by the scientific community. Cros and Maurin (1986) reported that some first year university students struggled to come up with the structure of an atom. They were reporting on research focused on the constituents of matter and motions of acids and bases, but did not venture into the aspect of intervention methods of instruction required to rectify the established alternative conceptions. Haider (1992) reported that 62% of the student teachers in his study had misconceptions about the conservation of matter and related concepts, whilst 15% had no understanding, but 12% had a sound understanding. He, however, did not report on the appropriate instructional intervention to enhance conceptualization. Cros and Maurin (1986) reported that misconceptions are liable to impede the learning of concepts. Taber (2001) reported that the learner’s prior knowledge is a key determinant of both the quality and quantity of learning that the learner can go through. The learner can effectively benefit from the teacher’s presentation if the learner has full and accurate background knowledge for the topic under discussion and as long as the teacher clearly links new learning and prior knowledge. If the learner is unable to perceive the links between previous learning and new learning or has alternative conceptions, new learning becomes unlikely. Novick and Nussbaum (1981) reported that some students failed to apply the idea of particle motion when evacuating air from a flask, picturing the evacuation as analogous to pouring a liquid from a container. Some of them felt that the remaining particles in the flask were concentrated in the upper part of the flask, near the opening of the pump and thus pictured the pump as pulling the entire mass of the particles towards the opening. They failed to apply the idea of particle motion to arrive at uniform distribution when a gas is evacuated from a flask, thus revealing a persistence of a static model despite exposure to the kinetic model. Few of them explained cooling in terms of decreased particle motion or decreased energy possessed by the particles. Similarly, heating was also erroneously understood, revealing that pupils differentially internalize aspects of a scientific model. The authors explained that this difficulty in conceiving a vacuum persists even into senior high school or university levels. It is therefore important to ascertain what misconceptions students have so that they may be helped internalize the correct concepts in their quest for scientific knowledge.

Peterson and Treagust (1998) reported specific difficulties students have with respect to chemical bonds. They noted that Grade 11 and 12 students held misconceptions that
intramolecular covalent bonds (instead of intermolecular bonds) are broken when a substance changes phase. Boo (1998) reported that students were confused about ionic and covalent bonds and structures, with some of them referring to “molecules in solid sodium chloride”, whilst others conceptualized the sodium and chlorine atoms as being held together by covalent bonds. Only a few students demonstrated a clear understanding of the three-dimensional lattice structure of sodium chloride. Boo (1998) further reported that many students’ difficulties with chemical bonds and energies could be traced to their lack of understanding of the particulate nature of matter.

De Vos and Verdonk (1986) indicated that students aged 15-16 years had difficulties classifying chemical reactions as exothermic or endothermic. Some students erroneously referred to the burning of a candle as an endothermic reaction since heat is needed to initiate burning. The same students inferred that the burning of copper is endothermic since the oxide is formed only when copper is heated. Novick and Nussbaum (1978) suggested that one of the reasons why many Grade 8 Israeli students had difficulty grasping bonding in chemical reaction is that they had either not abandoned the continuous view of matter or had adopted a distorted particulate view of matter, such as a static view of particles.

Boo (1998) argued that students aged 15 years had difficulty appreciating the dynamic as well as the particulate aspects of chemical reactions. The students’ view of chemical reactions appeared to be that of an addition rather than an interactive one. These students visualize the chemical reaction as a process of addition or gluing reactants to form compounds. They did not view chemical reaction as a process of bond breaking and bond making involving many particles and do not view a molecule of a compound as a new entry but rather as a mixture of constituents.

The conceptual difficulties with chemical bonding can be traced to something even more basic as the students’ understanding of the nature of atoms and molecules (Boo, 1998). Many students aged between 12 & 18 years thought that atoms vary in shape and size as the physical state changes, and they often erroneously attributed all kinds of microscopic properties to particles even to the point of suggesting that sulphur atoms are yellow and copper atoms are malleable. Students aged between 16 and 18 years had the misconception that endothermic reactions cannot be spontaneous, and that reactions which occur naturally are endothermic (Boo, 1998).

Students fail to realize that in order to evaluate whether a reaction is exothermic or endothermic, they had to consider the energy balance between that required to break bonds and that released when bonds are formed. They should not consider energy as the driving force for the reaction (Boo & Watson, 2001).

The majority of Grade 8 students did not appear to have understood the term chemical change, as revealed by their failure to apply their understanding of burning to explain the observations they made on burning things (BouJaoude, 1991). These students had difficulties appreciating that chemical reactions are not driven by external interventions such as heating (Novick & Nussbaum, 1978). The development of misconceptions among high school students learning chemical energetics may be attributed to the problems associated with understanding meaning of the large number of abstract concepts encountered in a limited time. Examples of such concepts are heat, energy, temperature, and bond energy. Educators should ensure that such terms are understood as they are introduced at the early stages so that they do not bewilder the learner by confronting him/her in large numbers (Boo, 1998).
Four basic ideas about chemical bonding appear to be so difficult for some students to grasp that they give rise to the development of misconceptions. (1). The students fail to grasp the idea that during a chemical reaction the entities reacting are changed in fundamental ways so that the products no longer show the same properties as the reactants. (2). The students view bonds as entities linking atoms. As a result, a giant lattice of ions in which no ions are specifically linked to other ions is difficult to understand in terms of bonding. (3). Many students failed to identify correctly the bonds being broken and those being formed in a chemical reaction, and failed to identify the direction of energy change when bonds are broken or formed, (4). Most students did not understand the idea that chemical reactions are driven by an increase in entropy in the universe. They looked for a causal agent for the change. About half the students considered bond breaking to be exothermic and bond making to be endothermic. A very common misconception was that ionic bonding results in ion pairs resembling covalent molecules and not giant ionic structures (Boo & Watson, 2001).

Love (1993) reported that students can carry misconceptions even up to university level. Zoller (1996) adds that students at all ages hold misconceptions and college science students are no exception. According to Love (1993), before a course in thermodynamics students linked the concept of work with potential energy but after lectures, they linked it with heat. Before the course students associated the concept of reversibility with reversible reactions and hence with equilibria. Equilibrium was relocated to chemical potential, indicating that its new thermodynamic association had been assimilated. Reversibility was now linked to thermodynamic concepts, in line with its new significance. Analysis of actual responses revealed that weaker students produced less appropriate responses, indicating lack of focus and clarity, as well as interference from misleading ideas. It is possible to identify a qualitative indication of weaknesses and lack of appropriate learning, and students so identified could be given suitable attention (Love, 1993).

Misconceptions may play a crucial role in learning as a result of interfering with science comprehension. The person holding misconceptions may have a great deal of difficulty learning new materials because their variant conceptions provide a faulty foundation for the formation of new insights (Novick & Nussbaum, 1981). When planning lessons, educators should determine which misconceptions are prevalent among their students so that they clear them before introducing new material. Science may seem confusing or incomprehensible to persons holding misconceptions because of the discomfort caused by cognitive dissonance that results from perceiving scientific phenomena that do not support already held misconceptions of science (Schoon & Boone, 1998). Awareness of misconceptions held by students would assist educators to come up with appropriate methods of instruction, hence the desirability for educators to have reliable information about prior knowledge, especially informal meanings and misinformation of students (Love, 1993). Knowledge and experiences students bring with them have great influence on their learning (Ausubel, 1963; 1968; Ausubel, Novak, & Hanesian, 1978; Cain, 2000; Novak, 2000). What students know on specific phenomena becomes the basis for acquiring new knowledge. Students refer the new knowledge to what they already know and if the two do not relate, students may find it difficult to construct meaning. An understanding of the concepts students hold prior to instruction assists the educator to guide students to construct meaning from what they are taught. The teacher should use the vast experiences and knowledge possessed by students to help them construct meaning from new experiences.
**Possible instructional strategies**

As a child increases and differentiates cognitive structure concerning the nature of matter, the “nature is made of particles” component, becomes increasingly powerful as a relevant concept for new learning. Development of basic science concepts in children’s cognitive structure should result in facilitation of future learning in science and handling actual materials is crucial in children’s learning of scientific concepts (Hibbard & Novak, 1975). Determining students’ construction of science involves complex components. Hence it is important for educators to consider seriously the importance of how learners perceive and conceptualize concepts before they come up with the appropriate teaching methods. In order to ensure meaningful learning, educators have to help learners become involved in constructing their knowledge and organizing it in a way that can help them apply the needed information correctly and easily (Ledbetter, 1993).

Emphasis has moved from teaching science as a body of knowledge but towards students experiencing the processes and procedures of science; learning science taking into account the prior conceptual framework of students and providing students with experiences that lead to conceptual change and development; teaching science as inquiry and teaching science by inquiry. Sound educational principles should involve continuity and interaction between the learner and what is learned. Science educators should give examples and tasks which are relevant and found in the environment of the students (Shumba, 1993).

Students need to be actually involved in the process of making knowledge for them to comprehend the concepts of science. They should be given an opportunity to build their own knowledge using their own experiences and thought (Cain, 2000). It is therefore important for science educators to understand the basis of how learners construct knowledge so as to be able to assist students build accurate concepts, use process skills and be able to reject incorrect ideas. Direct “hands-on” and “minds-on” experiences that involve the learners in using process inquiry skills to gain knowledge by investigating physical life and earth science must become the norm if we are to experience sustained reform that enables all students to become scientifically literate (Cain, 2000).

Students should take advantage of every opportunity presented to engage in the process of doing science. They must develop skills needed to seek information to solve problems. Students should develop an open and questioning attitude and constantly seek new knowledge and understanding (Haury & Rillero, 1994). They should learn to work with others and share responsibility for acquiring new knowledge and understanding with peers. They should value new experiences as opportunities to inquire and learn. By working constructively in groups, learners can share their understandings in their own words, expose any misconceptions, strengthening concepts, and in the process, help one another (Cain, 2000), basing their understanding on their previous knowledge (Bordner, 1986).

Reflective teaching strategies may overcome the problem of misconceptions and effect meaningful subsequent learning. Properly designed tests may be very effective for revealing students' misconceptions and may be particularly very useful for providing data for remediation purposes via appropriate modification of the teaching strategies (Zoller, 1996).

**Objectives**

1. To investigate misconceptions held by the college students’ teachers and establish their level of understanding on concepts related to matter and chemical bonding.
2. To investigate the challenges faced by student teachers and discuss appropriate strategies of instruction to be employed to enhance understanding of concepts related to matter and chemical bonding.

**Research Questions**

1. What kinds of misconceptions do college science student teachers have about the particulate nature of matter and chemical bonding?
2. What challenges do college science student teachers face in conceptualizing the concepts related to matter and chemical bonding?
3. How do college science student teachers view the methods of instruction used for teaching the concepts related to matter and chemical bonding?
4. How do college science student teachers view the relevance of the concepts related to matter and chemical bonding in the teaching and learning of chemistry at the college?

**Methodology**

Respondents were drawn from the first-year students who majored in science, employing the qualitative paradigm, where topic, theory, and methods are usually interlinked (Lancy, 1993). The qualitative paradigm uses the naturalistic approach that seeks to understand phenomena in context with the natural settings, focusing on understanding the individual’s perceptions of the world from his/her own frame of reference (Nyawaranda, 1998). Qualitative research is an interpretive inquiry, which is holistic, requiring participant observation, takes place in natural setting and is emic rather than etic (Lincoln and Guba, 1985). Since qualitative research is interactive in nature, the respondents and the researcher are active participants, and because it is interpretive, its emphasis is on interpretation and the meaning is derived from participants (Leedy, 1989). The research methodology was based on the fundamental belief that events must be studied in natural settings, i.e. field based. Events cannot be understood unless one understands how they are perceived and interpreted by the people who participated in them, hence participant observation is a major data collection device (Tuckman, 1994).

The methodology was designed on the basis of performance pen and paper test, face-to-face interviews, and group focus interviews (Bogdan & Biklen, 1982). Participants wrote a pencil and paper test comprising questions on concepts related to matter and chemical bonding in order to determine the level of content mastery of the participants and establish the misconceptions held by the respondents. Face-to-face personal interviews were held on fewer participants who answered questions addressing the research questions as a follow-up to responses obtained from the test, and focus group interviews addressed specific issues related to the research questions. Responses from the four methods were analyzed in an attempt to address issues on the research questions.

**Research instruments**

The researcher was the chief research instrument collecting data through pen and paper test on the concepts of particulate nature of matter and also on chemical bonding, open-ended interviews, focus group discussion interviews on specific concepts, and discussions (Lincoln & Guba, 1985) and supplemented by the understanding that was gained on the location (Leedy, 1989). Since the paradigm used in this research was interpretive, the researcher’s insight was the key instrument for data analysis during and after data collection.
The specific questions focused on the particulate nature of matter and on the general principles related to chemical bonding, in order to ascertain the levels of understanding exhibited by the college science student teachers. This was done to establish the misconceptions they held and also come up with possible intervention strategies to enhance understanding of these scientific concepts. Focus group interviews were carried out to establish the general understanding and to triangulate the findings from the pen and paper results. Selected individual face-to-face interviews were performed to get to the bottom of issues. These instruments were used so as to try and establish the actual comprehension levels of the concepts by the student teachers and to get an insight into what the student teachers regard as the most effective methods to employ when teaching the concepts regarding matter and chemical bonding.

Sampling Procedures

The participants were selected on the basis of their potential to contribute to the study (Bennett, Glatter, & Levacie, 1994). Only 21 first-year college science students, adjudged by the researcher to have the potential for providing information relevant to the research problem, were selected on the basis of the pencil-and-paper test and used as participants. Triangulation of data obtained from the pencil and paper test, face-to-face interviews, and focus group discussion interviews was used to validate the information. The thrust of all data collection instruments was to gather important information pertaining to the misconceptions held by college science students on the concepts in respect of matter and chemical bonding. It was also in order to get an insight into what these college students viewed as the most effective instructional strategies which must be employed to enhance better conceptualization of these concepts.

Participant characteristics

This group of 21 student teachers, aged 18-40 years, was composed of 13 male and 8 female students, the majority of whom had done the Integrated Science Syllabus, whilst a few had done Physical Science at O’level, graduating with grade C or better. The students were drawn from different parts of the country although the majority came from Masvingo Province, having attended rural day secondary schools. Only a few were resident at college, the majority having secured alternative accommodation in the different residential areas in the vicinity of the college, taking part in college activities as day scholars.

Settings

Of the 70 students enrolled in the department, 40 were in first year and 30 were in third year. The second year of the three-year course was spent doing teaching practice. There were three lecturers (one B. Ed) and (two M.Ed.), and one technician. Thus, although the situation was not ideal, the settings were healthy and comfortable.

Gaining field entry

The letter of introduction from The Department of Science and Mathematics Education, University of Zimbabwe was used to secure permission to do research from The Ministry of Higher and Tertiary Education, from The Teacher Training College Administration and acceptance by the students to take part in the Case Study. Getting permission to conduct the study involved more than getting an official blessing (Bogdan & Biklen, 1982). The process involved laying the groundwork for good rapport with those with whom the researcher would be spending time, so that they accepted him/her and what he/she would be doing. Helping them to feel that they had a hand in allowing the researcher in would help the research. Some of the
students were suspicious after being told that part of the data gathering involved pen and paper test. The suspicion was, however, eased when they were told that no marks would be awarded, even though some had shown interest on having a feedback. The student teachers became more convinced when they were told that each of them would be given enough time to complete the tasks given to them in the test.

Reliability and Validity

Reliability and validity are crucial in research. Validity is always about truth. It deals with the notion that what you say you have observed is, in fact, what really happened (Lincoln, 2001). Reliability and validity were ensured in this Case Study by employing triangulation, member checks, and thick descriptions. Triangulation on data collection and methods of data collection were employed to establish trustworthiness. Triangulation included sources of data and forms of data. Methods used were a written performance test, one-on-one face-to-face interviews, interviews of focus groups, on the concepts matter and chemical bonding. Member checking was employed and involved revisiting some of the respondents in order to ascertain consistence in what they had previously said. Verification was also ensured by thick descriptions by making sure that the quotations from the interviews were detailed. The information captured also included some social actions portrayed by respondents like facial expressions and some emphasis, obtained during interviews and focus group discussions.

Data collection techniques

Interviews and tests were used as the data collecting techniques in this Case Study. Respondents were given a performance test and they were interviewed as individuals and also as focus group interviewees. The purpose of the performance test was to ascertain the level of content mastery by the participants. It was one of the ways in which participants exposed their misconceptions. Student teachers were given a pen and paper performance test where they responded to specific concepts on the subject areas under study. Focus group discussion interviews were conducted where students were given questions which they discussed before giving their collective feedback. Follow-up one-on-one face-to-face interviews on individually selected student teachers were held on the specific concepts related to particulate nature of matter and chemical bonding. The use of multiple data collection sources as a form of data triangulation prevented exclusive reliance on a single data collection method, thus neutralizing any bias coherent in a particular data source. The triangulation of the interviews with a written test, as well as triangulation of interviews with focus group discussion interviews ensured a holistic understanding of the situation. Triangulation enables the researcher to view his data critically and be able to identify weaknesses and take corrective actions (Fielding & Fielding, 1986). This process of corroborating evidence from different sources encourages the researcher to develop a report that is both accurate and credible (Creswell, 2002).

Paper and pen performance test

The performance test materials were constructed on the basis of what one would like to measure (Tuckman, 1994). The test consisted of items involving phenomena, simple experiments, or situations. Participants were asked to complete diagrams, write a brief explanation (free response), or choose among a number of given explanations or drawings (forced choice). The test focused on aspects of particulate nature of matter and on chemical bonding. The aspects which were being probed regarding the degree of internalization by college
students included (1) that gas particles are randomly distributed in a closed system, (2) that gas particles are in constant motion, (3) heating and cooling causes changes in particle density, (4) liquefaction viewed as a change of state from gas to liquid, (5) existence of an empty space between particles in a gas, (6) chemical substances react to attain stability, (7) types of bonding: covalent and ionic, and (8) general periodic trends (Novick & Nussbaum, 1981). No time limit was set for the completion of the test and all participants were allowed enough time to complete the tasks.

**Interviews**

One-on-one interviews were used to triangulate data collected through the performance tests and focus group discussion interviews. The participants were individually interviewed after completion of the pen and paper test to maximize on the efficiency of data collection and minimize on bias (Tuckman, 1994). The open-ended interview guide approach was used and the researcher was free to probe and ask follow-up questions, trying to find out what the participants had on their minds, what they thought, and how they felt about phenomena (Fraenkel & Wallen, 1996). These interviews were held in the science laboratory at the Teachers’ College, when the students had free afternoons, hence involved no disruptions to the running of normal lectures for students.

**Focus group discussion interviews**

The respondents were put into groups of four individuals and each group interviewed. Questions were posed and group members would discuss amongst themselves, then, give feedback which was captured by the researcher. The biggest challenge about these interviews was that of communication. The respondents had difficulty communicating their responses to the researcher in English. On many occasions the researcher advised the respondents to use vernacular to communicate their ideas and the researcher would translate to English. Nobody indicated any possibility of offence arising from that suggestion. Some of the data expressed in vernacular could not have been given using any other data communication method. Thus the use of group interviews did not only serve as triangulation opportunities, but important sources of extra data as well. Capturing all things during an interview is crucial in qualitative research and is normally referred to as thick descriptions (Bogdan & Biklen, 1982). The use of focus group discussion interviews was also important in order to produce credible information from the study obtained by different sources and also by different methods. Triangulation of methods and sources of data collection are important since they actually ensure and guarantee the trustworthiness of the conclusions obtained from a research study (Lincoln & Guba, 1985).

**Data capturing**

The collection of data in a qualitative research study is ongoing, i.e., data is collected as the study progresses (Fraenkel & Wallen, 1996). Responses in the performance test were provided on paper since it was a written test. The data was thus captured in descriptive form as either explanation or diagrams in response to specific concepts on particulate nature of matter and chemical bonding. Data from the face-to-face interviews was obtained by listening to what was being said and was captured as words which were written down by the researcher. Capturing words from the respondents was rather difficult. The researcher had to strike a balance between listening and writing simultaneously. Coping with talking speed and writing speed was difficult since stopping respondents would disrupt their elaborations which would
consequently distort their feedback and concentration. Intermittent jerks during interviews tend to make interviewees unsettled. Capturing data from focus group discussion was done by first of all listening to the responses, then writing them down. The challenge here emanated from striking a balance between capturing as much information as possible, at the same time keeping the discussion under control and writing almost all that was being said as feedback in response to the specific questions asked. The recordings from all these sources were done promptly in order to capture all important issues when they were still fresh.

Data analysis

Analyzing data in a qualitative study involves synthesizing the information the researcher obtains from various sources into a coherent description of what he/she discovered (Fraenkel & Wallen, 1996). The purpose of analysis is to bring meaning, structure, and order to the data collected (Marshall & Rossman, 1999). Qualitative researchers tend to use inductive analysis critically as themes emerge from the data. Confronted with a large number of impressions, documents and transcribed interviews, the qualitative researcher has to make sense of what has been discovered. The raw data were qualitatively analyzed by placing them into logical and meaningful categories to enable the researcher to critically examine the data in a holistic manner. Each script from the pen and paper test, each interview excerpt from the one-on-one interviews, and each interview excerpt from the focus group discussions were recorded and analyzed individually. Meaning was given and the responses categorized.

Categories for the performance test responses were assigned depending on the level of understanding of the subjects and codes were subsequently assigned to the categories. Meaning was given and categorized in order to establish patterns. Continuous analysis and interpretation of data in qualitative research is very important and takes place from data collection stage throughout the whole research process (Bogdan & Biklen, 1982).

An analysis scheme adopted from Haider (1997) was employed for the pencil and paper test. The scheme consists of 5 categories: (i) sound understanding, (ii) partial understanding, (iii) partial understanding with specific misconceptions, (iv) specific misconceptions and no understanding, and (v) no understanding. The categories were translated into ordinate scale and points were assigned to each conception as follows: (i) no understanding = 0, (ii) specific misconceptions and no understanding = 1, (iii) partial understanding with specific misconception = 2, (iv) partial understanding =3, and (v) sound understanding = 4. This scheme was considered appropriate for this study because it enabled the researcher to look at the data from two angles. Firstly, the students’ responses could be separated into different levels of understanding, and secondly, students’ misconceptions could further be analyzed into different patterns.

Data presentations

Data analysis in qualitative research relies heavily on description. Even when certain statistics are calculated, they tend to be used in a descriptive rather than in an inferential sense (Fraenkel & Wallen, 1996). The responses from the performance pencil and paper test were analyzed as described above and presented using descriptive statistics as shown in Table 1.
Table 1: Analysis of responses from performance test

<table>
<thead>
<tr>
<th>Conception</th>
<th>Categories (N=)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound understanding</td>
<td>77</td>
<td>29.6</td>
</tr>
<tr>
<td>Partial understanding</td>
<td>80</td>
<td>30.8</td>
</tr>
<tr>
<td>Partial understanding with specific misunderstanding</td>
<td>30</td>
<td>11.5</td>
</tr>
<tr>
<td>Specific misconception, no understanding</td>
<td>10</td>
<td>3.9</td>
</tr>
<tr>
<td>No understanding</td>
<td>63</td>
<td>24.2</td>
</tr>
</tbody>
</table>

Interpretation in qualitative research entails a process of going beyond or transcending data (Marshall & Rossman, 1999). The researcher gives his/her own understanding and meaning to factual data and analytical explanation, thus making sense of the data obtained. Table 1 reveals that most student teachers had a higher conception on the concept of a uniform distribution in gas particles. A few participants showed a misconception on the effect of heat on matter. They appeared to have failed to retain the aspect of conservation of matter. They indicated that a substance becomes lighter when it is heated and changes state in a closed system.

The responses on the effect of heating and cooling on particle motion were predominantly descriptive. No particular mention of the energy aspect was given. Some respondents had the misconception that heating does not cause particles of a substance to expand. The majority of participants could not distinguish between particles and substances. They gave responses like: “A molecule is the smallest element in an atom”. Some regarded elements as particles which make up compounds. A few were able to clearly classify atoms and molecules as particles, and elements and compounds as chemical substances.

Mastery of the concept of chemical change was a problem. Some participants regarded a compound as a mixture of molecules. This revealed that most of the participants showed partial knowledge and misconceptions on concepts related to chemical bonding. The majority could not explain what covalent bonding and ionic bonding were, giving responses such as:

1. Covalent bonding is when an element loses an electron to become stable.
2. Ionic bonding is when an element shares electrons chemically.

This revealed faulty ideas on concepts related to chemical bonding. Results shown in Table 1, such as 11.5% partial understanding with specific misconception, 3.9% specific misconception, and 24.2% no understanding, reveal that the participants do encounter difficulties in understanding these concepts.

Face-to-face interviews

There were a variety of responses pertaining to why the respondents chose to specialize in science at college, but most respondents highlighted the following:

1. Their passion for the subject and the aspect of being comfortable with the concepts and subject matter.
2. There are prospects for diverting into other lucrative professions later on in life.
3. Influenced by the way they were taught science back at school.
4. Influenced by their desire to deal with things that affect peoples’ lives.
Parents’ role in enhancing children’s understanding of scientific concepts

The student teachers suggestions on what parents could do to enhance their children’s conceptualization of scientific concepts included the following:

1. Parents should encourage and praise their children when they performed well and should motivate their children to carry out experiments at home when opportunities arose.
2. Parents should encourage their children whenever they are involved in any scientific activities.
3. Parents should be part and parcel of their children’s learning of science.
4. Parents should give examples of careers for people who will have done science, for example doctors, nurses, engineers, and explain the benefits gained by being in such professions.
5. Parents should make their children aware of what is found in the environment and the importance of preserving natural resources.
6. Parents should support the efforts of schools to enable proper teaching of science in schools.

Instructional strategies that enhance understanding of scientific concepts

(i). Teachers should encourage students to perform experiments during lessons and desist from reliance on teacher demonstrations.
(ii). Teachers should create an environment that encourages students to carry out research on assigned topics.
(iii). Students should be given time to discuss concepts among themselves in groups during lessons so as to foster student-student interactions.
(iv). Students should be given exercises and tests frequently to enable the teacher to assess on what has been understood or not understood, as well as create chances for students to ask questions on areas of difficulty.
(v). Practical work given to students should be such that discovery learning takes place during experiments.
(vi). Teachers should use locally improvised materials and encourage students to use the environment as a laboratory and encourage students to talk about the environment so as to expose and correct misconceptions.
(vii). Teachers should promote the use of media and use field trips to expose children to the real world and real things in the environment.

Challenges encountered in teaching and learning of science in general included lack of infrastructure like laboratories where experiments could be carried out, lack of equipment and materials to be used when carrying out experiments, and shortage of science textbooks in bookshops. Failure to use appropriate instruction strategies on the part of the teacher and failure to prepare for the lesson on the part of the student was also problematic. The quality of teachers is crucial. Some them are not experienced and usually are not comfortable with the subject matter.

Focus group interviews

Twenty-one students were divided into four groups whose composition did not take gender sensitivity into account. Group responses on the meaning of the term matter revealed that most students could explain what matter was. Explanations on the effect of heat on the state of matter were dominated by description of what is observed as opposed to what the cause of the changes.
The effect of the energy possessed by particles was not mentioned. Participants showed sound knowledge and understanding of the changes which occur when heat is applied to a specific state of matter.

Responses on the reasons for chemical reactions taking place were diverse. There was a clear indication that most of the respondents had knowledge on the aspect of stability and importance of chemical bonding. The responses included:

(i) Chemical substances react to form compounds
(ii) Atoms share electrons to form stable compounds.
(iii) Chemical substances react because of the number of electrons and protons in the element.

Most respondents appeared to struggle on the differences between covalent bonding and ionic bonding. They did not appear to understand the terms as was also revealed by the performance test on the same aspect. They appeared to have a haze picture about this aspect, giving responses like:

(i) No idea.
(ii) Ionic bond has high melting point and high boiling point whereas covalent bond has low boiling point.
(iii) In covalent bond elements lose electrons and in ionic bonds elements share electrons.
(iv) Ionic bonding is formed when two of non-metals share electrons and of the two, one does not change back to the original.

Analysis of the responses revealed that the respondents did not understand the concept. Students’ explanation of chemical reactions revealed that they had misconceptions. About half of them considered the process of bond breaking to be exothermic and bond making as endothermic. Some respondents viewed bonds as physical entities; hence they used the term glued. Most respondents correctly stated the reactants and products in reactions between dilute hydrochloric acid and magnesium ribbon. Some respondents failed to define an endothermic reaction and an exothermic reaction correctly. The respondents showed lack of understanding on the formation of new bonds and breaking of bonds at microscopic level. They managed to state new products but they appeared to be unsure how the products were formed.

Respondents concurred that matter appeared relatively easier to understand than chemical bonding was. They said that chemical bonding was difficult because it was abstract and, in most cases, it was not taught properly. They suggested that most teachers appeared to be uncomfortable and unknowledgeable about the topic, hence their generally poor comprehension of the topic. They suggested that teachers and lecturers should incorporate use of experiments when teaching the concepts, as well as use of discussion groups. But, first and foremost, they should determine the level of understanding of their students before they taught them. Thus, science educators should use teaching strategies that engaged students by use of practical sessions and promote student-student interaction by group work. This conforms to the “hands-on” new vision.

The students felt that there was a wide gap between college chemistry and high school science. They highlighted that at school the apparent goal was just to pass the examinations whilst at college expectations were higher and the students themselves had to do much more than what is done in high schools. Thus the way students were taught at schools might have a bearing on the conceptualization of these concepts. The respondents agreed that it was vital for them as primary school teachers to learn chemistry at college. The knowledge that they gain would turn them into better science teachers since the study helps them build confidence in themselves.
Discussion

Some respondents pictured evacuation as analogous to removing a liquid from a container as was reported for Israeli 7th and 8th graders and university students (Novick & Nussbaum, 1981). Students in this study appear to reveal that the misconception was due to them having missed on the fact that gas particles are always in constant motion. Most respondents did not show sufficient knowledge on the effect of heating and cooling on particle motion. The most prevalent responses were descriptive, thus supporting findings by Novick and Nussbaum (1981), who reported that few of their respondents explained cooling in terms of decreased particle motion or energy. Based on the O’ Integrated science and the Ordinary Level (O’ Level) Physical Science syllabus, students are expected to convincingly explain what happens when matter changes state. The failure of the respondents might be explained in terms of the day schools they graduated from where laboratories with equipment and apparatus are scarce.

Many respondents did not show a sound understanding of chemical bonding. The majority failed to define the atom correctly, thus in agreement with Cros and Maurin’s (1986) observation that first year university students struggled to come up with the structure of an atom. The student teachers failed to show the difference between particles and substances. Some responses regarded the element as a particle and molecules as chemical substances, thus indicating a persistent and widespread misconception, in support of Boo’s (1998) observation that students’ conceptual difficulties with chemical bonding can be traced to their understanding of the nature of atoms and molecules. This knowledge of the misconceptions and the link between matter and chemical bonding will help chemistry educators to devise ways to help students out of their scholastic quagmire.

Results from the group focus interviews also revealed that many student teachers had problems with the nature of chemical bonding. They found it difficult to identify correctly the bonds being broken and the bonds formed in chemical reactions. More than half the respondents regarded bond breaking as endothermic, thus in agreement with Boo and Watson’s (2001) observation in Singapore. For the present study, the problem might be emanating from lack of practical experience since the students graduated from rural day secondary schools where facilities for hands-on studies of chemical reactions are insufficient.

The respondents were able to state the reactants and predict the products of chemical reactions correctly, although they did not have an understanding of the reactions at microscopic level. Boo and Watson (2001) reported that students could produce correct answers to various problems, including chemical reactions, although they lacked understanding of underlying chemical concepts. This indicates that students can appear successful without achieving real understanding. The existence of misconceptions justifies the need to identify them, and then decide on the method of instruction.

Unfortunately, most science educators rarely probe further after students have provided a correct response, hence many misconceptions go unnoticed. A few respondents regarded an endothermic reaction as that which releases energy and an exothermic reaction as that which absorbs energy. This misconception concurs with the observation by Boo and Watson (2001). The problem probably emanates from the respondents tending to concentrate on giving correct answers than to underlying concepts. The fact that misconceptions are acquired, and not hereditary, means that they can be eliminated through proper instruction and educators could successfully devise ways to deal with them as they surface at the different stages of the learner’s development.
Instructional strategies

In agreement with Hibbard and Novak (1975), most participants in this study, who incidentally had not yet been exposed to educational psychology, advocated for frequent use of practical and experimental work when teaching scientific concepts. Cain (2000) suggested that children should be involved in constructing their own knowledge. Hence children should be involved in practical and experimental work in an environment which is for them to discuss among themselves so as to gainfully engage in the process of learning. The participants suggested frequent use of properly organized group work and research to enable effective student-student interaction as they engage in the various scientific inquiry processes. Shumba (1993) advocated that science be taught as inquiry, by inquiry. This entails use of the processes of science to study science. Bencze and Hodson (1999) observed that the process of “hands-on” effectively involves actively constructing the meaning of one’s world, as happens when learners are encouraged, individually and in groups, to explore their natural environment.

By advocating for improvisation of teaching materials and the use of the environment as a laboratory, the participants supported Shumba (1993), who pointed out that use of what is found in the environment is the best way to make the learner more aware of his/her environment. Using the environment as a laboratory will make science learning more relevant and meaningful, facilitating constructivism (Ausubel 1963; 1968) and fostering meaningful learning (Novak, 2000). Thus science educators must commit themselves to professional development programs that enable them to change instructional strategies and adapt a hands-on teaching approach (Thorndike, 1920, cited by Haury & Rillero, 2008). When planning their lessons, teachers should determine which misconceptions are prevalent among their students so that they can work on strategies to eradicate them. Persons with misconceptions have difficulties understanding new materials because of their variant conceptions. Knowledge of the misconceptions the students had would help science educators equip themselves with the necessary strategies to eradicate the misconceptions and ensure understanding. An insight into the misconceptions will facilitate better planning and enhance effective teaching and learning of science concepts.

Conclusion

Student teachers had misconceptions on concepts related to matter and chemical bonding. Although most showed a sound and comprehensive concept that gas particles are uniformly distributed, some showed the misconception that gases consisted of static particles The majority of participants could not correctly define an atom, an element or a compound, and struggled to explain the nature of ionic and covalent bonds. Most participants had difficulties conceiving bond breaking and bond making processes in chemical reactions. They appeared to have a haze idea on how products are formed from reactants in a chemical reaction. Some participants had misconceptions on the aspects of endothermic and exothermic reactions.

The participants advocated for the use of methods which promote frequent use of practical work, group work, and research. They agreed that there was a gap between school science and college science. Parents play a pivotal role in motivating their children to like to do science by giving them career guidance and material support. Science educators need to be well acquainted with changes in the syllabus at high schools for them to be able to facilitate a smooth transition from school science to college science. Emphasis is required to assist students to become involved in constructing their own knowledge and organize it.
References


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