COMPUTER-AIDED INSTRUCTION TO IMPROVE PASS RATES OF FIRST-YEAR CHEMISTRY STUDENTS

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ABSTRACT

Past imbalances in the South African education system continue to perpetuate in poorly resourced schools and inadequately skilled teachers, resulting in under-prepared university students. At Tshwane University of Technology (TUT) a computer-based intervention was developed to address two of the conceptual difficulties identified in prospective first-year Chemistry students. After implementation of the intervention, average improvements of 13.6% and 6.4% were obtained for the concepts of conservation of matter and physical and chemical change respectively. The students' attitudes towards computer-aided study, assessed using a semi-structured questionnaire, were found to be extremely positive despite limited computer access.

Keywords: conceptual knowledge; Chemistry students; computer-aided study.

1. INTRODUCTION

The first year subject Chemistry I has been identified by Tshwane University of Technology (TUT) as one of the subjects with a low pass rate, which inevitably leads to retention of students in the system, and loss of government subsidy to the university. Statistics over the past three years show an average pass rate of 50% for all students registered for Chemistry 1. Several researchers have investigated the conceptual knowledge of first year students in the fields of mathematics and science in an attempt to discover why so many of these students fail to graduate, often falling out during the first year of study (Mulford, 2002; Potgieter, Davidowitz & Mathabatha, 2007; Yitbarek, 2006). In these studies, a distinction is made between traditional or lower order questions and conceptual or higher order questions. Lower order questions require the respondent to have memorised facts, definitions and explanations offered during lectures. Algorithmic calculations based on knowledge and skills developed during lectures also fall into this category. The ability to answer such lower order questions correctly is often the only formal assessment tool used to determine whether students have attained the required outcomes of a course. Higher order or conceptual questions require students to apply existing knowledge to new situations and assess underlying patterns of chemical behaviour.

Several researchers (Yitbarek, 2006; Mulford & Robinson, 2002; Treagust, 1988) report that questions relating to conceptual understanding, or higher order questions, are poorly understood, and misconceptions, when identified, are resistant to change by the usual instruction methods.

Although, when various intervention techniques have been applied, some level of improvement is reported, no complete solution has been found and a significant proportion of students still retain their misconceptions (Bodner, 1991; Basili & Sanford, 1991). The use of computer-aided instruction has been found by some investigators to result in substantial increases in the success rate of Chemistry students (Lowry, 1999; Yezierski & Birk, 2006). Lectures in the Chemistry department at TUT have traditionally been presented using overhead projectors with limited use of graphics and illustrations to aid student understanding. PowerPoint presentation of lectures is not yet in general use in the Chemistry department of TUT due to inadequate facilities. The majority of students enrolling at TUT have little exposure to computer technology and limited personal computer access.

2. THE PURPOSE OF THIS STUDY

The aim of the present study was to assess and identify the scientific misconceptions of first-year Chemistry students at TUT and then to compare them with those of students at other institutions. Once the nature and extent of these misconceptions had been established, a computer-based intervention using PowerPoint graphics and computer animations was developed in order to overcome those discrepancies in understanding which were regarded as the most fundamental. The misconceptions related to mass conservation as well as those regarding the nature of physical change were then specifically addressed. A further aim of this study was to use it as a pilot study in order to establish the feasibility of using such an intervention as a means to overcome fundamental student misconceptions throughout the Chemistry 1 course. Ultimately, then, this intervention is expected to increase the percentage of students who pass Chemistry 1 at the first attempt.

It was also important to assess the attitude of the students towards computer-assisted teaching and learning since it was planned to present the entire Chemistry 1 course in PowerPoint format, including either additional compact discs (CD), or WebCT access, to be used by the students in their own time.

3. ESTABLISHING BASELINE KNOWLEDGE

3.1 Selecting the sample

The current study investigates a group of 32 first year students (the experimental group) enrolled for the first year Foundation Chemistry course during the first semester of 2007 at TUT. These students have completed three years of high school Chemistry incorporated as a component of the subject Physical Science. Although they have passed the subject at Grade 12 level, the grades achieved were insufficient to allow admission to the mainstream Chemistry course, and these students had to first successfully pass the six month Foundation Chemistry programme before being admitted to the Chemistry 1 course.

The conceptual understanding of these students was assessed and intervention techniques designed in order to overcome some of the identified problem areas.

3.2 Conceptual test instrument

In order to assess the initial level of conceptual understanding, these Foundation Programme students were assessed during the third week of April 2007 (the pre-test) using the JCE conceptual concepts test developed by Mulford and Robinson (2002), and available online at jchemed.chem.wisc.edu. The purpose was to establish whether these students actually showed the same misconceptions reported by other researchers in the field who have used either the same or adaptations of the same instrument (Yitbarak, 2006; Potgieter, Davidowitz & Mathabatha, 2007; Mulford & Robinson, 2002). Multiple choice questions are a highly useful starting point in the identification of misconceptions, not only indicating that a particular concept is inadequately understood, but also indicating the alternative concept, which is believed to be correct by the respondent. The JCE conceptual concepts test comprises 22 questions which were clustered into groups evaluating different concepts and summarised as such in Table 1.

Table 1: Summary of concepts represented in the JCE chemical concepts inventory

Question number	Concept represented	Explanation of fundamental concept
1, 4, 7, 8, 12, 13, 18 & 19	Conservation of mass Conservation of matter Conservation of mass during chemical change	Mass of reactants and products always equal Number of atoms is equal for products and reactants Mass in solid and vapour form equal – only spaces between molecules change Why mass increases when rust forms
2, 3, 6, 10 & 11	Phase changes are physical change Matter conservation during phase changes	Heating water produces water vapour – a physical change only Water vapour condenses – physical change Liquid and solid forms of water
5	Stoichiometry and equations	Balanced reaction and limiting reagent Difference between coefficients and subscripts in a chemical equation
9	Enthalpy of reaction	Energy needed to break and reform bonds
14 & 22	Atomic size Macroscopic and microscopic properties	Estimating how big an atom is Atom smallest representative part of matter chemically but cannot represent macro scale
15, 16, 17, 20 & 21	Concentration properties of liquids	When more dilute molecules further apart Physical properties and physical change

3.3 Results of pre-test

The pre-test results of the current study (Figure 1) indicate that the experimental group of TUT students share the same misconceptions of fundamental scientific principles as those identified by other researchers in the field (Mulford & Robinson, 2002; Potgieter, Davidowitz & Mathabatha, 2007; Yitbarek, 2006). The percentage of students within the group who demonstrate these misconceptions is, however, greater than was reflected in other studies. Figure 1 compares the percentage of correct answers to the JCE chemical concepts test for the current experimental group with the first year Chemistry students results reported in Mulford & Robinson (2002), as well as the results of Ethiopian grade 12 learners, (Yitbarak, 2006). Yitbarak (2006) did not use all of the JCE chemical concepts questions; only those which were included are shown.

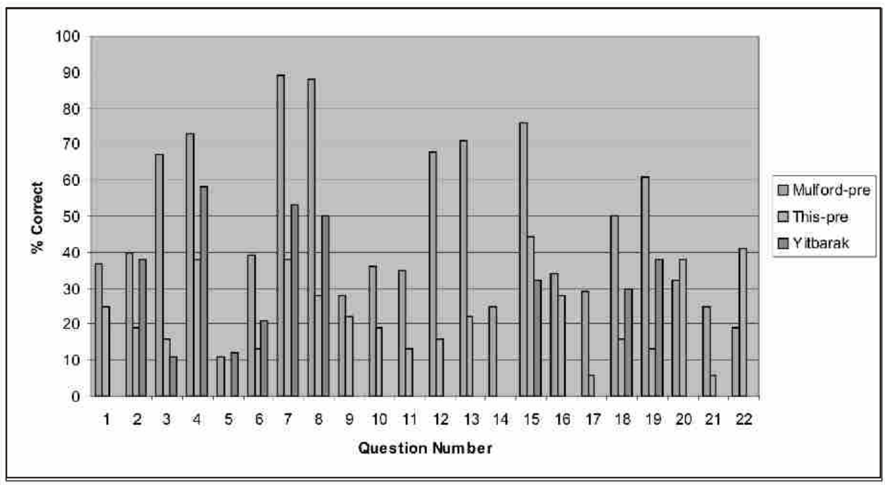

Figure 1: Comparison of pre-test results: the graph shows the percentage of correct responses for the questions of the JCE Chemical Concepts Inventory for the current study and the studies of Mulford and Robinson and Yitbarak

4. THE INTERVENTION

4.1 The intervention model

Once it was established that the students in the experimental group had serious misconceptions of important fundamental principles, an intervention model was designed. Since the intervention was to become part of the Chemistry 1 course material from January 2008 and was intended to be presented in place of the normal lectures to be conducted during the first week of the semester, the intention was to address the most fundamental concepts only.

Conservation of mass and of matter during both chemical and physical change was addressed together with the fundamental differences between physical and chemical change. Figures 2(a) and (b) show the concepts which were addressed in the current intervention as well as how the percentage of correct answers recorded in the pre-test of this study compare with Mulford and Robinson's (2002) pre-test results for the same concepts. Figure 2(a) represents the questions concerning conservation of matter while Figure 2(b) indicates the responses to questions about phase change. The results illustrated in both Figure 2(a) and Figure 2(b) indicate that the percentage of correct responses for the current study is close to the 20% level, which is consistent with a random guess. The students did not recognise the scientifically accepted concept of matter conservation itself or the concept of the changes which occur during any change of phase. These fundamental concepts are generally assumed to be in place when commencing tertiary studies in Chemistry (Scalise et al., 2003).

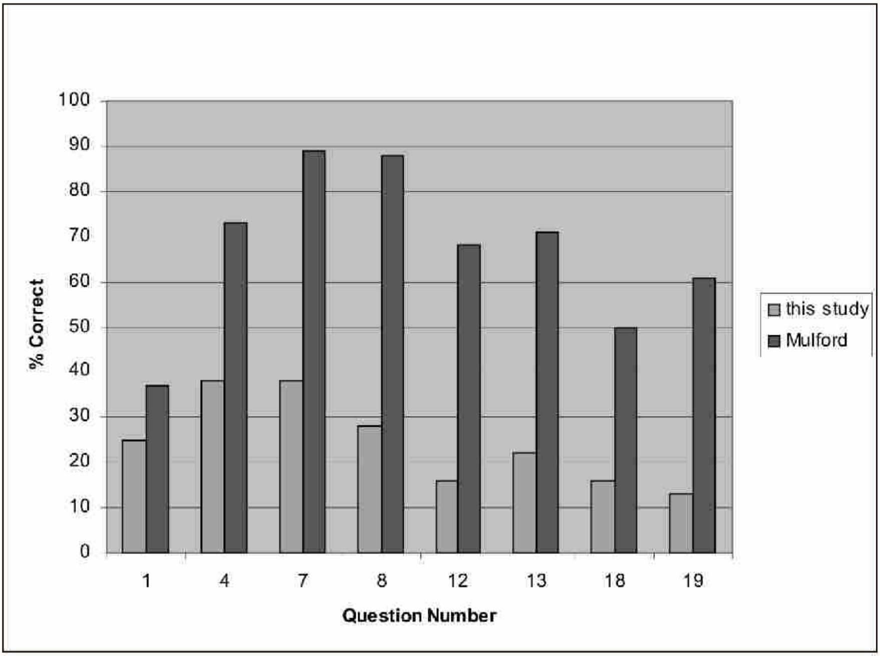

Figure 2(a): Conservation of matter: Graph of percentage of correct responses for the pre-test of the current study compared to pre-test results for Mulford and Robinson (2002) for questions concerning conservation of matter

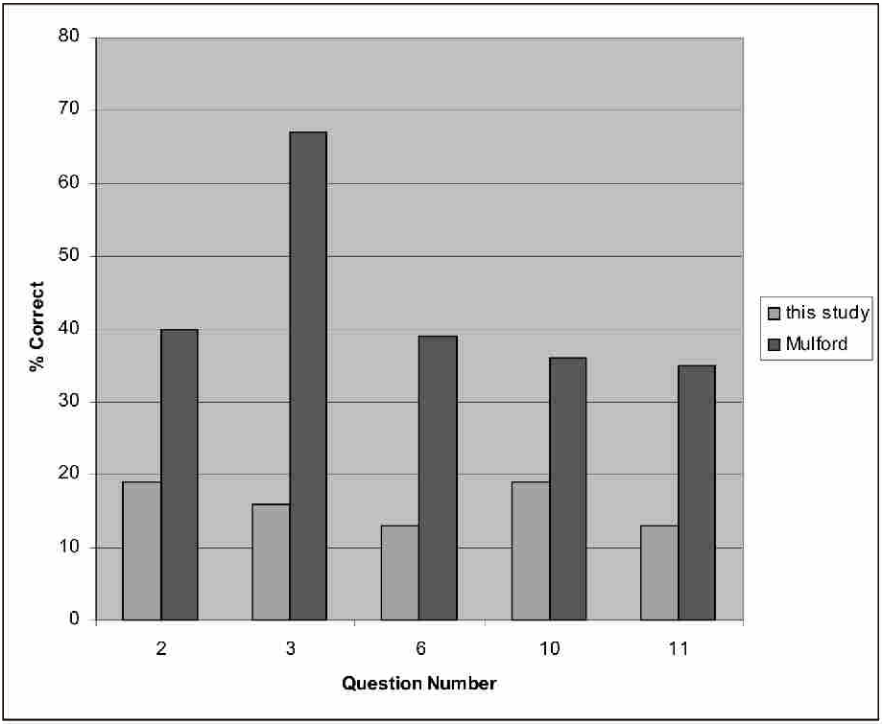

Figure 2(b): Physical change and phase change: graph of percentage of correct responses for the pre-test for the current study compared to pre-test results for Mulford and Robinson (2002) for questions concerning physical change and phase change

The framework of the intervention model is represented in Figure 3 and reflects an attempt to revise assumed knowledge. This was done using both graphic and animated computer generated examples in order to illustrate the fundamental principle of matter conservation during all forms of both chemical and physical change while emphasising the differences between the two. Great care was taken in order to ensure that all introductory knowledge, such as basic definitions of elements, compounds, mixtures, molecules and atoms, was first fully grounded before discussing either phase changes or chemical changes. Matter conservation in all types of change was meticulously explained with several graphic illustrations of everyday occurrences. This framework corresponds closely to the first two core concepts identified by Scalise et al. (2003) as being part of the knowledge students need in order to develop fundamental reasoning and understanding in Chemistry.

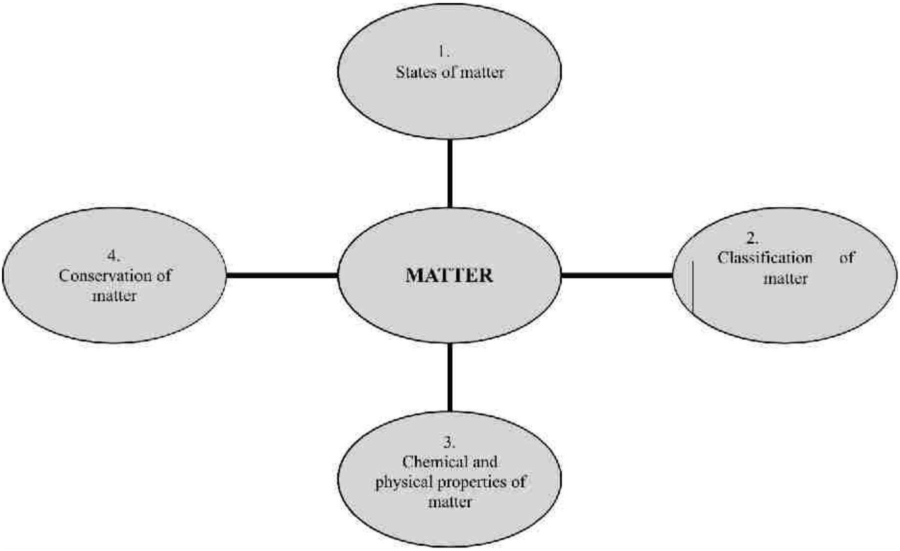

Figure 3: Intervention framework

The fundamental concepts represented in the framework and dealt with in the intervention could have been presented in several ways. PowerPoint lecture presentation and the use of computer graphics and animations have been widely used for many years as a general method of instruction, but these are not yet in general use in the Chemistry Department of TUT. The use of PowerPoint as a presentation method cannot of itself be conclusively shown to improve students' performance (Shallcross & Harrison, 2007; Waterman, 2007), but it was decided to use a computer-generated PowerPoint method in this study since this allows for more flexibility on the part of the lecturer. When using overhead transparencies, too much time is taken fiddling with transparencies and overlays, and very little direct eye contact with students is possible. In addition, the computer-generated graphics are much clearer and easier to understand, and they retain the students' interest longer (Lowry, 1999). It has also been found that the use of animations and computer graphics is of particular benefit in changing students' misconceptions regarding the particulate nature of matter (Yezierski & Birk, 2006). Students seem to hold a static picture of chemical reactions and only represent concepts with any level of accuracy at the macro level. The use of dynamic three-dimensional animations is predicted to be useful in overcoming these inadequate conceptions (Wu & Shah, 2004).

4.2 Results of the intervention

Figures 4 and 5 show a comparison of the results of pre- and post- tests for the current study. Figure 4 shows the results for questions dealing with the concept of conservation of matter, while Figure 5 shows the results for questions dealing with phase changes. The fundamental concept of conservation of matter was addressed in questions 1, 4, 7, 8, 12, 13, 18, and 19. The results reflected that, in the more difficult application of the concept, the oxidation of iron, which adds oxygen and causes an increase in mass (questions 18 and 19), students did not show improvement but actually scored 5% worse in answer to question 18. By contrast, however, question 19, which deals with the explanation of why the mass of the product was greater than that of the original piece of iron, showed an improvement of 14%. The remaining questions relating to this concept were successfully accepted, and students' understanding increased by an average 17%.

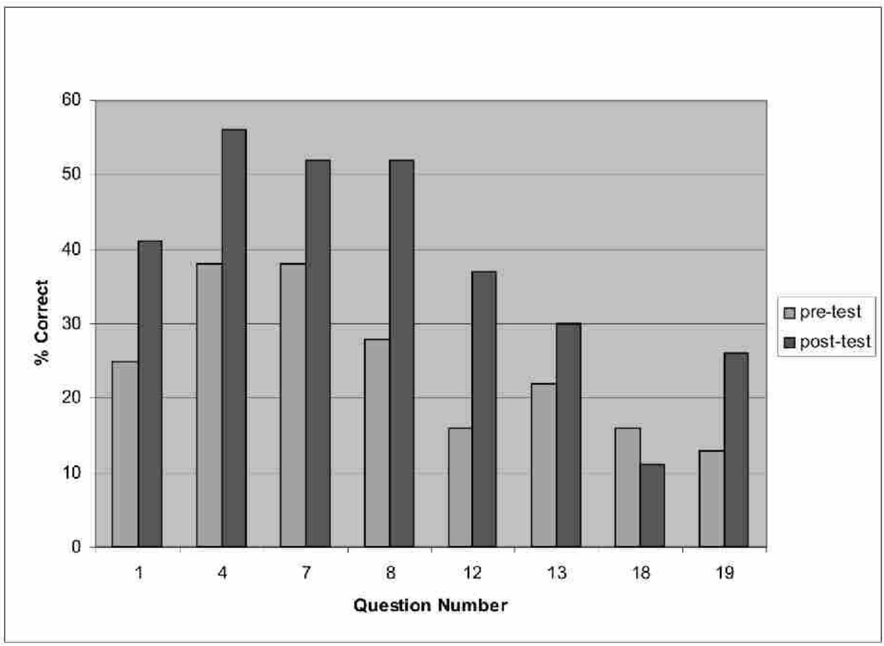

Figure 4: Conservation of matter: graph of % correct responses for questions related to the conservation of matter for pre- and post-tests in the current study

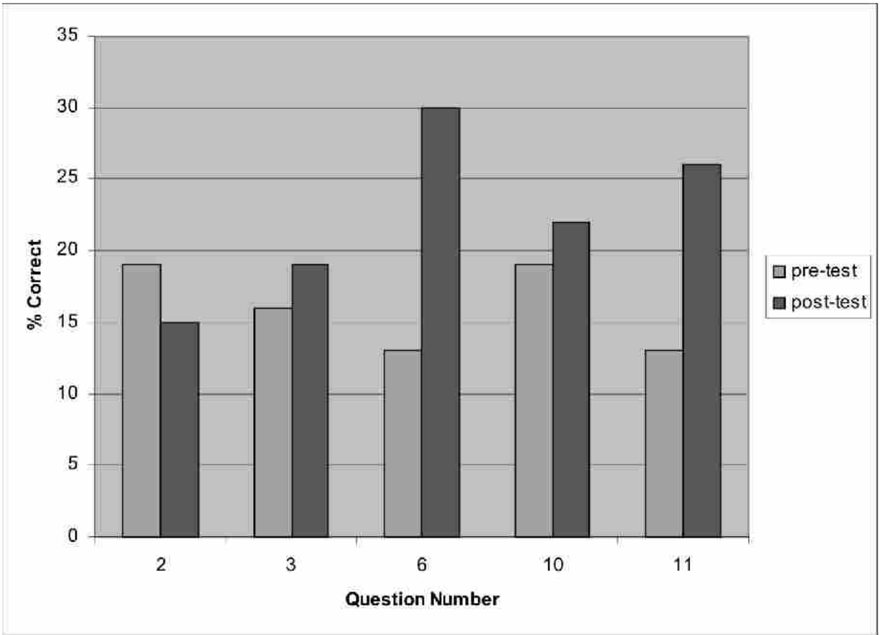

Figure 5: Physical change and phase change: graph of % correct responses for questions related to physical change for pre- and post-tests in the current study

The average percentage improvement in concepts related to physical change was 6.4% while those concepts related to conservation of matter showed an overall improvement of 13.9% (Figure 4). Although there was some measure of improvement, the level of understanding of these fundamental principles remains unsatisfactory since this is knowledge which is expected to be in place at the commencement of tertiary studies. Students who have successfully completed their final high school exams with mathematics and physical science as subjects are expected to know that the H_2O molecule remains exactly the same whether in the form of liquid water, solid ice or water vapour. This understanding should have been embedded during the primary school years. Differences between chemical and physical change are addressed in high school. The students tested during this study had great difficulty when substances were present in the gas phase. They did not accept that matter is conserved when a gas forms, since their answers indicate that the same amount of substance, when present as a gas, will have less mass. This was particularly evident in question 12, where a sealed tube of solid iodine was heated until all the iodine had vaporised. In addition, when reaction products are in the gaseous phase, the majority of students indicated that matter is not conserved but some of it is destroyed.

The majority of these students have an elementary understanding of matter in the gaseous phase, accepting that oxygen, hydrogen or nitrogen are gases since they have learned and experienced that these substances exist at room temperature in gaseous form.

5. INVESTIGATING STUDENTS' ATTITUDES

5.1 The structured questionnaire

Since this intervention was designed to be used as part of the Chemistry 1 course from January 2008, a further purpose of the study was to establish the students' opinions towards the computer-assisted lesson presentation. The PowerPoint presentation was made available to students in compact disc (CD) format with additional internet links and quizzes designed to stimulate further self-study. A semi-structured questionnaire was used in order to assess the acceptance and attitudes of students towards this teaching approach.

5.2 Results of student questionnaire

Both the PowerPoint presentation and the CD were peer assessed and modified before presentation to the students. After the presentation and time to view the CD, the students completed an assessment questionnaire. The logical sequence of the PowerPoint presentation was rated as excellent by 27% and as good by 50% of the group, and for the CD, only 13% scored it as average. Most students found the content interesting and confirmed that they were kept attentive. The majority of students believed that the intervention covered work they already knew, yet over 80% still indicated that it would assist in preparing for Chemistry 1. The second part of the questionnaire was more structured. When asked what section of the material presented was most useful, the examples explaining the conservation of matter ranked highest, with the difference between physical and chemical properties of matter and classification of substances closely behind and the difference between physical and chemical change being rated least useful. The concepts still reported as unclear were the conservation of matter during an explosion and inter-molecular forces. Most students were unable to view the additional internet links on the CD and overwhelmingly requested that the lecturer book sessions at the PC lab on campus in order to show the students exactly what was available and how to access it. The dates booked coincided with the commencement of strike action at TUT and had to be postponed. When lectures were interrupted for three weeks students understandably became more concerned about completing their course and lost interest in the CD. Only twenty of the thirty-two students who originally requested to view the CD with the lecturer eventually did so.

Questionnaire results from these students were all positive, indicating that 19 of the 20 found the additional internet links and lesson review valuable and will use the CD again; one student reported that only the internet links would be used again. Ten of the students indicated that being able to review the lesson was useful and eight found the molecular animations beneficial, while only two students expected the lecturer and textbook to be sufficient and did not believe computer support was needed. Five of the students indicated that they had a PC at home but only one of them had internet access; all remaining students had to make time to visit either the PC lab on campus or the internet café. The overwhelming response of students who made additional comments was that the PowerPoint presentation with added CD support was a very good idea and indicated that such a facility should be provided for the entire Chemistry 1 course as well as for other subjects.

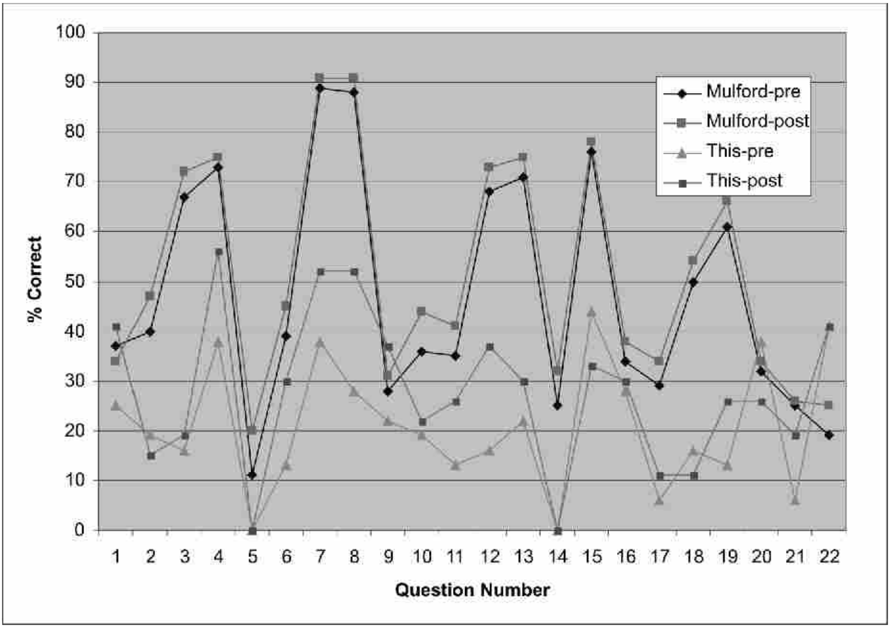

Figure 6: Comparison of the % of correct responses for pre- and post-tests for the current study and the study of Mulford and Robinson (2002)

6. DISCUSSION

It is clear from the results of the present study that fundamental misconceptions are held by the majority of students in the Chemistry 1 course at TUT even after they had completed a six-month Foundation Chemistry course presented using traditional methods. Most TUT students come from disadvantaged sectors of South African society with under-resourced schools and poorly qualified teachers.

The results of the present study for misconceptions regarding the phases of matter are similar to those reported by Potgieter, Davidowitz and Mathabatha (2007) for students from the University of Limpopo who draw their students from the same segment of South African society. Their pre-test performance on questions relating to phases of matter was found to be 23.1% and 20.1% for the mainstream and Foundation student cohorts respectively compared to 15 % in the current study.

The computer-based intervention was effective in resolving some of the misconceptions held by the students in the current study, but some of the most basic misconceptions were still retained. In comparison, the study of Potgieter Davidowitz and Mathabatha (2007) found that in a post-test the Foundation students of the University of Limpopo had improved their score on questions relating to phases of matter by only 9% to 29.8% after a year-long programme of quality instruction compared to the TUT sample group who showed an average improvement of 6.4% to 22% after the intervention.

The current study confirmed that misconceptions of phase change represent deeply embedded learning, which is evidently highly resistant to change. Several researchers in the field have found that misconceptions of fundamental principles are difficult to overcome. Fetherstonhaugh and Treagust (1992) found that many students' conceptions regarding light and its properties were not scientifically acceptable and were extremely difficult to change by means of regular instruction methods. It is possible that such misconceptions are caused by instructors' oversimplification of ideas when topics are first introduced. These explanations, which are intended to help students at a very basic level, are what they tend to remember, and they fail to retain the more correct and explicit reasoning which is introduced later (Bodner, 1991). This finding was reinforced in a study considering the alternate conceptions of Zambian High School learners, where it was contended that deep-seated incorrect understanding may be a result of over-simplistic explanations by primary school teachers, parents or the community (Imenda, 2005).

Other researchers (Gabel & Bunce, 1994; Brosnan & Reynolds, 2007) contend that students who demonstrate incomplete understanding of fundamental concepts and rely on memorisation of both facts and examples illustrated during contact lecture hours are usually the ones who fail Chemistry in their first year of study. However, students more capable of retaining memorised knowledge can pass through the system without ever fully understanding these fundamental concepts since assessment of their understanding is never formally completed but merely assumed. In order to illustrate this, Bodner (1991) found that 20% of Chemistry graduates failed to understand that the bubbles in boiling water were actually water vapour, the gas phase of water. Misconception of the fundamental concept of physical change, which emphasises that no bonds between molecules are broken or rearranged, is retained, and such students are still able to graduate.

The students in the current experimental group did not report any lack of understanding of physical change and indicated that the examples illustrating the difference between physical and chemical changes represented the least useful information presented. These students, in fact, had no idea that their understanding of this concept was incorrect. This particular problem has been found to be common to students from previously disadvantaged communities (Potgieter, Davidowitz & Mathabatha, 2007), who demonstrated an unwarranted confidence in their ability and a lack of discernment of the complexity of questions posed to them.

7. CONCLUSION

It is evident from the results and findings of this research project that the majority of students entering the Foundation Chemistry programme at TUT have serious deep-seated misconceptions of fundamental chemical concepts that, if left unattended, will cause many of them to fail Chemistry. The computer-based intervention which was implemented resulted in an improvement in the understanding of the concepts addressed, but a significant number of students retained their misconceptions. In order to improve the pass rate, more attention must be given to teaching methodology since conventional methods alone have shown little success and student misconceptions are highly resistant to change even when targeted with computer-based interventions.

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