Overcoming Conceptual Difficulties in First-year Chemistry Students by Applying Concrete Teaching Tools

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Received 6 April 2011, Accepted 3 June 2011.

Submitted by invitation to celebrate 2011 the 'International Year of Chemistry'.

ABSTRACT

Students entering university to study chemistry have difficulty understanding the concepts involved when attention is focused at the particulate level of matter. No-one can actually see what happens to individual molecules or atoms during any process of change and most means of explanation at the visible, or macro level are inadequate when describing behaviour at the particulate, or micro level. Structured worksheets and coloured Lego® building blocks were employed in order to facilitate understanding of the physical changes that water undergoes during changes of temperature. A sample size of 154 Foundation Programme students was used and the responses of these students investigated. A constructivist approach, enabling students to apply concrete reasoning in building their own knowledge, was evaluated. Students worked with interlocking building blocks to improve their understanding of molecular structure and behaviour. The students' academic performance improved when using these more concrete tools. This demonstrates that teaching is more effective when allowing visual and tactile senses to interact. It is therefore the purpose of this paper to substantiate the use of concrete tools, such as Lego® blocks, to help explain difficult concepts in chemistry, such as the behaviour of atoms and molecules.

KEYWORDS

Chemical bonds, Lego® building blocks, concrete reasoning, first-year chemistry students.

1. Introduction

Past imbalances in the South African education system have perpetuated a system of poorly resourced schools and inadequately skilled teachers, particularly in the fields of mathematics and science.[1,2] Mary Metcalfe, former Director-General of Higher Education, believes that the education system in South Africa is still not meeting the educational needs of the country.[3] This situation results in many students entering university with an inadequate knowledge of the fundamental principles which underpin the study of chemistry. Students who fail subjects, or who drop out of university during their first year of study, are a problem for universities all over the world.[4] Less than 50 % of first-year students at Tshwane University of Technology (TUT) pass Chemistry I at their first attempt. The university senate has identified the subject as a cause for concern since such low pass rates for a fundamental subject adversely affect throughput rate and cause loss of subsidy. In addition, most university programmes have restrictions on the number of students who can be accommodated and when students remain in the system too long, other eager and competent school leavers are denied access because the programme they have applied for is full. The development of a suitable means of intervention to improve the situation is then vital.

The South African education system has undergone several changes in recent years, including a paradigm shift from a curriculum driven system to an outcomes-based approach.[5] These changes have worked well at a number of schools, but the outcomes-based approach is more demanding on resources and many schools have experienced difficulty in this area[6]. As a result of the many difficulties experienced, the Department of Education is currently revising the outcomes-based approach and is phasing in a modified version, labelled 'new curriculum schooling 2025'.[7] Unfortunately, inadequate school systems result in poorly prepared students entering university and special programmes have been introduced to ensure that such students achieve success. Some universities have started extended programmes which allow students to complete the first year of study over a two-year period while others, such as TUT (at the time of this research), have used a Foundation Programme, which allows six months' preparation before starting first-year subjects. This preparation programme typically includes classes in communication skills and academic writing skills as well as mathematics, physics and chemistry classes.[8,9] A Foundation Programme offers the opportunity of ensuring that basic skills and knowledge are firmly embedded before the student starts the first-year programme.

A number of factors interact and influence the ability of students to acquire the skills and knowledge needed to complete the programme successfully. During a pilot study conducted in 2007, pre- and post-testing, following a computer-assisted intervention, revealed that the level of improvement in the area of understanding the conservation of matter, during both physical and chemical changes, was particularly poor.[10] Since this is such a fundamental principle, worksheets incorporating tactile models were developed and applied in an attempt to address this aspect more thoroughly.[11] In response to the success of this approach during the pilot study, the aim of the research on which this article is based, is to show that students, who cannot envisage what occurs at the molecular level of matter during processes such as phase changes of water, will understand more easily if allowed to start at the concrete level using tactile models. The success achieved by using these blocks to convince students that the molecules remain intact during all the phase changes of

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water, will be discussed. The tactile intervention incorporated worksheets combined with coloured Lego® building blocks. One block was used to represent a single atom; black blocks represented hydrogen atoms and white blocks symbolized oxygen atoms. The physical separating and joining of blocks was used to represent how atoms of hydrogen and oxygen are bonded in the water molecule.

2. Framework of the Study

2.1. Research Questions

- What is the effect of using coloured Lego® building blocks when explaining physical change processes such as the phase changes of water?
- Does this educational tool enhance students' understanding of the chemical (or intra-molecular) bonds between hydrogen and oxygen in the water molecule?
- What were the student's views regarding the use of Lego® blocks?

2.2.Theoretical Framework

This research project is underpinned by a constructivist framework intended to investigate ways to improve the fundamental knowledge of a student by using a conceptual change approach. The driving force for change relies on tactile, concrete, models rather than comparatively abstract graphical representations to explain molecular behaviour during physical change.

2.3. Conceptual Framework

Many abstract phenomena must be visualized and reckoned with when learning about science. The danger is that initial instruction, which occurs during the primary and high school years, may be over-simplified, to the extent that underlying fundamental principles are neglected. This over-simplification may significantly contribute to the difficulty students experience when trying to connect what is taught in the first-year university class with their existing knowledge.[12] As a result, the same chemical concepts identified as problems in the 1970s, still remain a hurdle to students in 2011, This, by extension, leads to the supposition that the high drop-out rate of first-year entry level students at tertiary institutions may be directly related to the manner in which they construct knowledge.[12,13] This problem is not unique to universities in South Africa or to TUT in particular.[14,15] A number of factors interact with and influence the ability of students to acquire the skills and knowledge needed to complete the programme successfully. An individual's previous experience and environmental background will influence how knowledge is interpreted and determine whether it is retained at all. Should the information contradict, or not fit in with, existing information, misconceptions may arise and the new information may be rejected until a link can be found to the new knowledge.[12,16,17] Several researchers have found that many students, unable to connect their existing knowledge with what is presented at university, often resort to memorizing formulas. This approach serves to answer questions and solve problems, but does not ensure adequate knowledge, or understanding, of the fundamental underlying concepts involved.[18] No-one knows precisely what happens at the particulate level of matter, since it cannot be seen. It is therefore hardly surprising that many students experience difficulty with the abstract concepts used to describe the way in which particles of matter interact during physical change processes. Graphic computer animations also proved insufficient to provide a convincing argument. The use of concrete models to facilitate understanding is supported by the work of the famous Swiss psychologist Jean Piagét (1896–1980) who described human cognitive development in four stages.[19,20] He described the first stage as *sensory-motor* and this is evident from birth to approximately two years of age. The second stage is *pre-operational* and this is apparent until about seven years of age. The *concrete level* (third stage) is evident from this point until the *formal operations level* (fourth stage) develops during adolescence. This last stage marks the point of full maturity when concrete objects are no longer required in order to make rational judgements. Piagét maintained that when the concrete level of understanding is not fully established students will be unable to manage more abstract representations. This is then a possible motivation to start intervention at a more concrete level for reinforcement. In addition, Johnstone, in a more recent publication, concurs with Piagét in emphasizing the need to build concepts from the macroscopic, tangible, level while gradually enriching with submicroscopic and representational aspects.[12] With the work of both Piaget and Johnstone in mind, the researcher believed that by incorporating more tactile, concrete models, such as Lego® blocks, before proceeding to abstract representations, students may improve their understanding of molecular behaviour.

2.4. The Framework of the Tactile Intervention

Although many teachers and researchers have used worksheets in the classroom, the international trend is to rather use computer-assisted methods, which allow more explicit three-dimensional interactive animations to be used.[21] The proposed model, which follows in Fig. 1, serves to summarize the manner in which Lego® blocks were used as tactile tools and the strategies involved in order to achieve correct understanding. The tactile intervention described in this article refers to the innovative application of Lego® blocks and worksheets to improve students' understanding of molecular behaviour. This intervention was only applied to the experimental group, E1. Although no chemical bonds are broken during any process of physical change, a clear explanation was important since initial, pre-tuition test results indicated that many students believed that water becomes hydrogen gas and oxygen gas in the vapour stage. The model was used as a starting point for solving, not only the problems experienced with phase changes in water, but also for application to many of the problems first-year entry-level students encounter when learning about atoms and molecules and their interactions. It is therefore relevant to all first-year chemistry students irrespective of whether they enter a Foundation Programme, an Extended Programme or the (mainstream) Chemistry Programme.

Figure 1 summarizes the way in which the Lego® blocks and worksheets were used. Initially students were required only to select what they believed to be the correct answer to a multiple choice question. The facilitator, using the Lego® blocks, then explained the question to the students. It was important to ensure that students knew how the blocks could be joined together to represent individual water molecules which have chemical bonds between each hydrogen atom and the oxygen atom. When the blocks were separated, this meant that no bonds existed between them, and they then represented single atoms. The inter-molecular attraction of hydrogen bonds was not described in this model. In the third step, while the students were working on their own, facilitators tried to ensure that students were able to use the blocks correctly. Some students were observed joining all the blocks together, which was incorrect, and they were then shown that this represented an individual H_4O_2 molecule and not two individual H_2O molecules.

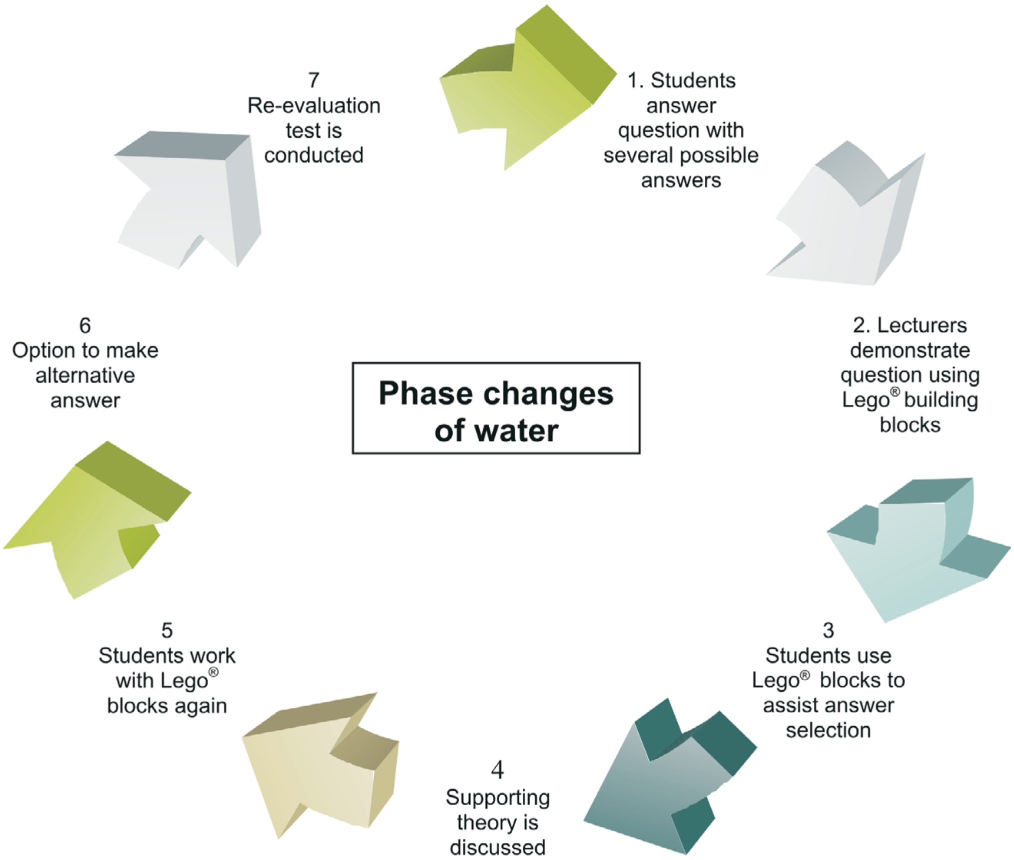

Figure 1 The tactile intervention framework showing how the worksheet questions were used with inter-locking Lego® building blocks.

After discussion of the supporting theory, included in the worksheets, students used the blocks to answer the question again. Students were then allowed to change their original answer if they wished in the space provided for an alternative answer. To confirm that the students really understood the principles involved during the phase changes of water, a re-evaluation was conducted.

3. Research Methodology

3.1. The Sample Population

The current study investigated students registered for the subject Foundation Chemistry at TUT for the first semester of 2008. Two groups of students are normally admitted to the university each year, Chemistry 1A Foundation and Chemistry 1B Foundation but for the 2008 academic year the Chemistry 1A group was further divided, forming three groups in total. It was expected that the groups would be equivalent since all students fulfilled the same entrance requirements for admission to the Foundation Programme, but since each group had a different lecturer it was important to establish initial equivalence by means of *t*-tests conducted before commencement of studies. The *a posteriori* hypothesis relating to this comparison is stated as follows:

H_O: There is no statistically significant difference in the performance of E1 and C1 students upon initial testing.

The equivalence *t*-test results for the two groups of students used in this comparative study, E1 ($n = 48$) and C1 ($n = 106$), are listed in Table 1.

The findings in Table 1 indicate a calculated (t_0) value of 1.947 that is only slightly smaller than the critical (t_{crit}) value of 1.976. This indicates that the two sets of results are not significantly different at the 95 % confidence level (the actual confidence level is 94.66 %). The null hypothesis is, therefore, accepted and for the purpose of this study, the two groups E1 and C1 were considered to be statistically equivalent at the beginning of the semester prior to commencement of formal tuition.

Table 1 *t*-Test comparison between E1 and C1 on the initial test.

Comparison	Standard deviation	Mean	d.f.	t_0	t_{crit}
E1	2.060	4.27	152	1.947	1.976*
C1	2.280	5.02			

* $P < 0.05$.

The Lego® blocks and worksheets were used with the experimental group (E1) $n = 48$. The remaining two groups were combined ($n = 106$) and used as a comparison group, C1. All of these students had completed three years of high school chemistry incorporated as a component of the subject Physical Science. Although they passed the subject at Grade 12 level, the grades achieved were insufficient to allow admission to the mainstream Chemistry Programme, and these students were required to pass the six-month Foundation Chemistry Programme before being admitted to the Chemistry Programme. The conceptual understanding of these students was assessed using a concepts inventory developed by Mulford and Robinson.[22] After discussing the results of this initial pre-tuition test amongst the first-year chemistry lecturers, it was decided, by unanimous decision of all involved lecturers, to focus the initial intervention techniques at the most fundamental problems.

3.2. Research Design

This study employed a quasi-experimental design using pre- and post-testing of a control and experimental group of students.

Emphasis was on quantitative analysis although there was a qualitative contribution to the study since all first-year chemistry lecturers were involved in deciding where to start the intervention and some comments made by students in the experimental group after the intervention are included in the discussion. Quantitatively, this study can be seen as employing an experimental design but it was also a descriptive study. Qualitatively speaking, this was a one-entity case study.[23]

3.3. Data Collection

The study made use of a concepts inventory[22] to evaluate students both before and after formal lectures. The tactile intervention incorporating Lego® blocks as models was designed keeping the students' initial results in mind. Not all of the concepts addressed in the standardized test of 22 questions were dealt with during the current intervention. Thirteen questions were regarded most fundamental and were focussed on explicitly during this and earlier interventions. Six of these were directed at conservation of matter during chemical change, and thus not relevant to the current study. Only seven questions were focused at phase changes of matter, with three of the questions related specifically to phase changes of water.

After comparing students' answers to the questions concerning phase changes of matter both before and after the topic was presented in formal lectures, the level of improvement was disappointing. Structured worksheets incorporating Lego® blocks as tactile models were then developed as an additional tool.[11,24] This tool, the tactile intervention, was administered after completion of formal tuition concerning phase changes as a further attempt to remediate misconceptions in the basic science knowledge of the students. The accompanying worksheets were based on an adaptation of the concepts inventory using only two questions, but explaining and expanding in detail. These questions had been used for testing both before and after phase changes had been addressed during the course of tuition. The questions were then re-worded and presented in a different style. The questions used in the worksheets were: 'What is in the bubbles of boiling water?' and 'Do the particles/molecules in liquid and evaporated water appear the same and retain their integrity?' It was not believed to be a problem to merely re-phrase the same questions since the student response to both had been poor and little difference was observed after formal tuition. The tactile intervention incorporated worksheets used together with Lego® blocks, which the students could use to help them envisage the actual breaking and reforming of chemical bonds between atoms. It was hoped that by starting with concrete (tactile) tools the concepts would be more readily understood. Allowing students to approach the problem in this way stimulated the tactile sensory organ and allowed poor performers to catch up. Although this is undoubtedly not the only way, or even the best way, to solve the problem, it nevertheless allowed students who struggled with abstract reasoning to grasp the concepts better. By starting at the concrete level, a bridge linking abstract reasoning, theory and active experimentation, as described by Kolb's experiential learning cycle, allowed students to make full use of their own preferred learning style.[25] The students were assessed again, using a re-evaluation test, the post-test, after completing the tactile intervention. The questions applied in this test, to assess the level of success, were similar, but not identical to those used in the concepts inventory.[22] To assess the merits of using Lego® blocks to explain the phase changes of water, the test results obtained before and after the tactile intervention were compared as pre-and post-tests, respectively.

3.4. Justification of the Study

The initial test results of the sample group, before commencement of studies indicate that these students share the same misconceptions as those identified by other researchers in the field.[22,26] These are misconceptions of the difference between the changes which occur during physical changes and chemical reactions as well as confusion between the concepts of mass and density, especially when components are in the gaseous phase. The average level of understanding measured at the beginning of the semester for the concepts pertaining to phase changes, such as 'What is in the bubbles of boiling water?' was 13 % for the experimental group, E1, and 14 % for the comparison group, C1. After completion of formal tuition concerning this topic, the overall average percentage score for all questions related to phase changes of matter remained below 25 %.

4. Results

4.1. Initial Testing

The overall average percentage score for questions related to phase changes of matter after presentation of formal lectures remained below 25 %. Although an improvement from the initial scores of 13 % to 22 % and 16 % to 22 % for groups E1 and C1 respectively, could be regarded as significant, a score of 25 % for multiple choice questions is at the level of a random guess.

4.2. Improvement After Applying Tactile Intervention

According to the tactile intervention framework in Fig. 1, a question with several possible answers was initially presented to the students. Following that, the question and possible answers were demonstrated with building blocks and the students were then able to work with the blocks themselves. An initial answer was selected and then the accompanying theory was discussed with the students, with lecturers facilitating at a ratio of eight students to one lecturer. Final answers for two questions were recorded and the completed sheets were handed in. This was done for the E1 group only. Question 1 required the students to correctly identify a water molecule in the vapour state as being the same as in the liquid state and not diatomic hydrogen or oxygen gas. Question 2 was taken directly from the conceptual test bank[22] and required students to identify what was contained in bubbles of boiling water. The following day, a short four-question multiple-choice test, post-test, was completed by both E1 and C1 students in order to determine the effectiveness of the intervention. Two of the questions from this test are included in Table 3 of this paper. Results of the post-test questions were compared with the test results recorded after completion of formal tuition concerning phase change, but before application of the tactile intervention, referred to as the pre-test results. It was possible to do this because the same questions were used throughout the study. The percentage of correct answers for the E1 student group increased from 29 % to 42 % for the question 'Where do the droplets which form on the outside of a cold glass of water come from?' C1 students, who only wrote the test and were not exposed to the tactile intervention, achieved 17 % compared to 16 % on the pre-test for the same question. For the question 'What is in the bubbles of boiling water?' the percentage of E1 students identifying the correct answer rose from 29 % to 61 %. There was virtually no difference in the percentage of C1 students who could answer this question correctly, their score remained just below 30 %.

Lecturers and facilitators noted some of the general comments made by the students during discussions while the intervention was applied. None of the students are identified and the comments

Table 2 Comments that reflect the way in which students experienced the intervention.

Student	Comment
1	I really like this work – I understand for the first time. Can I use these blocks in the exam? *Many students expressed this attitude towards the blocks*
2	This takes my extra time – why don't lecturers do their work when we have class? *This student failed to understand that this was additional assistance and not expected of their lecturers*
3	I have 2 molecules of water – in ice they are together then they break apart. *This student showed H_4O_2 then separated to 2, H_2O*
4	Molecules moving from liquid to vapour don't split up, they move apart *This student also showed us a 'mega molecule'*
5	Water vapour has more energy so the molecules escape but still look the same. *This student built the molecule correctly retaining integrity of the bonds when in the vapour state*
6	Water vapour is oxygen and hydrogen *This student demonstrated with the blocks but actually formed separate atoms*
7	My maths and chemistry were always good at school, I know water vapour goes back to water – it's just like smoke – the molecules in smoke separate too *This student had separated the molecule into atoms and backed up the statement by re-building the molecule for the liquid phase*
8	This is fine I know about water and ice and vapour – just don't ask me that question about the drops on the outside of the glass *This student was uncooperative and refused to use the building blocks*
9	I don't like the question about the drops on the outside of the glass – stop asking that question. *Several students reacted in similar vein on overhearing what the student had said*
10	Why do we need to know this? Is it going to be asked in the exam? *Unfortunately many students are only interested in the exam and do not want to study everything but only specific questions they expect to be asked during examination*

were not recorded but were discussed amongst the lecturers and facilitators while the results were being analysed before the assessment was conducted. These comments, although not verbatim, reflect the general feelings expressed amongst the E1 student group and are recorded in Table 2.

Two of the four questions used in the post-test, together with the scores for each group, recorded as percentages, are included in Table 3. From the left, results for E1 are in the first column and C1 in the second. The correct option is italicized. A summary of students' progress is included at the end of each question.

The post-test administered after completion of the tactile intervention of worksheets with Lego® blocks recorded a greater improvement in understanding; E1 achieved an average of 53 %, while C1, to whom the intervention was not applied, only completed the post-test and achieved an average mark of 29 %. The tactile intervention designed and developed for this study addressed only the most fundamental concepts of phase change in water.

4.3. Comparison with Other Local Studies

The results obtained with the students investigated during this study, which concern the basic concepts of phase change in water, fall far below the results recorded by Mulford and Robinson.[22] It is therefore suitable at this point to offer some comparison of results to similar conceptual questions obtained by another local university. This is included because local universities all draw their students from the same pool and it is reasonable to expect that similar problems will be encountered. In other words, the students are all from similar high school backgrounds and in general achieve much lower scores than expected of first-year entry-level students. Researchers at the University of Pretoria (UP) developed a test instrument, similar to Mulford's concepts inventory,[22] which was used in this study, in order to investigate the basic understanding of chemistry concepts held by third-term final-year high school learners. A further extension of this study compared these results with those obtained after students had completed an Extended Chemistry Programme at UP. Their results confirm that the high school learners from all groups investigated in the study displayed a weak understanding of all basic chemistry concepts at the molecular level. This includes the concepts involved during phase changes in water.[26]

5. Discussion

It is relevant at this point to discuss some of the results recorded in Table 3 and link them to comments recorded in Table 2. The first of the two questions investigated the condensation of water vapour from the air onto a cold surface. Many of the E1 students commented on this question during the discussions while working through the intervention. Those who did comment were not happy about the question since it seemed to confuse them. There was no opportunity to discuss this question with the C1 group of students and 43 % of them believed water from inside the glass of cold beverage must have formed the droplets on the outside of the glass. Only 12 % of the E1 students gave this answer, but they had been able to discuss it – unfortunately 37 % of them still understood and answered that hydrogen and oxygen from the air re-combined to form the droplets. In the second question a disturbing 37 % of C1 students and 21 % of E1 students believed that bubbles of boiling water consist of oxygen and hydrogen gas. Furthermore, 28 % of C1 students indicated that the bubbles would contain oxygen gas.

In using the same questions, just slightly re-phrased, it was easy to track the progress students made with the targeted concepts. The only meaningful difference occurred when one of the student cohorts was given the opportunity to start at the concrete level to facilitate understanding of fundamental concepts. When these students were able to incorporate their tactile senses and use the worksheets together with Lego® blocks, there was a marked improvement in their understanding of the concepts addressed. In the case of the E1 group, the average for

Table 3 Two of the re-evaluation questions applied after application of the tactile intervention including a summary of progress.

1st Question:

E1	C1	**The ice cold glass of Coca-Cola you are drinking forms droplets of water on the outside of the glass. Where do these droplets come from?**
37	22	Oxygen and hydrogen from the air combine on the glass to form water
12	43	Water evaporates from the Coca-Cola and condenses on the outside of the glass
42	***17***	***Water vapour condenses from the air***
9	18	The glass acts as a semi-permeable membrane allowing only water through

Initial-test score	**Pre-test score**	**Post-test score**
C1 13 % correct	**C1 16** % correct	**C1 17** % correct
E1 14 % correct	**E1 16** % correct	**E1 42** % correct

2nd Question:

E1	C1	**When water has been boiling for longer than 30 minutes what is in the bubbles in the boiling water?**
9	6	Air
21	37	Oxygen gas and hydrogen gas
9	28	Oxygen
61	***29***	***Water vapour***

Initial test score	**Pre-test score**	**Post-test score**
C1 9 % correct	**C1 27** % correct	**C1 29** % correct
E1 10 % correct	**E1 27** % correct	**E1 61** % correct

questions related to phase changes of water was 23 % on pre-testing, and improved to 52 % on post-testing after the intervention. By comparison the C1 group remained at 23 % on average for both pre- and post-test assessment. It is evident from this comparative study that when students were allowed to work with tactile models and discuss what they were doing with lecturers and facilitators it enabled them to understand more clearly what happens during phase changes in water.

First-year chemistry students can be helped to overcome much of their incomplete understanding by using a more tactile, 'hands-on' approach. Lego® blocks are simply one tool that was applied successfully during this study. The completion of some questions in a practical laboratory will no doubt serve the same purpose. It would not be difficult to boil water in the laboratory and collect the vapour in order to demonstrate that the bubbles, when rising to the surface and becoming vapour if collected and condensed, are in fact still water. The same is true for a beaker of cold fluid such as water and ice; the droplets that form on the outside can be shown to be water as well. Students should also be challenged when their response suggests the liquid inside the glass could have evaporated and then condensed on the outside since such process is highly unlikely in the absence of heat energy. When students are allowed to see and experience this for themselves the knowledge can be applied effectively as a means for overcoming their apparent misconceptions.

6. Conclusion

The results of the current study indicate that only 29 % of first-year Foundation Chemistry students can demonstrate a clear understanding that chemical bonds are not broken during physical change processes such as those involved during the phase changes of water. When one group of these students was allowed to reinforce their learning by using coloured Lego® building blocks, their comprehension of these questions increased to 61 %. It is then reasonable to assume that this tool enhances students' understanding of the chemical (intra-molecular) bonds between atoms of hydrogen and oxygen in the water molecule. Students made only positive comments regarding the use of the Lego® blocks.

It is uncertain why the first-year students taking part in this study have such poor comprehension of fundamental chemical principles, or why they are reluctant to do any additional work in their own time. The transition from high school to university is not easy and students must learn to balance their social activities with their studies. Lecturers at university expect students to attend classes regularly, and spend some time doing additional work independently, yet from some of the student responses it seems there is an expectation that the lecturer be responsible for all learning. It is discouraging when students do not attend all classes, but it remains important to intervene and remediate in order to ensure that all students are enabled to complete their studies successfully. Similar intervention projects have been applied to other sections of first-year chemistry, particularly to the concepts involved with reaction stoichiometry and limiting reagents, which have been identified as a problem.[27] It is recommended that more basic experimental work be done in the laboratory since when starting from a level where students can see, feel and experience science it is reasonable to assume the concepts will be more clearly grasped. This assumption is based on the order of learning proposed by Bloom and on the more recent work of Johnstone[12] where a more tactile level is emphasized as crucial to understanding more abstract concepts of chemistry. Phase changes in water can be safely and easily carried out and many of the problems relating to conservation of matter can first be completed by allowing the students to do the experiments themselves. A simple example is the addition of a solid salt to water. Students can experience that, although the salt dissolves in the water, the mass is not lost; but adds to that of the water. Use of physical models, such as the Lego® blocks is recommended, and students should then be encouraged to use simple sketches to represent what the blocks helped them to visualize. In this way, the students can develop their own learning and can apply the skills to other parts of the programme.

It is the firm belief of this author that by starting with tactile models and 'hands on' practical experiments first-year chemistry students will improve their understanding of fundamental chemical concepts, which will facilitate the successful completion of their studies. Although lecturers do address conceptual understanding during both lecture presentation and discussion, this is not formally assessed as such, which means that when students fail to master a section of the work no further investigation is made and the matter is closed. It is assumed that students will eventually understand more fully as they continue their studies in chemistry. The required outcome is to pass a written exam which is based on procedural knowledge; this means that some students may achieve the goal without necessarily understanding the fundamental chemistry concepts involved.

Acknowledgements

Dr Marietjie Potgieter (University of Pretoria) and Dr Thapelo Mamiala (North West University) are thanked for validating the suitability of the educational materials used during this study with regard to their use in the development of conceptual understanding of the fundamental concepts addressed.

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