Learning how much about gases using MBL?
A case study from a chemistry classroom

(Work in progress)

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Abstract

Chemistry learning with understanding is a challenge. From a social constructivist position we view students 'chemistry learning from experiments as involving the shared negotiation of meaning that uses experimental data to confirm or challenge their existing scientific theories. This study investigated teaching and learning practices related to the use of MBL in a high school chemistry laboratory where students were studying gases and kinetic theory. Given the widely accepted view that the use of such technology is a 'cure-all' for educational problems, the learning of students as a consequence of their use of this technology might be considered disappointing. We find that little or no higher order thinking was employed as students engaged in using the MBL and that some alternative conceptions remained unchallenged through its use. It is necessary to consider the positioning of the computer in the group and experimental context if the promise of the use of such technology is to be fulfilled.

Introduction

It is the start of another lesson in Anne's Year 11 chemistry class. Today the students are to continue with the topic of gases and kinetic theory. Previously they have used the computers to investigate the relationship between the pressure of a fixed amount of gas at constant temperature when the volume of the gas is changed. Anne begins. "OK. Today, remember we're going to do the experiment where we have a look at the relationship between pressure and temperature in a system where we're going to hold the volume of gas constant and the moles of gas we have constant. Remember that we have those 4 variables that are inter-related and experimentally we're going to have a look at trying to understand what the relationship is, and try to come up with a total understanding of how the whole four of them are related by just looking at two of them at a time. So the equipment that we're going to have is a little flask of gas like this (she holds the flask up for the class) that's going to be connected to a pressure sensor like we used with the syringe except the syringe won't be there anymore. This (the flask) will be connected. It will be connected to the computer. We'll also have the temperature probe that looks like this connected in so the computer will be measuring both the temperature and the pressure. If you have problems with the temperature probe we can always put in a thermometer so that if it does start playing up you've always got a back up for that one. You don't have any other way of measuring pressure other than this but they've been very reliable.

Now what we are going to have to do is get this flask and put it at various temperatures. So we're going to put it at room temperature and measure the pressure. And with it absolutely sealed we'll keep on putting different temperature water baths around it. So, having measured at room temperature, we're going to put an ice bath around it, then we're going to put hot water out of the tap around it which is normally around 60 degrees Celsius. And then we're going to put some almost boiling water, hopefully 80 or 90 degrees; we won't have it absolutely boiling but we'll have water from these hot plates. It's important to make sure that the seals on these things are really good. OK, so we're setting it up and trying to make it so the seals are really good so none of the air escapes as it changes temperature. What you have to do is, when you're moving it from one water bath to another, make sure that none of this (the seal of the flask) comes loose. OK? What we've got to try and do is have the water bath swap over as quickly as they can and still do the experiment properly. It takes, oh, sometimes three to five minutes depending on the temperature of all of this to settle down and the pressure to settle down. So, we can't swap over temperature baths as quickly as we could change the volume in the last experiment…it's going to take a little bit longer. But you have to sit there, put in the new water bath, wait for it to equilibrate, take the pressure, get onto the next water bath as quickly as you can…so the instructions [Appendix 1] that you have are for the computer…you can see that on the back of the sheet you have that there's a table for writing in the results, the pressure at four different temperatures, and there's a piece of graph paper there for graphing it…I'll set up the experiment (on the computers) and as soon as I have it going, we will get started on that." On the completion of Anne's instructions, and once she has opened the operating programme on the computer they are to use, Jason, John and Neil, move to the computer to begin the experiment.

The role of laboratories in high school chemistry learning

Learning chemistry with understanding is not an easy task. The literature (see, for example, Pfundt & Duit, 1994, Treagust, Duit, & Fraser, 1996) is strewn with examples of students' alternative conceptions in relation to the broad spectrum of chemistry concepts, including those relating to gases and kinetic theory which is the focus of this paper. The difficulties in learning chemistry relate to its own innate complexity and the need for each chemistry learner to make connections between different representations of matter and the changes and interactions relating to matter (Gabel, 1998). We concur with Gabel that a key element of learning chemistry is the need to consider chemical phenomenon at macroscopic, molecular and symbolic levels and that a further reason that learning chemistry is complex is because, even though observations focus on the macroscopic level, the explanations and theories which are integral to chemistry understanding are focused on the atomic and/or molecular levels which chemists use symbols to represent. We also suggest that it is necessary for students to consider their theories of chemistry, which consist of macroscopic, molecular and symbolic elements, and to use experimental data as evidence for supporting or challenging those theories. Science reasoning is characterised by the formulation of theories with consideration of the evidence that supports them and Glaser (1984) has proposed that the construction and revision of theories is at the heart of cognitive development. Such a position on chemistry learning is congruent with a social constructivist orientation as proposed by Milne and Taylor (1995), McRobbie and Tobin (1997) and Tobin (1993) which suggests that learning is strongly influenced by what the leaner already knows and that learners make sense of their experiences with reference to their existing conceptual structures (Tobin & Tippins, 1993). Therefore, students should engage in such theory-evidence coordination by acknowledging their theories and beliefs and being able to assess evidence independently of these theories and beliefs (Duschl, 1994; Kuhn, Amsel, & O'Loughlin, 1998). It is such reasoning skills that are necessary if students are to learn from laboratory investigations.

Chemistry, like other branches of science, has a strong experimental character. In many high schools this character is manifested in the provision of specialist chemistry laboratories, laboratory assistants, and apparatus and provisions specific for the teaching and learning of chemistry, often at considerable cost to schools. The necessity of conducting and providing for experimental work in high school chemistry laboratories is generally "taken for granted" within schools and the general community. The benefits of laboratory work are also mooted widely within the science education literature (Lunetta & Hofstein, 1982). However, several authors like Hodson (1990, 1992) have, more recently, questioned the "taken for granted" nature of laboratory work and have posed issues for consideration regarding the value of school science laboratories as effective learning environments. Roth, McRobbie, Lucas & Boutonné (1997) have highlighted the need to make detailed studies into what students do in traditional science laboratories. Further, Hodson (1990, p. 39) has argued that "until we focus more sharply on what children are actually doing in the laboratory, we are unlikely to have a definitive answer to our questions about the pedagogic value of laboratory work" and to be able to capitalise on the potential for learning in this important context. Such detailed studies are needed to lay bare and illuminate the practices of teachers and students so that we can better understand the nature of teaching and learning in laboratories. It is only through further increasing our understanding of what occurs in laboratories and how such events influence learning that a credible evaluation of the value of laboratories for students' learning of chemistry in high school can be proffered.

The potential of microcomputer based laboratories in high school chemistry learning

Microcomputers (PCs) have been shown to have considerable potential as learning and teaching tools in chemistry and other high school science laboratory activities (Nakhleh, 1994; Linn, 1998). One increasingly implemented application of microcomputers is microcomputer-based laboratory (MBL), often referred to as computerised data logging. MBL involves linking single or multiple sensors to a computer to enable the sensor's relayed single to be calibrated and viewed on the computer's screen in tabular and/or graphical form. The data can become available instantaneously as students perform an investigation. The potential of such technology to enhance learning is purported to lie in its usefulness in reducing delays in processing experimental data, in facilitating observation of phenomena via multiple representations, and in providing the possibility of simultaneous multiple measurements (Nachmias, 1989, cited in Lazarowitz & Tamir, 1994). Because such technical work is done by the computer, it is proposed that students have increased opportunities to employ higher order thinking strategies in problem solving and conceptual development (McCorduck, 1985), and that the real-time interaction with the data representations should aid in students' development of conceptual understanding. Such a proposed application of computer technology is compatible with broad contemporary goals of science education, which increasingly focus on providing students with opportunities to develop strategies of investigation, reflection and analysis, and to construct and/or refine their knowledge and theories. The development of higher-order reasoning encapsulated in such aims coupled with the goal of increasing students' conceptual understanding of the science they study are central to reform directions in science education (Bybee & DeBoer, 1994).

Coupled with the increased use of MBL in schools has been a corresponding increase in the science education literature in suggestions for its use in chemistry education (see for example; Soares & Creevy, 1995; Adamson, Zimmerman, & Nakhleh, 1997) and research into some aspects of students learning through the use of this technology (see, for example, Friedler, Nachmias, & Linn, 1990; Nakhleh & Krajcik, 1994). However, despite this increase in suggestions there has not been a corresponding increase in fine-grained research into the use of MBL or of the learning resulting from such use. Much of the literature on MBL use focuses on the technical applications of the technology rather than benefits to students' learning (Rogers & Wild, 1996). Such a lack of research is symptomatic of the general lack of studies that focus sharply on students' actions and discourse in science classrooms as previously noted. Few studies on the use of MBL have closely examined what students do and how the technology affects their learning. Nakhleh (1994) has suggested that research is needed into MBL use and resultant learning in naturalistic classroom contexts where the technology is used as an integral part of the curriculum. She suggested that we need to understand how MBL use influences student learning and knowledge construction, and the relationship students make (or don't make) between the MBL representations and the physical phenomenon represented.

In a forthcoming publication that draws on the same data pool (McRobbie & Thomas, in press) we reported on the Anne's influence on her students use of the MBL and provided an overview of the learning that occurred. We concluded that the learning of students in Anne's class as a result of the MBL use was minimal and reflected the classroom learning environment, which in turn was strongly influenced by Anne's deeply held beliefs about the nature of science and the level of thinking that should occur in her class's chemistry laboratory. Her objectivist epistemology resulted in her using MBL solely as a means of collecting data to confirm chemistry laws. The introduction to this paper provides a context for this paper by highlighting and confirming Anne's focus on the procedural matters of the experiment and the absence of guidance for students in making their theories explicit and using experimental data to confirm or revise those theories at the molecular level. While Amend *et al.* (1990) have suggested that understanding the gas laws is underpinned by graphical and mathematical analysis of gas law data we suggest, in accord with our previous assertions, that understanding gas laws should be further underpinned by understanding the behaviour of gases at a molecular level. In this paper we look more closely at the learning that took place in an experiment, the second of two that utilised MBL in this unit. We seek to further understand the students' actions, words and thinking as they used the MBL. Such a goal is consistent with our theoretical position on learning chemistry with understanding.

Design and Data Collection

In this study we adopted an interpretive methodology and sought to understand students interactions with the MBL, and the learning that resulted from such interactions, as "human social actions that are locally distinct and situationally contingent" (Erickson, 1998, p. 1155). Such an approach was congruent with our social constructivist position. Like Roth *et al* (1997) we suggest that students' reasoning is "observable in the form of socially structured and embodied activity" (p. 111). Further, as Kelly and Crawford (1996) suggest, the study of what students say reveals the role that the computer plays in the context of their group. Such considerations were important in the design and data collection of this study.

For a period of 5 weeks one of the authors visited the classroom daily to investigate the teaching and learning that took place. The classroom data for this study comes from one of the lessons in that five-week period. Such immersion in the research site was seen as essential to try to acknowledge any variations in teaching practice and student action that might occur, both using and not using the MBL in laboratory activities, and to build rapport with the teacher and students. In accordance with our above considerations in relation to students' reasoning, we videotaped the teacher, the students and their classroom activities with a view to using the videotapes and their transcriptions as reflections of students' thinking and sense making in relation to both the classroom events and their physical and social environment. Two video cameras, one at the front and one at the rear of the classroom were used. To ensure that we were able to capture students' utterances clearly amongst the clamour of the classroom, we used radio mikes that were worn by the students and teacher. To capture closely students' actions and words as they used the MBL we used technology that enabled us to record a real-time image of the computer screen as the students saw it and to superimpose on that image of the screen another video image of students' interactions with the computer, the associated experimental apparatus, the teacher and each other. Having such real time data meant that we could analyse students' actions as the experiment proceeded in terms of what they did, what they saw and what they said. We also used this split-screen video data for the purposes of stimulated recall interviews (O'Brien, 1993) with students. In these interviews we asked students to try and recall their thinking at various stages of the experiment and to comment on their awareness and interpretation of changes in the appearance of the screen as the experiment proceeded.

To establish the extent of students' conceptual understanding of gases and kinetic theory prior to and following the unit we used tests, pre- and post instruction, based on the alternative conceptions literature and test items that had been used in past research (drawn from those used by, for example, Brook, Biggs, & Bell, 1983; Hwang, 1995; Osborne & Cosgrove, 1983). The post-test contained items that were analogous to those of the pre-test. Further, the post test items attempted to relate closely to events occurring at the molecular level during the MBL experiment itself. Two analogous items that are salient to this study are shown as Appendices 2 and 3. We interviewed students on their responses to the test questions to try to understand the reasons for their answers.

The three students, Jon, Jason and Neil (pseudonyms) whose practice and learning is investigated in this study, are reflective of the learning of the other class members in relation to their use of the MBL. There was substantial homogeneity in relation to the practices and learning across the whole class of students, as evidenced by their discourse and their self-reports, during the MBL activities. Therefore we feel justified in providing a case study of results and analysis for these three students alone.

Results

We present our data related to students learning in several modes, each attempting to provide a different interpretive frame for understanding students' actions and learning. Firstly we present data from the pre- and post-tests that provides insights into students understanding of molecular aspects of the phenomenon they were investigating during the MBL experiment. Then an example of students' dialogue as they used the MBL apparatus is provided with our interpretation. Finally, we use an experimental map that seeks to represent the use of the MBL by these students. The experimental maps use a notation derived from Gooding (1992) and adapted by Roth et al (1997). A key for interpreting the notation is provided as Appendix D. Sequences of actions are represented by line segments with horizontal line segments representing actions that lead to new learning and vertical lines representing actions that lead to no new learning. Triangles represent goals and decisions. The outcomes of manipulations on the material world (seeing, recording) are shown as squares. Mental operations like, for example, imagining, describing, and comparing are denoted by circles. These means of presenting students' actions and learning are complementary and provide multiple interpretations of students' use of the MBL and the learning resulting from that use.

Comparison of pre- and post-test data

In Table 1 the students' responses to the pre- and post-test items that investigated aspects of their understanding in relation to the effect of changing the temperature on the distribution of gas particles when the temperature of the gas is changed are displayed. As well as providing insights into changes in gas particle distribution, their responses also provide insights into their individual understandings of particle theory and revisions of their theories over the course of the unit.

Table 1.
Comparison of students pre- and post-test responses for Question 3 on Pre-test (Appendix B) and Question 2 on Post-test (Appendix C).

Student	Response on Q.3	Reason given for response to Q. 3	Response on Q.2	Reason given for response to Q. 2
Jon	C	Because the particles are cooled; they contract and become more stable, i.e. the particles become closer	(a) D (b) D (c) D	(a) The particles always completely fill a container (b) The particles still completely fill the container, they just move slower at a lower temperature (c) The particles completely fill the flask but they just move quicker.
Jason	C	Particles may contract when the temperature becomes closer to the element's freezing point	(a) D (b) C (c) A	(a) Particles are evenly displaced because the pressure inside the container) is even to the pressure outside the container. (b) Particles contract together as a result of the colder temperature therefore the pressure is lower. (c) More pressure because particles have greater velocity because of temperature. They want to push out of the container.
Neil	D	It's still a gas so the particles are just slower.	(a) D (b) D (c) D	(a) Because the particles are floating freely at room temperature (b) Temperature affects the speed of the particles not their arrangement in gas form (c) Reason above (b).

Prior to the start of the unit Jon held and inappropriate alternative conception regarding the behaviour of gas when the temperature is cooled. However, by the end of the unit we suggest that this alternative conception had been addressed and that he now showed reasonable understanding of the behaviour of gas in relation to temperature changes. Neil seemed to start the unit with an understanding of the effect of temperature change on the behaviour of a gas that was congruent with canonical science. It is interesting to note his use of the word 'floating' in the post-test, as this suggests there may have been either some inappropriate conception of the behaviour of gases at a fundamental level or an inability to find the appropriate word to describe the nature of gases. However, we suggest that, on balance, Neil had a reasonable understanding of gases as investigated by these questions. The data for Jason, however, suggests that prior to the commencement of the unit he had alternative conceptions regarding the behaviour of gases and that such conception remained at the end of the unit despite his experiences in both the classroom and the laboratory. On the basis of this data we can say that these students came to the study of this unit with a range of conceptions on the effect of temperature on a gas and also concluded the unit with a range of conceptions.

Students' dialogue while using the MBL

The following dialogue is representative of the discourse that took place between the three students during their use of the MBL. It is from a section of the students' practical activity after they have taken their first reading at room temperature. Neil is sitting to the right of the computer screen and his task, decided with the other group members, is to read from the instruction sheet for the group. Jon is sitting in front of the computer and he has control of the mouse. Jason is sitting to the left of the screen and he has been charged with changing the water baths, making sure that the seal is intact, and keeping the flask submerged in the bath. All students have a good view of the screen.

Neil	(Reading from the instruction sheet) *Ok, next step is to change to ice bath.*
Jon	*Ok*
Anne	(Coming in from a preparation area) *Have I filled that* (the ice bath) *too full?* (Hands Jason a small handled brush) *Can you hold it down under the water* (of the ice bath) *using the brush Jason?* (Jason submerges the flask in the ice bath) *OK. Is there anything you need? Is that going to work OK? That* (pointing to a beaker on the shelf) *will be for your warm water when the time comes.* (Anne moves away from the area to talk with other students; The three students begin to look at a table on the bottom right hand side of the monitor where the changing temperature and pressure of the gas in the flask, [as it comes to a stable temperature] are being displayed)
Neil	*Click on 'Mon' to observe measurements. If it's stable, click on stop.*
Jon	*When stable click on stop*
Neil	*Yeah, when stable* (Students are looking at the fluctuations on the table)
Jon	*Decreasing, decreasing*
Jason	*The pressure's staying exactly the same*
Neil	*I don't think that it's going to get any more stable than that.*
Jon	*Yeh, it will. When it stops moving, that's when it's stable.*
Neil	*Yeh, the temperature's falling.*
Jon	*It'll take a while to stabilise* (8 seconds pass and students are stilling looking at the screen)
Jon	*It's going up.* (20 seconds pass and students are still looking at the screen)
Jason	*This is frustrating isn't it?*
Neil	*Wanna go away and leave this for a while.*
Jon	*Jason's got to hold the thing.* (35 seconds pass and students are looking around at the classroom and then back to the screen to check. The temperature and pressure are still fluctuating but only slightly)
Neil	*Should we just stop it there?*
Jon	*I don't think we can. It just says, "When stable click on stop."*
Jason	*Ask Dr Anne…frustrating.*

In this representative transcript we see evidence that students were concerned with only the procedural aspects of the MBL use. This was also the case in their use of the MBL in the previous experiment. There is nothing to suggest that there was any consideration, either individually or collectively, of what the data that was appearing in the table on the screen actually represented, why it might be changing second by second, or what might be occurring at a molecular level to cause such changes in the screen display. The long pauses between student talk at the end of the dialogue suggest that such considerations were not even a remote possibility as the students seemed to be set, despite their impatience and frustration with the time for the temperature to stabilise, on only collecting the data and recording it on their sheets. Anne’s input into their session at the computer does nothing to stimulate such consideration of factors by the students because, as previously noted, she was focused on ensuring that the experiment was performed properly and that the logistics were under control. Interestingly, no students made any comments on the appearance of points on a set of axes as they put the flask from one water bath to another. Such was their intense focus on the table where the temperature and pressure were displayed.

Experimental Map

Figure 1 shows a representation of the situated practices that were observed by the researchers during the class and interpreted from videotape of these students’ interactions in the experiment involving the MBL. Such a representation is congruent with the dialogue that students engaged in as they were using the MBL as reported previously. In this representation we see evidence of a clear pattern of action. The students set up the computer as per the instruction sheet. Then the students’ actions in relation to the MBL involved four cycles of placing the flask of gas in a water bath of a particular temperature, waiting for the temperature of the gas inside the flask to become constant, recording the temperature and pressure at that constant temperature. There are no horizontal lines indicating learning. The students were engaged in looking at the screen but did not make any comments in relation to what they saw apart from those comments relating to the procedural aspects of the experiment. The broken squares indicate possible observations that students may have made that were not discussed or commented on. This map shows that students were predominantly engaged only in data collection using the MBL and showed little evidence of relating the events and actions of the experiment to their existing conceptual understanding of changes to the gas in the flask that took place as the temperature was changed. Further, there was no interpretation of the experimental data by the students.

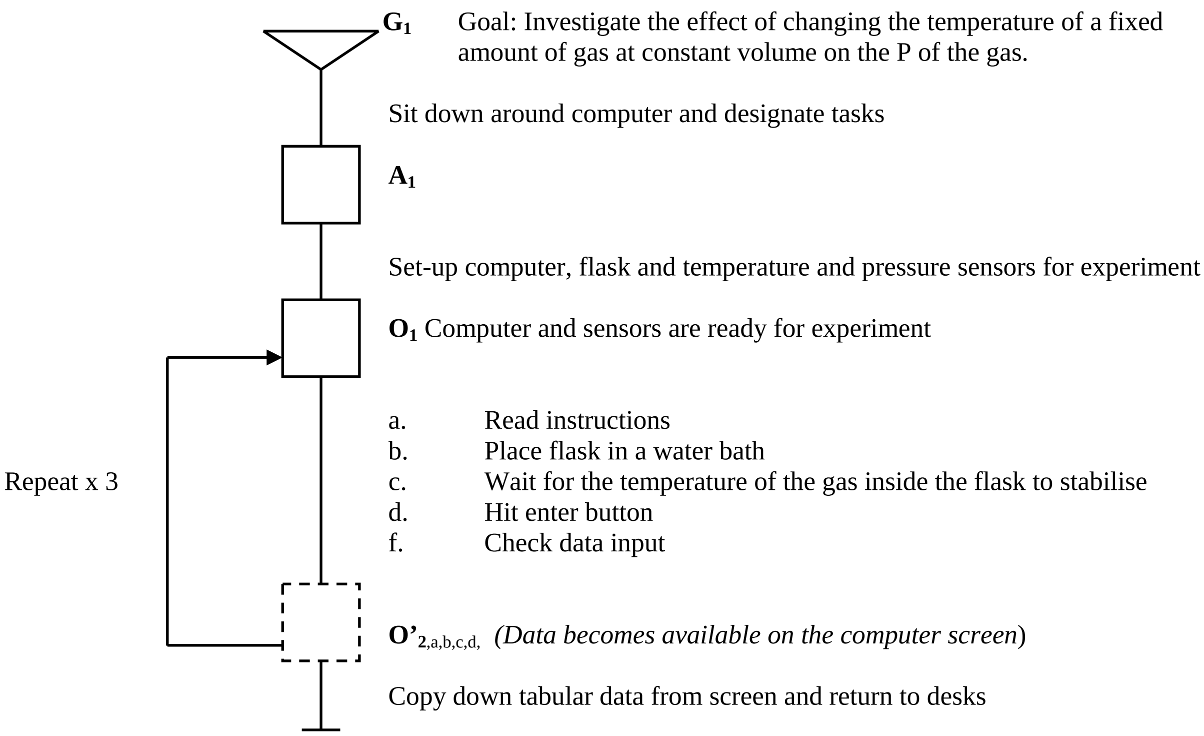

Figure 1. Map representing Jason, Jon and Neil’s investigation of the relationship between the pressure of a constant amount of gas and its volume. **O’**$_{\mathbf{2,a,b,c,d}}$ are possible observations that the students might have made but gave no indication of doing so during the experiment, discussions or interviews.

Discussion

On the basis of this review of a representative group's reasoning and learning via the use of MBL we suggest that the potential of the MBL for developing students' understanding was not fulfilled in this case. The three data representations provide multiple ways of interpreting the actions and learning of the students. Earlier we noted that chemistry teaching and learning should entail contemplation through social interaction between students of chemical phenomena and concepts at macroscopic, molecular and symbolic levels and that students' theories should be at the forefront of their thinking as they engage with data during experiments. In elaborating the potential of the MBL for chemistry learning we highlighted the real-time display of data as being of great value in that students would be able to engage in the type of higher order thinking that is a goal of science education. We suggest on the basis of the data presented in relation to this experiment that both the students and Anne were concerned predominantly with using the MBL to contemplate the relationship between the pressure and temperature of a fixed amount of gas, at constant volume, at only macroscopic and symbolic levels. Students sought to gather data to enable them to check such a relationship and little attention was paid to important sections of their existing theoretical conceptual frameworks. Consideration of the sample of gas at the molecular level is not evident in any of the data, nor is there any evidence of students engaging with their molecular theories of this aspect of chemistry. Therefore, according to our framework for chemistry learning with understanding, we suggest that there was little point in using the MBL in this instance.

In particular, Jason's conceptions of the phenomenon they were investigating at the molecular level, as evidenced by his answers to the pre- and post-tests, seems not to have been challenged through the use of the MBL. It is reasonable to claim that, given the narrow use the MBL was put to, that it might be unreasonable to expect any conceptual change to have occurred in this student. Such an expectation is, however, quite contrary to the much mooted potential of the use of MBL. On the basis of the pre- and post-test data, two questions can be posed in relation to Jason's engagement with, and learning from the MBL. Firstly, we should ask whether or not he could have understood the significance of the experimental procedure given the extent of his alternative conceptions, both prior to and following the unit. We would suggest that the answer to this question is a firm "No." Secondly, we would ask what the MBL contributed to his learning of chemistry is relation to the topic. We would suggest that the answer to this question is, on the basis of our analysis, "Nothing." Indeed, on the basis of the evidence provided it seems credible to suggest that consequence of the use of the MBL for students' learning as we have conceptualised it was, at best, minimal. Such a result is disappointing. But this result was not uncommon amongst class members. Further, even though Jon was one students who revised his understanding of the effect on the pressure of a gas as its temperature was varied over the time of the unit, on the basis of (a) the dialogue between he and the other two students and, (b) the experimental map that summarises his actions and those of his peers, we suggest that whether or not his understanding was modified as a result of his experiences with the MBL is unclear. It is more likely that his reconceptualisation of this phenomenon was a consequence of some other learning experience.

On balance, we suggest that the computer was a superfluous element of the classroom learning environment in this instance and that it contributed little to these students' understanding of the molecular aspects of the pressure/temperature relationship of gases. However, it is difficult to be surprised by such a finding, as it is consistent with what is already known to be the case in many high school science laboratories. Irrespective of the potential of the technology, as long as teachers and students continue to view laboratory work as a series of step-by-step exercises for students to confirm canonical laws and equations there will be little evidence that can justify the provision of such computer resources. Students, as we have seen in this and our previous study, generally follow the guidelines set down by their teachers. If such guidelines do not engage them in constructivistly oriented considerations and discussions of chemistry at macroscopic, molecular and symbolic levels then there is a constant risk that their understanding will be less than desired. Such a suggestion is congruent with that of Kelly and Crawford (1996) who suggest that it is profitable to view the computer as a member of in the group and conversation but that without student consideration and mediation of the computer representations such a relationship may be of little value. If the MBL is viewed simply as a high-tech measuring device, as was suggested by Anne, and as used by her students, it will never realise its full potential.

Concluding remarks

There is a widely held view that the use of computer technology is “often viewed as a catalyst, panacea or limitations in students’ science understanding” (Linn, 1998, p. 265). Such a view of the potential of computer use in science classrooms is consistent with a technicist view of educational technology (Bryson & de Castell, 1998) which seeks to propose causal relations between the attainment of such educational goals and students’ engagement with computers. Current reform agendas in relation to the implementation of computer technology such as MBL into high school chemistry laboratories often seem to ignore what we already know about effective teaching and learning of chemistry. This study which extends our previous reports of this research and demonstrates further that there is more to enhancing students’ conceptual understanding of chemistry than can be achieved simply through the provision of MBL technology. As schools engage in increased expenditure in relation to the provision of such technology is seems prudent to take a step back and begin to look more closely at what happens when teachers and students use such technology. At times we may not like what we find yet it is only through such findings that we can suggest means of using the technology to enhance students’ conceptual understanding across the range of science topic areas.

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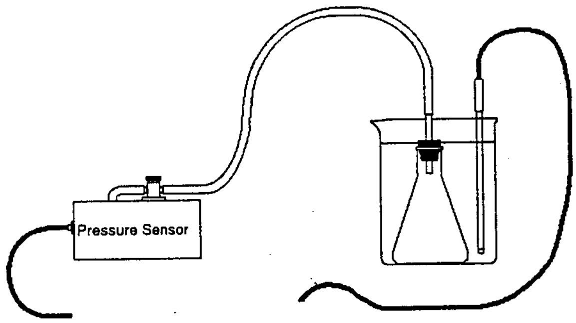
Appendix 1. Instruction sheet for students for the experiment investigating the relationship between the pressure of and temperature of a fixed amount of gas at fixed volume.

Pressure-Temperature Relationship in Gases

Gases are made up of molecules that are in constant motion and exert pressure when they collide with the walls of their container. The velocity and the number of collisions of these molecules is affected when the temperature of the gas increases or decreases. In this experiment, we will study the relationship between the temperature of a gas sample and the pressure it exerts. Using the apparatus shown in Figure 1, we will place an Erlenmeyer flask containing an air sample in water baths of varying temperature. Pressure will be monitored with a pressure sensor and temperature will be monitored using a temperature probe. The volume of the gas sample and the number of molecules it contains will be kept constant. Pressure and temperature data pairs will be collected during the experiment and then analyzed. From the data and graph, you will determine what kind of mathematical relationship exists between the pressure and absolute temperature of a confined gas. You may also do the extension exercise and use your data to find a value for absolute zero on the Celsius temperature scale.



PROCEDURE:

1. Check that the temperature sensor is in port A and the pressure sensor is in port B, and the file is C09.

2. Minimise Experiment Notes (▼ at top right)

3. Start at room temperature. Click on REC and then on STOP

Record mean temperature and pressure in your table.

4. Change to ice bath. Weight flask to keep it under water.
Click on MON to observe measurements.
When stable, click on STOP .
Click on REC and then on STOP
Record mean T and P on your table.

5. Change to other water baths and repeat. Speed is important as there may be some gas losses.

6. Minimise Table to observe graph.

7. To get ready for next group, click on Table(at bottom) and Restore. Click on Run#1 at top left, press delete key on keyboard and answer OK. Repeat for all data.

8. Plot your own graph of P vs T.

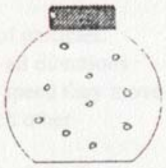
9. Express in words the relationship between gas pressure and temperature.

10. Explain this relationship in terms of molecular velocity and collisions of particles.

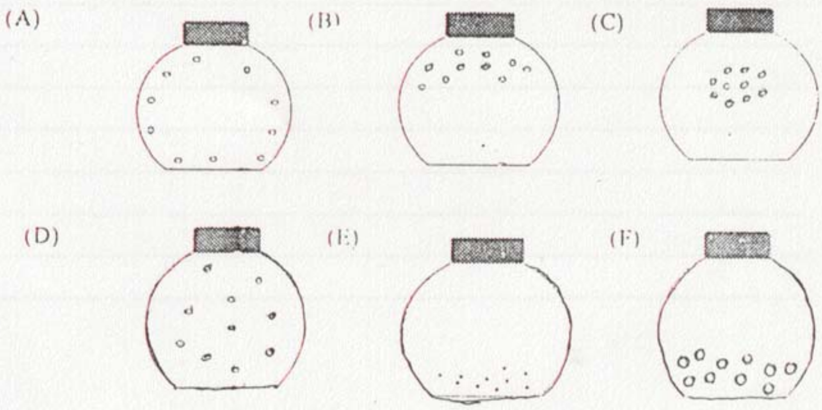
11. Write a mathematical equation for the relationship between pressure and temperature in Kelvin.

Appendix 2. Pre-test question related to the effect of changing the temperature on the behaviour of a gas. (Hwang, 1995)

3. The figure below shows the distribution of hydrogen particles at room temperature and constant pressure.



Which of the figures below, in your opinion, best shows the distribution of the hydrogen particles if the temperature is changed to -15^{0}C? In the space provided provide a brief explanation of why you chose your answer.



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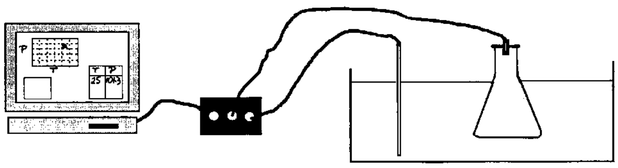
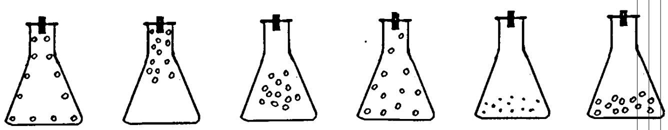
Appendix 3. Post-test question related to the effect of changing the temperature on the behaviour of a gas.

Question 2

A flask containing air and a temperature probe are placed in a water bath and connected to a computer as shown in Figure 2. The flask is attached to a pressure measuring device and the pressure registers on the computer. No gas can enter or leave the flask. The temperature also registers on the computer. The temperature of the water bath is 25°C. The pressure registers as 101.3 kPa.



(a) Which of the diagrams below, in your opinion, best shows the distribution of air particles in the flask at the temperature of 25°C? Briefly explain your answer.



A. B. C. D. E. F.

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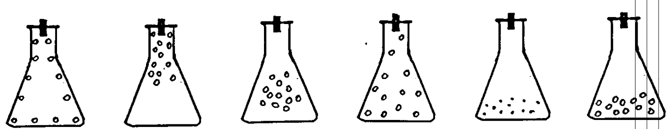
(b) Ice is added to the water bath and the temperature changes to 0°C. Which of the diagrams below, in your opinion, best shows the distribution of air particles in the flask after this temperature change has been allowed to affect the temperature of the air particles in the flask? Briefly explain your answer.



A. B. C. D. E. F.

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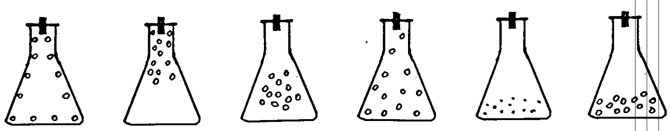
(c) Hot water is added to the water bath and the temperature changes to 60°C. Which of the diagrams below, in your opinion, best shows the distribution of air particles in the flask after this temperature change has been allowed to affect the temperature of the air particles in the flask? Briefly explain your answer.



A. B. C. D. E. F.

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Appendix D. From Roth et al. (1997).