The Development of Student Conceptions of Pressure and Boyle's Law

by

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Abstract

Creating congruent links between the three representations of science understanding - macroscopic, microscopic, and symbolic (Johnstone, 1991), is important for the conceptual understanding of pressure and Boyle's Law. Twenty-one grade 11 chemistry students participated in a science program that culminated in students scuba diving. Students recorded their initial conceptions throughout the four-and-a half week teaching intervention and completed assignments using Johnstone's three representations as the basis for their responses. A two-tier multiple choice diagnostic was developed to assess student conceptions of pressure and Boyle's Law at the end of the teaching intervention. Results of this study suggest that these methods were helpful in promoting conceptual change. The structured sampling of student conceptions throughout the intervention provided information about the following: (a) similarities in student naïve conceptions; (b) changes in student conceptions; (c) the presence of tenacious, alternate conceptions; and (d) teaching strategies, lesson sequences, and demonstrations that appeared to be effective in promoting scientific understanding of pressure and Boyle's Law.

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Dedicated to my husband and children,

Craig, Malaya and Raina Gertley

and my parents

Gerald Richard and Conchita Trinidad Richard

who have made all my dreams a reality.

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Chapter 1: Introduction

1.1 What Does Learning Look Like?

My name is Melanie Gertley, and for ten years I was a high school teacher in Winnipeg. I taught grades 9 and 10 general science, grades 11 and 12 chemistry and grades 11 and 12 biology. I currently am the math specialist at a technical college. I teach trades related mathematics to students who struggle with these subjects. Many times, I end up teaching science to these students as the mathematics is difficult to learn without an understanding of the science behind it.

As a teacher, there are questions over which I agonize each school day. Those that I struggle with most often include the following. How do students learn science? That is, what cognitive processes are necessary for developing deep, scientific understanding? How can we use this knowledge about learning to create lessons that encourage scientific understanding? How should scientific understanding be assessed? That is, how will students know if they understand the scientific concepts being taught, and how will teachers determine if each student's understanding of a concept is scientific and at the level of the provincially mandated learning outcome?

In order to explore these questions, I have reflected on formal and informal teaching episodes during my career when I knew that the students in my classes had learned. I then attempted to determine what these particular teaching/learning events had in common. As will be described, it is experiences such as these that have helped to form my conceptions of teaching and learning.

1.1.1 Science Students' Association

The ***Science Students' Association*** **(SSA)** was an extra-curricular program where high school students were provided with an opportunity to create a "magical" chemistry show and workshop. Interested students would begin by using the internet to research “magical” science demonstrations they would like to try. Small groups of students with interests in similar demonstrations would develop an understanding of the chemical reaction behind the demonstrations of their choice along with all of the necessary safety precautions. Based on this research, the student groups prepared and optimized each demonstration. They were expected to discuss the modified protocols with me and to justify their modifications. Even when I knew a modification would not work, I didn’t inform the students. I would, however, provide clues after several failed attempts.

Once the small-group demonstrations were optimized, the students shared their work with the members of all other groups and taught these students the science behind each demonstration. When presenting, students in each small group would explain the chemical basis of a demonstration, outline safety protocols, and assist students in carrying out the reaction shown. This was followed by a discussion focused on how best to present the demonstration during the “magical chemistry” show. All students evaluated each demonstration and created a “magic show” and chemistry workshop from what they collectively considered to be the best demonstrations and activities. As it was up to the students to gather information, identify problems, and implement solutions, they had a taste of “authentic” scientific research after working on a few demonstrations for a number of weeks.

SSA members were acutely aware that the club had very little money to support the group’s preparatory work, the “magic show” and the workshop. The SSA students came up with resourceful ways to do some very expensive demonstrations and even built any required apparatus out of scrap materials.

One year, the SSA partnered with *Auxilium Apparel*, a Junior Achievement company run by students in another high school. *Auxilium Apparel* produced and sold SSA t-shirts to the audience after each workshop. The proceeds from their workshops and t-shirt sales were used to purchase medical supplies for a school in Sierra Leone.

What seemed to help students with the understanding of science in this case appeared to be due to a few factors. These were:

- being actively engaged in learning,
- collaborating to find solutions to problems (both in optimizing experiments and finding ways to reduce costs),
- having the time to keep on trying as there was no curriculum,
- having fun, and
- doing this for a reason (in some cases, it was the opportunity to perform in front of an audience and, in others, it was to help less fortunate children).

I wondered if these were factors that were common to other times students learned science. The next project that came to mind where students truly understood the science they were learning was through a project called the Seven Oaks Curriculum Cooperative.

1.1.2 Seven Oaks Curriculum Cooperative

The Seven Oaks Curriculum Cooperative (SOCC) was a transition program in which grade 11 students designed interactive biology lessons for grade 8 students who would be attending the high school in grade 9.

The grade 11 students were responsible for all aspects of teaching, including the gathering of materials, preparing lesson plans, delivering the lessons and marking. I observed, provided moral support and was prepared to deal with major disciplinary problems or emergencies if they arose. The middle school students were treated as high school students and were praised and disciplined in keeping with high school expectations. In this respect, transitioning students were exposed to behavioural expectations of their new school and made bonds with students who would be in grade 12 when they entered grade 9.

It was exciting for me to watch the grade 11 students prepare and practice their lessons. They would argue about the best way to teach the required content, how to represent organelles using candy, how to have the students memorize the names of blood vessels, or how to incorporate the dramatic arts. Of even greater interest to me was the realization that they always did well on the tests for the units they taught and would comment on how much easier the tests were on the units for which they created lessons. Even though I used similar tests year-after-year, the students would wink and smile and think that I had made the test easier for the SOCC units. Though I never told them, I believed that the fact that they were preparing lessons for the grade 8 students before school, during class time, at lunch, and after school almost every day for two weeks most likely helped. Many students taught these lessons without notes. Clearly, they knew the material.

As time went on, the lessons the students produced became more interactive and thoughtful. I remember asking students who showed marked improvement to talk with me about the reasons they attributed to why they were doing better. Their responses included many if not all of the following:

- They were the teachers and had to know what they were doing because they could not afford to look ineffectual;
- They couldn't let grade 8 students down as it was important for the younger students to learn well and to feel good about learning (they felt it was their responsibility to ensure this occurred).; and
- It was their responsibility to model appropriate high school behavior and to take care of the grade 8 students both academically and emotionally (they remembered what it was like to transition from the middle school to the high school, and many cared enough to ensure they would look after the new grade nines.)

The grade 11 students participating in the SOCC project also made comments about increased self-esteem and how my teaching methods were different from the way I "usually taught". These latter comments were insightful and showed me that there were, and continue to be, major gaps in my teaching. Some of the comments addressed changes in note taking. Rather than having the students write notes, I had made the decision to provide students with notes or hard copies of my PowerPoint presentations before delivering each lesson. Apparently, I would say, "Put down your pens and just listen." Moreover, students could ask questions at any time during a lesson, and in many lessons I would have them work on challenge problems, first individually and then in small groups, to ensure they understood the material.

We discussed applications from several different perspectives rather than one. We discussed how a concept worked in their own bodies, in other people, what effect it may have, and how they were going to teach the concept. I was more open to free discussions, and students "looking things up" on the spot.

Assessment was based more on authentic tasks during these units. There were two students in particular that could not write tests well, but could definitely teach the students without using cue cards. They knew the material, and if they did not do well when responding to test questions on the specific sections they had prepared and taught, I told them that the skill they were lacking was test writing, not understanding or knowing content. How I viewed assessment and evaluation was starting to change, and how they viewed their assessment of their understanding also seemed to change.

My attitude improved while I was teaching the SOCC units. I was enthusiastic about what the grade 11 students were doing, and I knew they were going to do well. I set the expectations high for the group, and told them I was excited to watch them deliver. They did. I think that because my attitude changed, my teaching changed. Because my teaching had changed, student attitudes changed and their learning changed. Though they did not use the exact phrase, the students essentially described the Pygmalion Effect.

It appeared that again, students were engaged in hands-on activities that were for a purpose other than learning the material for a grade. They had to collaborate and find solutions, and again they had fun. These seemed to be the keys for meaningful learning.

The final project that came to mind when thinking about meaningful learning was the WKC Scuba Project.

1.1.3 WKC Scuba Project

The WKC Scuba Project was a series of lessons originally designed for the gas laws unit in that Manitoba grade 11 chemistry curriculum (Manitoba Education, Citizenship and Youth (MECY), 2006). This curriculum suggests that the concepts of pressure and Boyle's Law can be applied to scuba diving and that teachers discuss these concepts in the context of scuba diving (MECY, 2006. pp. 15-27).

I am a certified diver and had prepared a series of lessons on gas laws based on the material from the Professional Association of Diving Instructors (PADI) open water certification program. The students seemed genuinely interested in the effects of pressure systems, especially when looking at diving footage and seeing pictures of various barotraumas. There were questions about why ears hurt on airplanes, and students reacted with great interest to the imploding can demonstration.

While teaching these lessons on the gas laws, students would ask if we could go scuba diving. I thought back to when I was certifying and remembered thinking how much easier it was to understand buoyancy when I was floating in the middle of the water column looking at beautiful fish and how this would be a great way to learn. Not only was scuba diving an interesting pursuit, you had to understand pressure systems and gas laws to ensure personal safety.

Based on student comments and my own experiences, I began to design a series of lessons where students would scuba dive and conduct experiments based on the concepts of pressure systems, Boyle's Law and buoyancy. It took two years and a team of teachers to cobble together the resources, equipment and safety protocols in order to implement the first dive session for, what turned out to be, biology students.

During the respiration unit in biology, I was discussing the process of inhalation and exhalation through pressure systems and Boyle's Law, and talked about scuba diving and buoyancy control. I showed pictures of barotraumas, and the students in the class began a spirited discussion of different types of barotraumas, especially pulmonary, ear and mask barotraumas, “the bends”, animals that live deep underneath the ocean, and several mentioned the swim bladders in the fish they had eaten for supper the night before. I was amazed at the number of questions, comments and ideas that this group of students shared. It was one of those moments when you know the students are engaged and learning is happening.

Many of these same students wanted to try scuba diving, and a student said, “Hey ‘Frizz’, you should take us on a field trip to the bottom of the ocean!” I replied, “Unfortunately, the school budget doesn’t allow for a “Magic School Bus” no matter how often I may put it on the science supply list. However, would you like to go scuba diving?" Most of the students were on board.

The next few weeks were atypical, as gas laws and physics are not commonly taught in biology class. Nonetheless, it seemed that the students were willing, even eager, to learn. They wrote lab reports, created an instructional video, and designed t-shirts. To further assess student understanding, a long answer test was given that incorporated physics and chemistry applications to biology.

So, why did the students seem to learn? Why did these endeavors appear to be successful? After talking to the students, it appeared that there were several factors at play. First, it was about the students. In each case, although I dictated the subject matter to some extent, the dissemination of information and the learning format were generated by the students, not by the teacher. This process required the processing if information in many different ways, through different media, and with numerous pedagogical and academic discussions and arguments. Second, the lessons were interactive. Third, learning became more than a grade. Grades were still important (except for a group of chemistry students who did not get course credit), however, learning had a greater purpose than a letter or number on a report card. It was about helping others, having fun, and staying safe - no one wanted to blow off a finger or lose their hearing. Fourth, we had time and resources, which are often limiting factors when teaching.

However, questions still remained. How do students learn science? How do teachers help students to understand science? This brings me to EDUB 7550.

1.2 Experiences in “EDUB 7550 Seminar in Science Education”

A number of years ago another chemistry teacher and I gave a presentation in an undergraduate Curriculum and Instruction in Chemistry class about “Maples Magic” (see SSA on page 1). As we showed each of the demonstrations developed by the students, the professor told the future teachers in his class to, "Think about how you build experiences for your students." He discussed different sequences in which the demonstrations could be presented to facilitate what I now know as conceptual change. It really made me think about the progression of demonstrations that I would incorporate in the scuba lessons, and the types of models and laboratory work that would best suit learning based on students’ prior experiences. Ten years later, I registered as a Master’s of Education student in *Seminar in Science Education*. This was a course where I was formally introduced to constructivism (reviewed in Coll, 2000), the Generative Learning Model (Osborne and Wittrock, 1983), Mahaffy’s Model (2006), the five characteristics of meaningful lessons (Johnassen, Peck and Wilson, 1999), and the use of two-tiered diagnostics (Treagust, 1995). These experiences, coupled with my own learning and observations of students processing and developing understanding of information fit well with constructivist learning theory.

The “big ideas” that stuck with me at the time were that learning is built on a series of experiences, these experiences shape each student’s mental model, students bring to science classes ideas and notions that are well established, persistent, and frequently inconsistent with the knowledge of scientists and science teachers, and these ideas or pre-instruction conceptions influence learning.

1.3 Exploring student preconceptions

How students use their own experiences to make meaning of new information resonated with me. As one example, the students in my grade 12 chemistry class were learning about solubility. They observed a demonstration were two solutions were mixed and an insoluble precipitate was formed. Students were asked to visualize the atoms and draw what happened. When these drawings were shared, they would argue with each other about which model best fit their observations. During the discussions, common pre-conceptions were expressed. Many times, the most persuasive arguments were based on common student experiences and who was considered to be the most proficient student in the class. These arguments showed a lot about student thinking. Interestingly, the student pre-conceptions were powerful, and appeared to stay with a few students even at the end of the course.

The WKC Scuba Project (see page 9) was run four times before implementing the project for this study. The first time the project was implemented, persistent student pre-conceptions were observed and recorded. Several of these persistent pre-conceptions are included in Table 1.1 along with the experiences students based these pre-conceptions upon.

Table 1.1.

Student pre-conceptions and experiences, first session of the Scuba Project.

Pre-Conception	Experience
Pressure increases with increased elevation	"Pressure in the ears" when in an airplane
Volume decreases with increased elevation (even if there is no change in temperature)	Observation of balloons going up into the sky, helium balloons at the top of the ceiling after a few days
Spaces between water molecules (much larger, to the point that water looks to be compressible)	Teachers, museums, textbooks
Ear drum is semi-permeable, permeable, or can open and shut like a door	The sensation of ears clearing after a bath or swim

It was essential to address these pre-conceptions, to tackle each one head-on. As important, was the need to re-frame the experiences used to construct these pre-conceptions.

1.4 Influence of my own pre-conceptions on my learning and my teaching

When designing the scuba program, I had a very difficult time understanding what happens when people “pop their ears”. Even though I had been engaged in many discussions of this phenomemon with scuba instructors and had re-read the PADI manual numerous times, I still did not understand what was happening. I realized that there were two problems. First, the tympanum was never drawn and neither were air and water molecules, so there was confusion as to where the pressure imbalance was occurring. Second, the word "vacuum" was used during these discussions, and a large part of the problem was the way the word “vacuum” was used in lieu of "pressure differential". While descending a “vacuum” did not occur. It was a pressure difference that was occurring on either side of the tympanum that led to ears popping. It took me days to understand. It was difficult to visualize how this "vacuum" was occurring. During descent, air does not physically leave the inner ear. So, where was the air leaving? Where did this air go?

It took a few weeks with many hours of internet research, numerous discussions with teachers and instructors, and countless drawings to try to figure out how ear barotraumas and equalization occurred. All of my initial drawings were not remotely in keeping with scientific models. They were, in fact, a combination of what I knew about pressure based on many of my own experiences.

I came to realize that my pre-conceptions influence how I teach and how I interpret student understanding. For example, every time I taught the course, or another instructor taught the course, I ensured that the word "vaccuum" was used only in specific instances. However, my pre-conceptions also led me to phrase statements in such a way that caused students to construct logical, but unscientific models. For example, the first time I taught the course, many students thought the tympanum was permeable and that water entered and left the sinuses.

Where I decide to start a lesson, how I decide to tackle a concept, and how I decide if a student has scientific understanding of a concept are based on my experiences and pre-conceptions and on the way I process information and have processed it in the past. I was taken aback when I came to this realization.

1.5 Tetrahedral Model

Johnstone (1991) proposes that chemistry is represented in three ways. These are the macroscopic or what is observed, the sub-microscopic or the visualization of molecules and molecular motion, and the symbolic or representation through the use of symbols, such as mathematics (reviewed in Gabel, 1999). In 2006, Mahaffy added a fourth dimension to the

Johnstone model. This was the human element that addresses the societal aspects of science. Thus, to truly gain an understanding of chemistry (or science), Mahaffy argued that coherent and simultaneous connections should occur between these four representations (Figure 1.1). Ergo, teaching strategies should incorporate the macroscopic, the sub-microscopic, the symbolic, and the human element.

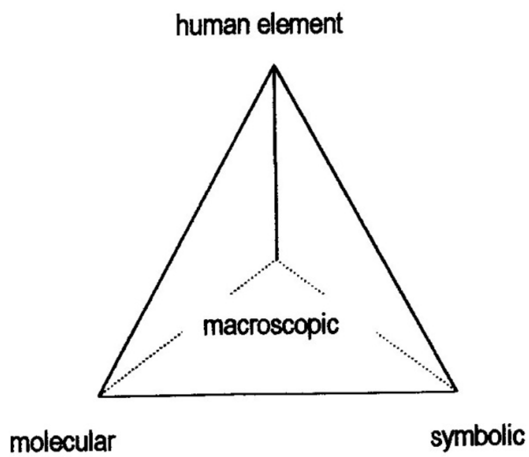


Figure 1.1. Tetrahedral model of chemistry education (Mahaffy, 2006, p. 51).

This means that students should be educated to think of science in this manner, and be able to use Mahaffy's Tetrahedral Model to determine whether their conceptual models are consistent with scientific models. In addition, lecture notes should address the four representations, and assignment questions should be posed in such as way that the answers require students to show each one of the representations and the relationships between them. Finally, computer simulations should show all of these representations, and any teacher demonstration should be discussed in terms of the macroscopic, sub-microscopic, symbolic, and human element.

When I first heard about the Johnstone and the Mahaffy models, I remember thinking "Well...this means re-doing my entire unit and a lot more marking." However, I quickly came to realize that the potential benefits far outweighed a few sleepless nights. I used Mahaffy's Tetrahedral Model (2006) to design lesson plans and assignments for the grade nine chemistry unit and the grade 9 electrostatics and electricity unit. In these units, students were introduced to the concepts of macroscopic, sub-microscopic (shortened to microscopic), symbolic and humanity (also called the "human connection" or "what it means to us" or "my experiences with it" or "application") representations of science understanding. Throughout the lectures and the notes and assignments the students received, they were asked to explain their understanding using these four forms of representation. They were also told that if they could not explain even one of those four aspects, then they did not have true scientific understanding.

During the electrostatics unit, "Buddy" (pseudonym), a boarder-line special needs student who was not at all enamored with science told me, "I get the macroscopic and the microscopic. I don't get the symbolic." Buddy was able to use multiple representations to pinpoint where his learning was deficient. Instead of a student stating, "I don't get it" with a blank stare, the model gave them the ability to check their scientific understanding and describe the mode of representations that did not yet make sense. This awareness also saved time. I found that I could zero in on where a gap in understanding existed.

Ultimately, Buddy just multiplied or divided until he got the number he knew would substantiate his maco- and sub-microsopic understanding. If you were to compare his mathematics marks and the marks he was receiving for work in the electrostatics unit, you would find them to be diametrically opposed. His mathematics teacher was astonished when learning that Buddy was passing the electrostatics unit as he could not transpose a three variable equation with one unknown. However, because Buddy had a clear understanding of the macroscopic and microscopic, and could tie it to things around his house (humanistic), I realized that he had a fairly good understanding of electricity. It had been his inability to transpose a mathematical formula that initially held him back.

This single incident opened my eyes to the power of Mahaffy's model (2006). But there other situations that turned out to be just as eye-opening. A student who was good at mathematics was using her calculations to figure out the macroscopic and microscopic. If her math was wrong, she changed her macro and micro explanations to fit the math. Another student who was also very good at math completed the symbolic component of an assignment, but neither of the macro or sub-microscopic representations. She was distressed by the mark she received on this assignment because she normally received very good marks in mathematics and science. In my discussions with her, she was able to explain that she did not understand the two representations she had left blank.

It should be noted that it took the students and myself an entire unit in chemistry, previous to the electrostatics unit, for us to get “into the routine” of demonstrating (and in my case modeling) the multiple representations. It was only towards the end of the electrostatics unit that some students began to autonomously use the multiple representations to gauge their understanding.

I was left wondering, out of the hundreds of assignments I had given in the past, how many students, like Buddy, who actually had a good understanding of the concept failed because of symbolic difficulties? How many students who were exceptional at plugging numbers into a formula had received excellent marks with no conceptual understanding of the macroscopic and sub-microscopic?

To this day I still wonder if it is because mathematics can be so esoteric in nature, and without a context, that it lacks meaning. Does that have any implication for the way in which simple transposition should be taught? I wonder if this is why physics can be such a tough subject for students. How do you teach light when even scientists cannot agree on a sub-microscopic model? Recently, a physics teacher asked for a better way to explain to her students why water does not leave a bucket when you tie a string to the bucket and swing it in circles perpendicular to the ground. The symbolic is there, the macroscopic is there - but what about the microscopic?

1.6 The Development of the Scuba Project

1.6.1 Demonstartions, lessons and cognitive probes. In science, the concepts of pressure and Boyle's Law and applications of these concepts are particularly difficult for students at the middle and high school levels (reviewed in Basca and Grotzer, 2001). The scuba project was originally conceived to help students understand the applications of pressure and Boyle's Law in a real-world, hands-on and fun manner.

As mentioned previously, the scuba project had been completed four times before the implementation of this research study. I led the first run of the scuba project, and it was conducted with a grade 11 biology class. Approximately one-third of the participating students were enrolled in grade 11 chemistry, not biology. None were enrolled in grade 12 chemistry. Lecture-style lessons were given, with students writing notes for basic understanding of Boyle's Law and its application to dive physiology. Students worked in groups during assignments, lab activities, and a final multimedia project. No formal cognitive probes were used, and there was no attempt to determine student pre-conceptions of pressure, gas laws or applicable anatomy and physiology in the context of diving. Assessments were in the form of two Boyle's Law laboratory activities, two buoyancy laboratory activities, and a final test composed only of long answer questions. For each type of laboratory activity, one experiment was in the class and one experiment was underwater at a community swimming pool. Students completed a multimedia assignment that documented the entire project. Students were responsible for all aspects of the final project, including planning, execution and creating rubrics for evaluation. Computer science students began the development of a Boyle's Law computer simulation that modeled the Boyle's Law underwater experiment. The simulation addressed macroscopic and symbolic orientations only.

As the teacher, one of the most notable moments in this project was while we were scuba diving. A student was practicing fin pivots, which is an exercise used to help student divers obtain neutral buoyancy. The student had successfully obtained neutral buoyancy and was rising and falling with each breath. Suddenly, he signaled me to do an immediate surface. Once we had surfaced, he took out his regulator and mask then exclaimed with wide-eyed wonder, “Mrs. G! I felt the math!”

I taught the second run of the scuba project to students in the chemistry class of another teacher. This occurred while I was enrolled in *EDUB 7550 Seminar in Science Education*, and two other teacher divers, one from the seminar course, helped with both the in-class instruction and the in-pool activities. This session of the scuba project was documented and submitted for the final paper assignment in the seminar course.

As a student in EDUB 7550, I analyzed the alternative conceptions indentified in the test written by students the first run of the scuba project. Based on these conceptions, and with the recommendation of a number of educators (Alderson, Bush, Dann, Dubois-St. Jacques, Edwards, Lewthwaite, Lukie, Matwyczuk and McMillan, personal communications, 2008), cognitive probes were developed and physical models were built to aid student learning of the effect of differential pressures on the ear and ear barotrauma.

A number of alternative conceptions in the student responses were identified for both pressure and Boyle's Law that supported findings in the published science education literature. Also, alternative conceptions of the eardrum were found that were consistent between certified divers and the students in the class.

Interestingly, when students were asked which activities and/or demonstrations helped them the most, 98% of the students responded "the scuba diving ear models." One of the teachers thought that part of the reason that the ear models seemed to be effective (though not totally effective, as there were still alternate conceptions at the end of the course), was that during descent the ear drum in the model ear moved to a large extend due to the differential pressures. At the same time, the students could feel this pressure in their own ears. Essentially, the students could actually see what they were physically feeling.

In order to directly address alternate conceptions, a refutational text assignment (Anders and Guzzetti, 2005) was created. The chemistry students in this second run of the scuba project were asked to mark hypothetical assignments where a question is posed and a student has responded by writing an incorrect answer based on a common alternative conception. The students were to correct the answer and devise a marking scheme. In some cases, students gave correct answers, in others, as their alternative conception matched those in the hypothetical assignment, incorrect answers were marked correctly. In some cases, it was difficult to determine student reasoning. Many of the students remarked on how difficult it was to mark the student's answers, and how long it took. Few commented on the educational value of the exercise.

I found the whole process to be utterly fascinating. Frankly, I'm not sure who learned more, the students or me. I realized that the way I phrased ideas and drew diagrams unintentionally led students to develop alternate conceptions. Also, by comparing the lessons from the first to second run of the project, I found that I myself had alternative conceptions in the first session that were passed on to students. I found it frightening that I honestly thought I understood a concept thoroughly, but realized later that I had not. Students in the first session had learned a misconception. Aside from my own professional embarrassment, I could not even go back and rectify the situation given that the students had completed the course. Teacher reinforcement of alternative and naïve conceptions has also been demonstrated in the literature (Besson, 2004; Osborne and Freyberg, 1985).

The third run of the scuba project was taught by a chemistry teacher who was instrumental in helping in the design and implementation of the scuba program.

Cognitive probes from the second session were used again in the third session. Though the frequency of alternative models were found to differ, many of the alternative models were identified as being the same as those identified second session.

Based on observations from the third session, more in class demonstrations were developed that built on previous demonstrations. The computer simulation created by computer science students was presented, however, the computer model was missing microscopic representation. Computer science students continued to work on the computer simulation to add the microscopic representation. This simulation is currently being used as an exemplar in another teacher's M.Ed. thesis (Matwyczuk, personal communication, 2011.)

In the fourth run of the scuba project, microscopic representation was added to the computer simulation, but there were difficulties in programming the randomized motion of particles. Equipment for the underwater experiments were refined and rebuilt. The equipment developed in the fourth session was used for the study being described in this thesis.

1.6.2 Scuba session summative evaluations (or "unit tests"). The development of the two-tiered multiple-choice test used in this study occurred over the four sessions of the scuba project as follows. In the first session of the scuba project, the test was entirely composed of long answer questions. As previously described, pre-conceptions were analyzed in *EDUB 7550 Seminar in Science Education*. Test questions that were vague or confusing were also identified and re-worded for the second run.

The second unit test in the scuba project was also long answer, with some questions re-worded to be more concise. Some similarities between conceptions from the first to second session were observed. Preconceptions identified from the first two tests and from the science education literature were used as distracters in the development of the first two-tiered multiple-choice test (Treagust, 1995).

The unit test for the third run of the scuba project was a two-tiered multiple-choice test that took students two periods to complete. The difficulties identified with the first run of this test were as follows: back-to-back questions testing same concepts, no attempt at separating re-written questions; questions did not always test for the three modes of representation (macroscopic, sub-microscopic, symbolic), too many questions, too difficult for students learning English as an additional language, students rarely wrote responses in the boxes provided, and some answers, unbeknownst to the teacher, had inadvertently been highlighted (some students ignored the highlighting but others selected the highlighted answer). What was of interest to the researcher and teachers was the realization that many students who chose the "correct" answers (that were highlighted) proceeded to choose answers in keeping with their alternative conceptions in the question that immediately followed. When correct answers were not highlighted, answers were also consistent with a student's alternative conceptions.

The test for the fourth run of the scuba project was given to two sets of students. One set of students came from the high school where the scuba project originated and with the teacher who conducted the third run of the scuba project and the other set of students came from the class of the teacher who had agreed to implement the fifth run upon which this thesis reports.

Given the feedback of the third test, changes were made with input from teachers (Datzkiw and Edwards, personal communications) and dive masters (Alderson, personal communications) who had been involved in the project. These changes were as follows: questions were re-worded so that for each analogous pair of questions the macroscopic, microscopic and symbolic orientations were represented as much as possible; some questions were omitted to reduce test fatigue; questions were divided into two tests to be taken over a period of two days; the highlighting on the third version of the test was omitted; questions were re-worded to provide simpler language, EAL students were allowed to ask clarification questions on vocabulary; and back-to-back questions were kept to determine if there were effects similar to test three results.

Feedback from the students taking the fourth test resulted in the identification of further difficulties for EAL students. Students also asked, "Are we answering the same questions over and over again? Why?" As before, students did not write in spaces provided despite encouragement from their teachers. Moreover, it appeared that conceptions seemed consistent between similar questions.

In the fifth draft of the test, and in consultations with educators (see Methodology), the questions were randomized and more questions were re-worded in an attempt to facilitate comprehension for EAL students. These tests became pre-and-post tests 1 and 2 used for this study.

1.7 Research Questions

I found myself asking the same questions throughout the sessions of the scuba project. These questions became the research questions that were investigated in this study. They are as follows:

1. What are the pre-conceptions of students in respects to pressure and Boyle’s Law and what experiences shape their mental models?
2. What information about student understanding of Boyle’s Law can be obtained from assignments based on multiple representations of science understanding (Johnstone, 1991)?
3. What alternative models do students have at the end of the teaching intervention?
4. Do students find model building activities useful for understanding pressure and Boyle’s Law?
5. Do students find the tetrahedral orientation (Mahaffy, 2006) useful for learning pressure and Boyle’s Law ?
6. Do students find the scuba activity useful for learning pressure and Boyle’s Law?
7. Does the collaborating teacher find model building activities useful for understanding pressure and Boyle’s Law?
8. Does the collaborating teacher find the tetrahedral orientation (Mahffy, 2006) useful for teaching and evaluating science understanding (for the concepts of pressure and Boyle’s Law)?

9. Does the collaborating teacher find the scuba activity useful for learning pressure and Boyle’s Law?

The chapter that follows presents a review of the education literature relevant to the study. In Chapter 3, the research method and the methodologies employed for this research study are presented and explained. Chapter 4 describes the types of alternate conceptions identified at the beginning of each lesson of the intervention. Chapter 5 describes the types of information gained about students' conceptual understanding of pressure and Boyle's Law and potential attitudes towards science understanding. Chapters 6 and 7 illustrate the types of alternate conceptions that remained with students after the teaching intervention and discuss limitations particular to those analyses. Chapter 6 focuses on general conceptions about pressure and Boyle's Law, where as chapter 7 focuses on student conceptions of pressure and Boyle's Law in the context of scuba diving and flight. In chapter 8, general limitations, suggestions for improvement, pedagogical implications, and future studies are presented and discussed.

Chapter 2: Literature Review

2.1 Pedagogical Frameworks Used to Inform Program Design

A social constructivist framework (reviewed in Clement, 2000; Woodruff and Meyer, 1997), model based learning (reviewed in Coll, France and Taylor, 2005), Conceptual Change Theory (Posner, Strike, Hewson and Gertzog, 1982), the Generative Learning Model (Osborne and Wittrock, 1983), and the use multiple representations for science understanding (Johnstone, 1991; Gabel, 1999; and Mahaffy, 2006) were used to inform and develop the teaching intervention for this study. The relationships between these frameworks as viewed by the author are discussed below. The integration of these frameworks in relation to the teaching intervention are summarized in Figure 2.1.

2.2 Model Based Learning

Boohan (2002) describes models as "…simplified representations of the real world" that can describe and predict what happens in the "real world" but are not exact replicas of reality (p. 117). Models are used to focus attention on specific features or characteristics of an unfamiliar concept, and relate it to something familiar, thus easing understanding of the new concept. However, models are limited to the extent that in many cases they are "based on incomplete understandings of how nature works" (Coll, France and Taylor, 2005, p 185), and may be "incorrect" in that they are too simplified to scaffold the understanding of a concept.

There are different types of models. For the purposes of this study, the variety of models used in teaching science are identified and defined as follows:

- Mental models are "human cognitive constructions" (Ibid., 1995), which are simplified versions of the real world that can be used to describe a concept and predict what may happen.
- Physical models are physical representations of mental models such as diagrams, scale models, computer simulations, and written explanations (Boohan, 2005).
- Expressed models are mental models that are communicated publically, through speech, writing, action or other forms. For example, teacher expressed models include analogies, metaphors, diagrams in textbooks, and scale models (Coll, France and Taylor, 1995).
- Consensus models are expressed models that are tested by scientists and are socially accepted (Ibid., 1995).
- Scientific models are consensus models that are currently in use by the scientific community (Ibid., 1995).
- Target Ibid., 1995).
- Historic models are noted scientific models that have important historical context but have been replaced by more current scientific models (Ibid., 1995).

One major goal in science education is for students at the end of a learning process to understand a target or scientific model. In 2000, Clement introduced a simplified theoretical framework of the learning process where students construct partial or intermediate models in order to understand the target model. At the beginning of the learning process, before instruction begins, students start with preconceptions and natural reasoning skills (Clement, 2000). The preconceptions held by students may be alternative conceptions that conflict with the target model, or they may be useful conceptions that will help them to learn the target model more easily. Clement also proposes that "anchoring conceptions" (Clement, Brown and Zietsman, 1989), intuitive, self-evaluated conceptions, play a major role in model building as does the 'conceptual ecology' of the students. Conceptual ecology is defined as the 'mind set' of the student, which includes student's attitudes/dispositions, social and practical contexts and metacognitive beliefs.

During the learning process, students may develop intermediate or partial models when trying to understand the target model. At the end of the learning process, it is hoped that the target model replaces alternative conceptions. However, the target model may dominate or coexist with alternative models or the alternative models may persist (Clement, 2000). The simplified model-based learning figure designed by Clement (2000) is shown at the top of Figure 2.1 in black.

2.3 Group Work to Enhance Model-Based Learning – A Social Constructivist Perspective

To facilitate model building, Woodruff and Meyer (1997) propose a socio-cultural based learning pedagogy that simulates knowledge building in scientific communities. Woodruff and Meyer (1997) contend that in the "real world", scientists first develop ideas and mental models (a model that has not been discussed with others), which may consist of incomplete ideas and partially developed models. These models and ideas are discussed with their immediate peers (becoming expressed models, or a model that has been discussed with others), with little risk to their self-esteem or professional reputations. Scientists then test and critique their models, and discuss their models and findings with larger communities including other laboratories and the public at large. In these large group discourses there is a high demand for models to clearly explain and predict phenomena. During this time, the models are tested and critiqued again with the collective knowledge of the community at large. This discourse improves the clarity and predictive power of the model. In essence, Woodruff and Meyer (1997) maintain that scientists first have a mental model, which is then discussed, critiqued, and tested in small groups. The models are then shared with larger scientific communities, which again critique and test these models. Finally, the models are shared with the general public.

As such, Woodruff and Meyer (1997) suggest that classrooms can implement a similar approach, where students build models though small group and whole class discourse. In small group discussions, students share, critique and build on each other's ideas. In whole class discussions, the demand for clarity and the ability for the model to explain phenomena is higher; thus models are again shared and critiqued and new models may be generated that have better clarity and explanatory power.

From a social constructivist learning perspective, Coll, France and Taylor (2005) contend that prior to being introduced to the target model it is important that students learn to build models and to justify and critique their models even if they are not in keeping with the target or scientific models.

> The consensus view in the literature on group work in science from a social cultural or social constructivist learning perspective appears to suggest that sometimes it is necessary to ease up on expecting students to construct understandings that are scientifically accurate. In this view it is important, at least initially, to allow them to experience what it is like to build original models, theories and explanations in the way that scientists do. (Hogan, 1999b as cited in Coll *et. al.*, 2005, p. 192)

The approach suggested by Woodruff and Meyer (1997) complements the model building framework suggested by Clement (2000) in that students are encouraged to develop intermediate models through series of group discussions.

Studies conducted by Woodruff and Meyer (1997), Hogan (1999) and Taylor, Barker and Jones (2003) provide evidence in support of student model building combined with small and large-group discussions to promote student understanding of science concepts. Taylor (2000) emphasizes that the systematic critique of student models attributed to the success of a teaching intervention. Research investigating the efficacy of student learning of scientific (or target) models suggests that conceptual development can be aided when lessons include activities where students can construct and critique their own models (Abell and Roth, 1995), where links between conceptual and physical models are provided (Penner, Giles, Lehrer and Schauble, 1997), and where students can understand the use and limitations of models (Taylor, Barker and Jones, 2003).

Based on these suggestions, the general method of instruction for the teaching intervention of the study being reported here, and shown in Figure 2.1 in green, was constructed as follows:

1. Students write down their personal mental models, using their knowledge, reasoning skills and experiences to justify their suppositions. This preliminary model is described as "Individual Model 1".
2. Students then are asked to predict what will happen in a discrepant event demonstration or activity and to use their mental models to justify their predictions. The discrepant event is demonstrated and students can then test their mental models against the

observed discrepant event and keep, modify or change their mental models. Modified or changed models are shown as "Individual Model 2".

3. Students discuss their individual models in small groups. In these small groups, students identify, describe, critique, and maintain, add to or change their models. These models are justified by their experiences, alternative and useful conceptions, natural reasoning abilities, and the relationship between macroscopic, microscopic and symbolic representations (Johnstone, 1991). Here, the "Small Group Model" is formed.
4. Students discuss their small group models in a whole-class setting. Again, the models are described, critiqued and justified using the criteria described above. The class tries to achieve consensus as students make choices between strong alternate, but at this point plausible, models. A "Whole Class Model" is potentially developed at this stage.
5. The teacher explains the discrepant event using the target or teacher model. It is important to note that the target model is not necessarily the full-blown scientific/expert model. This is a decision made by a teacher that depends on the concept, age of students and type of science class (general vs. specialized). During this time, the teacher and class compare the target model to the whole class model. The teacher may use analogies, simulations, and demonstrations to support student understanding of the target model. At this time, the teacher also addresses alternate conceptions. The teacher, and potentially other students, challenge experiences that support these alternate conceptions.
6. Students are asked to use the target model to predict and explain other related demonstrations or situations using "real-world" contexts.

The general classroom method to support model building and how it relates to the development of each potential partial model is shown in Figure 2.1 in red. The information in blue at the bottom of Figure 2.1 represents the theoretical and pedagogical models that underpin the instructional sequence described in items 1 through 6.

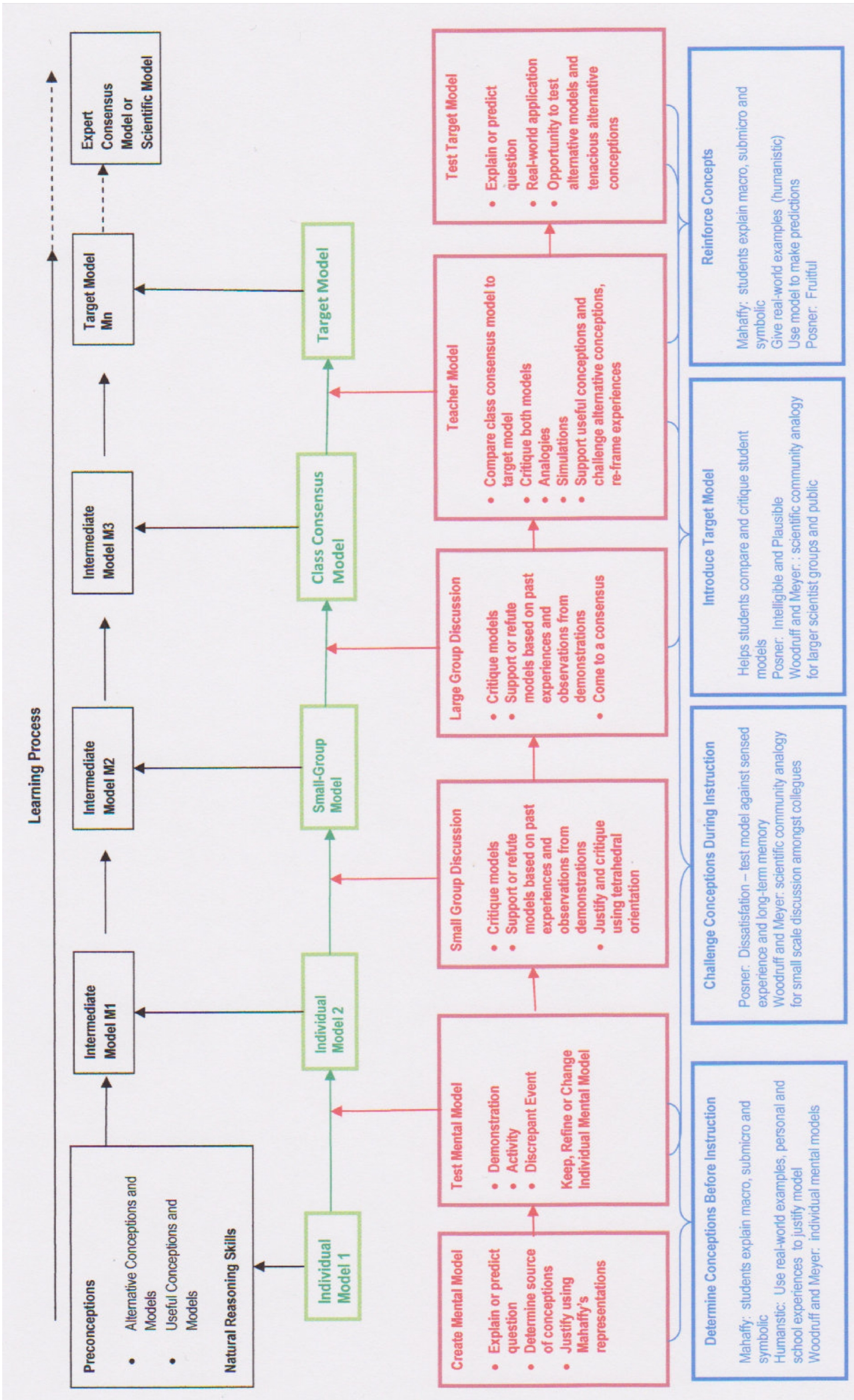


Figure 2.1. Integration of social constructivist pedagogical frameworks into lesson plan development.

Black: Learning process by Clement (Clement 2000, p. 1042) Green: potential partial models developed by students

Red: Teaching methods to support conceptual change Blue: Theoretical frameworks underpinning lesson progression

2.4 Multiple Representations for Learning Chemistry

As previously discussed in Chapter 1, Johnstone (1991) and Gabel (1999) propose that chemistry be represented in three ways: macroscopic (what is observed); sub-microscopic (visualization of molecules and molecular motion); and symbolic (representation through the use of symbols, such as chemical formulas, numbers and mathematical equations). Mahaffy's Tetrahedral Model (2006) of science understanding includes a fourth dimension, the human element, which addresses the historical and societal contexts of science. To truly gain an understanding of concepts in the physical sciences, students need to be able to translate from one form to another depending on the stage of reasoning (Adadan and Savasci, 2012; Chandrasegaran, Treagust and Mocerino, 2008), and integrate or explain the interconnectedness between the representations (Chandrasegaran, Treagust and Mocerino, 2008; Krajcik, 1991). Ideally, understanding of a target model occurs when students are able to create coherent and simultaneous connections between these four representations. Thus, teaching strategies should incorporate all four representations.

Research into the efficacy of using multiple representations as described by Johnstone (1991) and Gabel (1999) suggests that emphasizing multiple levels of representation generally improves student understanding of various concepts such as chemical reactions (Chandrasegaran and Treagust, 2008). For example, in 2008, Chandrasegaran, Treagust and Mocerino conducted a study where students learning about chemical reactions participated in a supplementary program that emphasized three representations (macroscopic, submicroscopic and symbolic). Results showed improved scores for students participating in the supplementary program versus the control group.

The authors also demonstrated that in both groups, several alternative conceptions persisted. As Tytler explained, "This is not unexpected as students' conceptions are deep-rooted and often 'have proved surprisingly difficult to shift, and can offer a serious barrier to effective teaching' (2002, p. 15 as cited in Chandrasegaran *et al*., 2008, p. 246). The tenacious nature of alternative conceptions will be discussed later in the literature review.

Given the results of this study, Chandrasegaran and colleagues suggest that classroom practices include, (but are not limited to):

- greater emphasis on use of representations;
- providing students with opportunities to perform experiments, observe and discuss representations, then follow up with further demonstrations and/or experiments;
- addressing and challenging students' conceptions and conceptions found in literature (to be discussed in following sections); and
- using multi-media software and computer animations that address the three modes of representation.

Mahaffy's Tetrahedral model is one of the pedagogical frameworks underpinning the Manitoba grade 11 chemistry curriculum (Manitoba Education Citizenship and Youth (MECY), 2006) and is demonstrated within learning outcomes (Lewthwaite and Wiebe, 2010). As one example, in the Grade 11 *Gases and the Atmosphere* unit, the specific learning outcome related to Boyle's Law, C11-2-05, states "Experiment to develop the relationship between the pressure and volume of a gas using visual, numeric and graphical representations. Include: historical contributions of Robert Boyle." (MECY, 2006, p. 22)

Students are expected to engage in hands-on activities, such as experimental work, to observe the relationship between pressure and volume (macroscopic) and to understand why the phenomenon occurs through molecular (sub-microscopic) visualization/models. Based on the relationship between the macroscopic and sub-microscopic, students can then solve quantitative (symbolic) problems through the use of formulas and graphical representations (Lewthwaite and Wiebe, 2010). The emphasis on these three representations is demonstrated in an example problem suggested in the Manitoba grade 11 chemistry curriculum (MECY, 2006, p.24). In this problem, pressure is calculated given a decrease in volume (symbolic representation). It is suggested that students include macroscopic and sub-microscopic drawings with their answers that show the change in volume and the relative spacing and numbers of gas particles. As well, students are expected to apply Boyle's Law within a historical context. In this case, the contributions of Robert Boyle address the human element (Lewthwaite and Wiebe, 2010; MECY, 2006).

For the purposes of the study described here, the human element is addressed by discussing and participating in a scuba diving activity; discussing applications to flight and viewing a video on the ill-fated Helios Flight #522 that crashed due to inadequate cabin pressurization; and a discussion with professional scuba diver Dave Anderson, who manages a local scuba diving business, has conducted underwater experiments for scientists, and is a deep-sea recovery expert for various industries, and police agencies in western Canada.

In order to facilitate conceptual understanding through multiple representations, during the course of each lesson of the teaching intervention students are asked to justify and critique their models of pressure and volume based on macroscopic observations, sub-microscopic visualization, symbolic representations, and through discussion of personal experiences and information they've obtained through various means (human element). In class, the teacher also discusses student partial models and target model in terms of multiple representations. Also, when possible, physical models and computer simulations that simultaneously show macroscopic, microscopic and symbolic representations are used.

In formal assignments, students are required to explain their answers using macroscopic, sub-microscopic and symbolic representations, similar to the recommendations in the Manitoba Curriculum (MECY, 2006, p. 24). Reference to this method and how it relates to the overall instructional framework is summarized in Figure 2.1 in red.

2.5 The Use of Physical Models in Learning Science: Rationale for the Physical Models Used in the Teaching Intervention

The use of models and analogies can facilitate understanding of target models by simplifying the concept and helping the learner to focus on specific targets, and, in the case of analogies, by relating the as-yet unknown concept to something known (Boohan, 2002; Harrison and Treagust 1996). Physical models and analogies can be simple or detailed and complex, and both share common characteristics with the concept being taught. However, they are also limited in that they are not exact replicas of reality (Boohan, 2002; Harrison and Treagust, 1996).

In addition, studies conducted by Ardac and Akaygun (2004) suggest that computer models that display the three modes of representation (macroscopic, microscopic, symbolic) simultaneously help students understand the particulate model of matter and phase changes. Liu (2006) provided evidence confirming that computer models combined with hands-on activities support student learning of temperature-pressure relationships. Thus, combinations of static 3D physical models, pen and paper models, and computer models that represent the macroscopic, microscopic and symbolic modes of science thinking, used in conjunction with hands-on activities should improve science learning.

In summary, Wu and Shah (2004) suggest that physical models can facilitate visual-spatial thinking for learning chemistry concepts by:

1. providing multiple representations and descriptions;
2. making linked referential connections visible;
3. presenting the dynamic and interactive nature of chemistry;
4. promoting the transformation between 2D and 3D; and
5. reducing cognitive load by making information explicit an integrating information for students.

2.5.1 Complex versus simplified models. There is some debate as to the effectiveness of using simplified intermediate models versus students using more accurate, detailed models such as computer simulations (Clement, 2000). In a 1996 publication of Harrison and Treagust, when looking at high school students' models of atoms and molecules, they suggest that, "…whenever an analogy or model enters the classroom discourse, teachers should consciously ensure that the analogy is familiar and that they make the effort to identify both shared and unshared attributes with the students" (p. 532).

In the current study of pressure and Boyle's Law, for more sophisticated concepts a simplified physical model was initially shown and then compared to more accurate models. For example, when demonstrating the effects of increased ambient pressure when scuba diving, students are given the simplified ear model diagram (see Methodology) that shows only the ear canal, tympanum, middle ear and Eustachian tube. The tympanum is shown to be in a vertical position when equalized, and in a concave or convex position during pressure differences. All other parts of the ear are eliminated in order for students to focus in on target anatomical structures (B. Lewthwaite and B. McMillan, personal communications, date unknown). Students are then shown a large-scale replica of the ear, a computer simulation, and later, photographs and videos of people who have ear barotraumas. These complex models were compared to the simplified physical model of the ear to show students the shared and unshared attributes.

2.5.2 Multiple representations in physical models. It was difficult to find models that address could all three representations (macroscopic, sub-microscopic and symbolic) simultaneously. If possible (or desirable), combinations of physical models were used. In the example described above, the pen and paper simplified diagram showed macroscopic, sub-microscopic and symbolic representations. In the computer simulation, macroscopic and symbolic representations were shown and compared to the simplified diagrams. In the video, there were only macroscopic representations of footage from patients suffering from ear barotraumas.

In this particular example, the comparing of multiple models is used to satisfy the guidelines suggested by Wu and Shah (2004). However, not all guidelines were met for each physical model presented during the teaching intervention. This is due to time limitations and available resources. Also, students were only tested on the simplified model of the ear anatomy and ear barotraumas as it is the model used for students certifying for their open water diving certificate (PADI, 2009), and there was not enough time in the chemistry course for complete biology/physiology lessons.

2.6 Relationship Between Conceptual Change Theory and the Generative Learning Model

2.6.1 Conceptual change theory. According to the framework developed by Posner, Strike, Hewson and Gertzog (1982) and summarized by Atasoy, Akkus, and Kadayifci (2009), in order for conceptual change to occur (i.e., the development from initial mental models to partial models to the target model), learning situations should address each of the following four conditions:

1. Dissatisfaction. Students should be *dissatisfied* with their current mental model. Student mental models are tested against sensed experience before it is rejected or considered successful (Osborne and Wittrock, 1983). In this case, the "sensed experience" is in the form of a teaching strategy such as a discrepant event demonstration, augmentation activities and/or collaborative "observe and explain" challenge questions (Atasoy *et al*., 2009) that students can test their mental models against. At this stage, teachers and students need to determine pre-conceptions (alternative conceptions and nascent conceptions in line with scientific models) and identify the experiences students use to build these conceptions.
2. Intelligible. The new conception (or target model) should be understandable or *intelligible* to the student. As suggested by Atasoy and colleagues (2009), using analogies in teaching may help students to develop an understanding of new

concepts. Computer simulations and strategies addressing Jonassen, Pick and Wilson's (1999) attribute of intention ("Why are we doing this?") may also facilitate understanding. The use of approaches such as these should help to make a concept "intelligible".

3. Plausible. The new model should "make sense". That is, it should be logical and in harmony with existing conceptions. Liu (2004) suggests using strategies that demonstrate the relationships between concepts. Learning situations where students use multiple methods to demonstrate such relationships, and having students describe the relationship between microscopic, macroscopic, symbolic, humanity (Mahaffy, 2006) may also assist students in their understanding new concepts.
4. Fruitful. The new concept should be applied to other situations and new fields. The learning situation provides opportunities for students to use the new concepts in other fields or applications. Approaches in science education that focus upon conceptual change have been shown to be effective in science education and other areas (Atasoy *et al*., 2009). As described in the following section, this is related to Jonassen, Pick and Wilson's (1999) attribute of using authentic or constructive activities.

These conditions can be directly related to the Generative Learning Model, which explains how learners process information to create mental models.

2.6.2 Generative learning model. Osborne and Wittock, developers of the Generative Learning Model (1983), contend that learning is an active, constructive process. Students develop models or conceptions to explain different phenomena long before they experience any formal science teaching (Ibid., 1983). These pre-instructional conceptions are based on personal experiences and, many times, are in conflict with current, scientifically accepted models. These so-called "alternate conceptions", generated from previous experiences, are often tenacious and difficult to change with traditional teaching methods (Osborne and Wittrock, 1983; Driver, Guenesne, Tiberghien, 1985; Benson, Wittrock and Baur, 1993; Chandrasegaran, Treagust and Mocerino, 2008). Thus, it is crucial for teachers to first determine and understand student pre-conceptions, and then develop appropriate activities that build on or modify these conceptions (Osborne and Wittrock, 1983; Chiu and Liang, 2004).

The learning process starts with students attending to, then perceiving information. Links are made to memories, and a tentative, mental model is made. This mental model is tested against sensed experiences and long-term memories. If successful, an active construction of the interpretation of the information occurs, and inferences are drawn. That is, the mental model is coded and incorporated into long-term memory.

Based on the Generative Learning Model (Osborne and Wittrock, 1983), and summarized by Freyberg and Osborne (1985) in an *ideal* situation, and within the context of this study, conceptual change is thought to occur in the following manner:

1. Attention. In a busy classroom, students actively select and pay attention to certain environmental inputs and ignore others.
2. Type of Input. As Freyberg and Osborne (1985) demonstrate, for most students, simply hearing a teacher's statement is not enough for students to attend to and learn the concept that is being taught. Thus, it is important to ensure the students are attending to the information on hand using different methods. In this study, the teacher asks the students to draw or write down their individual models on paper and

to predict what will happen in an up-and-coming demonstration. This requires the students to pay attention to the task on hand.

3. Links with memory. Students access memories that *they consider applicable*, and create links with the input to generate a mental model. Some of these links are nascent with scientific or target models and facilitate understanding; some have one or more common characteristics, but are not actually helpful in understanding the target model; and some links are made that were not intended by the teacher.
4. Model construction**.** Learners access long-term memory stores to actively create meaning from the sensory input. In this case, students access memory to predict what will happen during a demonstration.
5. Testing**.** Learners then test their models against experiences and memory. In this study, the "sensed experience" is in the form of a teaching strategy such as a discrepant event demonstration, augmentation activities or collaborative "observe and explain" challenge questions (Atasoy *et al.*, 2009) that students can test their mental models against. If the sensed experience goes against their initial mental models, *dissatisfaction* (Posner *et. al.*, 1982) occurs.

The demonstrations employed in this study are intended to cause dissastisfaction, also referred to as disequilibrium, for students with conceptions and models not in keeping with the scientific and/or target model. Students have the opportunity to modify and build on their models through small-group and whole-class discussions, again, testing partial models against the collective experiences and memories of classmates. At this point, the teacher introduces the target model. Through classroom discussions, the teacher can address and re-frame any alternative conceptions that may hinder understanding of the target model. The teacher may also use computer simulations, metaphors, analogies and other methods to make the target model intelligible. Explanations using multiple representations (Mahaffy, 2006) are also used to aid in making the target model intelligible.

If tenacious alternative conceptions have been sufficiently refuted or changed, and the target model is intelligible for the student, then the target model becomes *plausible.* That is to say, the target model "makes sense". It is logical and in harmony with existing conceptions. For example, in a previous session of the scuba project, a student believed that ambient pressure increased with increased elevation. This was based on her observations of helium balloons that floated to the ceiling in her room. After a few days, the balloons shrunk. The teacher directly addressed this pre-conception by explaining that the helium diffused out of the balloon, and explained the process by drawing a "before and after" diagram that included macroscopic, microscopic and symbolic (hypothetic pressure units) representations. Since the existing pre-conception was addressed, the target model (pressure decreases with increased elevation) became plausible, as it was no longer in conflict with her pre-conceptions, but in harmony with other, helpful conceptions.

6. Subsuming target model. At this point, the target model may be subsumed into memory. In some cases, the target model is readily integrated into already existing ideas stored in long-term memory. In others, extensive restructuring of ideas and re-framing of existing memories may be required to successfully subsume the target model. In the case of the learner discussed above, the discrepant event demonstrations and the re-framing of her experiences (why the helium balloon

shrunk) helped to restructure her ideas, and the target model was now in harmony with her conceptions and experiences. In essence, the target model "made sense", or was *plausible* (Posner *et. al.*, 1982). Furthermore, as the target model was applied to various examples and demonstrations throughout the teaching intervention successfully (to this student at least), the target model was *fruitful* (Posner *et. al.*, 1982).

In the event that the target model can be understood by the student (is *intelligible*), "makes sense" and is in harmony with consisting conceptions (*plausible*), and can be used in other applications successfully (*fruitful*), the target model will be stored in long-term memory (Posner *et. al.*, 1982).

7. Target model integration. Freyberg and Osborne (1985) explain that initially, the learner subconsciously places some status on the new model. The new model and previously existing models/ideas are held simultaneously. Over time, the status of one model may increase while the other decreases. Intelligibility, plausibility and fruitfulness (Posner *et. al.*, 1982) as well as emotional and social factors influence the status of the competing models and ideas.

Osborne and Wittrock (1983) suggest many conceptual change strategies based on the generative model. These strategies include providing students with opportunities to test their constructions against previous knowledge, to use their constructions to make predictions, to use discrepant events to facilitate modification of conceptions, to make many connections, and to construct information through multiple modes of representing.

With respect to science teaching, research conducted by Coustu, Ayas, Niaz, Unal, and Calik (2007) demonstrates that conceptual change activities are fairly effective in promoting student understanding of boiling. Furthermore, there is specific reference in the forward of the Manitoba Chemistry Curriculum to the importance of prior knowledge (pre-conceptions), the construction of meaning in both a generative learning sense (Osborne and Wittrock, 1983) and social constructivist/model building sense (Woodruff and Meyer, 1997); as well as the importance of educational research to inform teaching practices:

> Ideas and understandings that students develop should be progressively extended and reconstructed as students grow in their experiences and in their ability to conceptualize more deeply. Learning involves the process of linking newly constructed understandings with prior knowledge and then adding new contexts and experiences to current understandings. It is increasingly important that chemistry educators draw professional attention to how fundamental research in learning theory will affect their efforts in the science classroom. (MECY, 2006, p. 3)

Based on the Generative Learning Model (Osborne and Wittrock, 1983) and Conceptual Change Theory (Posner *et. al*, 1982), the structural basis for in-class lessons is summarized below, and can be found in 2.1 in blue.

1. Determine conceptions before instruction.
2. Challenge alternative conceptions during instruction. Posner *et. al.* (1982) describes this stage of the teaching process as creating "dissatisfaction". During this time, students test models against sensed experience and long term memory as discussed in the Generative Learning Model (Osborne and Wittrock, 1983). Students also use multiple representations (Mahaffy, 2006) to gage whether their mental models are

plausible. At this point, dissatisfaction may occur through small and large group discussions, or through discrepant event activities.

3. Introduce scientific models. At this point, the scientific or target model is introduced. In order to be effective, the model should be intelligible and plausible (Posner *et. al.,* 1982). Mahaffy's model (2006) is used to gage if the model is intelligible and plausible. During this time, the teacher may use different strategies such as suggested analogies, building physical models, and computer simulations to reinforce the target model.
4. Reinforce scientific concepts. Posner and colleagues (1982) explain that in order for learning to occur, students need to successfully apply the new concepts in other fields or applications. When students can use "fruitful" scientific models to successfully make predictions, active interpretation of the information occurs and inferences are drawn. This information is coded and stored into long term memory, and learning has occurred (Osborne and Wittrock, 1983).

2.7 Characteristics of Meaningful Learning

Jonassen, Peck and Wilson (1999) contend that there are five interdependent characteristics of meaningful learning. They state that meaningful learning activities are active, constructive, intentional, authentic and cooperative. and that these five attributes are inter-related and interdependent (Figure 2.2). If a lesson or series of lessons includes these five attributes, meaningful learning should result.

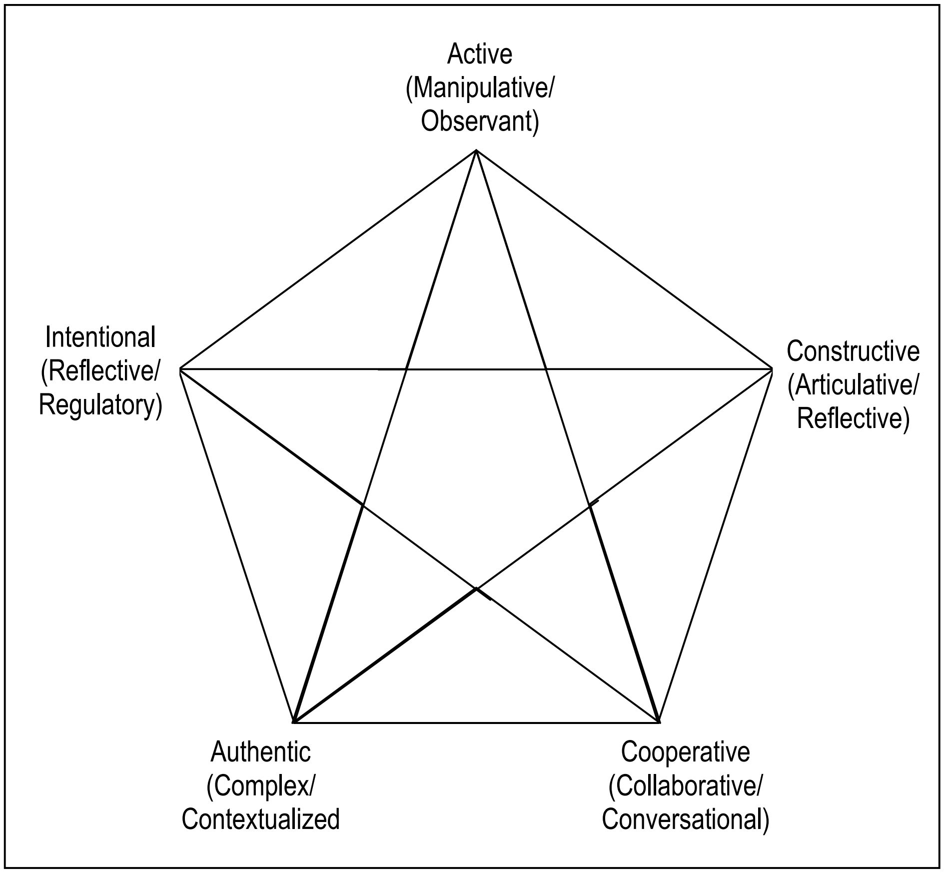


Figure 2.2. Five Attributes of Meaningful Learning Are Interdependent (Jonassen, Peck and Wilson, 1999, p. 170)

In active lessons, "…learners are actively manipulating the objects and tools of the trade and observing the effects of what they have done" (Ibid., 1999, p. 170). Active lessons encourage students to attend to the task at hand and perceive the information (Osborne and Wittrock, 1983). However, active lessons alone are not sufficient.

Students must construct meaning from these activities through reflection, generating mental models, testing these mental models and refining them to create more complex models. As previously discussed, this is in agreement with the suggestions of Woodruff and Meyer (1997) and Osborne and Wittrock (1983). As recommended by

Osborne and Wittrock (1983) and Anders and Guzzetti (2005), Jonassen and colleagues (1999) suggest using "discrepant events" or "augmentation activities" to stimulate model building and providing opportunities for students to test and modify their mental models.

Learning must also be intentional. Students and teachers must be able to answer the question, "Why they we doing this?" Learners should be able to articulate what they are doing, discuss the strategies they are using, communicate the decisions they are making, describe the answers they are constructing, and reflect on the process and outcomes.

Learning situations should be authentic. Jonassen and colleagues (1999) maintain that learning in the classroom is generally algorithmic, distilled into its simplest form, and taught in isolation from reality. Thus, students have no idea how to relate their skills and knowledge to new contexts. The authors stress the importance of providing real-world learning tasks that promote higher-order thinking skills and ensure that students relate learning to new situations.

> A great deal of recent research (described in Chapters 3, 4, and 7) has shown that learning tasks that are situated in some meaningful real-world task or simulated in some case-based or problem-based learning environment are not only better understood, but are also more consistently transferred to new situations. And we need to engage students in solving complex and ill-structured problems as well as simple problems. (p. 172)

Finally, Jonasson, Peck and Wilson (1999) argue that learning activities should be cooperative and collaborative. Humans naturally work cooperatively when knowledge building. Thus, learning strategies should be collaborative, and conversation amongst students should be encouraged.

2.8 Rationale for Teaching Strategies Used During In-Class Lesson and During the Scuba Activity: Integration of Pedagogical Frameworks into the Teaching Intervention

2.8.1 Identifying pre-conceptions. As identifying and challenging student pre-conceptions is an important method to support conceptual change (Osborne and Wittrock, 1983; Chiu and Liang, 2004), the sequence and structure of the in-class lessons are based on the work of Basca and Grotzer (2001). Basca and Grotzeer created a pressure unit based on student alternative conceptions, which was demonstrated to be fairly effective in promoting conceptual change. This will be discussed in more detail later in this chapter.

2.8.2 In-class lessons. In this pressure and Boyles Law study, the in-class teaching strategies suggested by Osborne and Wittrock (1983) and expressed in the Manitoba Chemistry Curriculum (MECY, 2006) are incorporated into Woodruff and Meyer's (1997) approach. Students are asked to construct and test their individual models, and then discuss and critique these models with their peers. This approach is *intentional*, (Jonasson, Peck and Wilson, 1999) as students are asked to determine "how something works", *collaborative* (Ibid., 1999) as students work together to create partial models and understand target models, and *constructive* as students are asked to create meaning through generating these models. In turn, the suggestion to use multiple modes of representation (Mahffy, 2006; Johnstone, 1991; Osborne and Wittrock, 1983) is integrated into the lessons, as students are required to use macroscopic, submicroscopic, symbolic and humanistic representations (Mahaffy, 2006) to justify and critique their models (including the target model). Some lessons are *active* in that students will manipulate computer simulations or participate in laboratory activities. In other lessons, though less active, students will observe discrepant event demonstrations. The lessons, to a greater or lesser extent, are also *authentic* in that students discuss and/or apply the concepts in real-world contexts such as scuba diving and flight.

2.8.3 Scuba activity. The current implementation document for grade 11 chemistry in Manitoba suggests that the concepts of pressure and Boyle's Law can be applied to scuba diving and encourages teachers to discuss these concepts in the context of scuba diving (Manitoba Education, Citizenship and Youth, 2006, pp. 15-27).

As previously noted, meaningful learning occurs when conceptual change strategies provide students with the opportunity to create and test mental models, understand the four modes of representation, actively manipulate objects, and become immersed in a "real world" context or situation. In regards to the characteristics of meaningful learning, the strategy is *intentional*, *contextual,* and *authentic* in that the students are applying the gas laws to learn scuba skills, and they discuss their experiences with Master Diver Dave Alderson. The strategy is *collaborative* in that the experiments and learning to dive are accomplished in groups. The strategy is *constructive* as students are encouraged to construct and apply their models in a scuba context. Not only would the students learn the concepts in a classroom setting, they would also see and feel, first-hand, the effects of the concepts they are learning.

2.8.4 Boyle's Law experiments. Bopegedara (2007) reports that students find it easier to derive the gas laws through experiments and recall the graphs plotted rather than memorizing from a textbook. In this case, the syringe experiment suggested in the

Manitoba chemistry curriculum (MECY, 2006) is used to help students understand Boyle's Law. As well as plotting graphs, students are asked to show macroscopic and microscopic representations of certain data points, and to discuss Boyle's Law using "real world" applications (humanistic representation). This experiment is repeated in the scuba diving activity and compared to the in-class experiment. Conducting laboratory investigations should meet the five characteristics of meaningful learning in a similar manner noted in the scuba activity.

2.9 The Role of Alternate Conceptions in the Learning Process

2.9.1 Identifying and Confronting Alternate Conceptions: Rationale for Use in the Teaching Intervention. Upon reviewing numerous articles in science education, and based on their own observations, Akkus, Kadayifici and Atasoy (2011) suggest that at the beginning of instruction, many teachers do not identify students' learning difficulties, nor do they identify and challenge students' alternate conceptions in an effective manner. As previously discussed, it is important to identify and challenge student alternative conceptions including those found in the literature in order to prevent the development of alternative models (Akkus, Kadayifci, and Atasoy, 2011; Hamza and Wickman, 2008; Garnett and Treagust, 1992). In this section, the alternative conceptions found in the literature, the theoretical understanding of how these alternate conceptions and models are formed, and a framework for analyzing alternative models are discussed.

2.10 Student Alternate Conceptions of the Particulate Nature of Matter, Pressure, Boyle's Law and Ear Physiology

2.10.1 Alternate perceptions of the nature of gases. Benson, Wittock and Baur (1993) found that 25% of the high school participants in their study viewed gases as particulate with large empty spaces between the gas particles, 26% drew the gas particles closely packed together and filling up the container, and 39% shaded in the container. When representing a vacuum, many of the participating students drew fewer particles randomly distributed in the flask with larger spaces between each particle. A few students, however, drew particles in the bottom of the flask and represented the vacuum by leaving the top of the flask blank or empty.

2.10.2 Alternate perceptions of the nature of liquids. In the study discussed above, Benson, Wittrock and Baur (1993) also found that many students viewed the behavior and structure of gases as similar to the behavior and structure of liquids. Alternate conceptions regarding the relative spacing of particles in the liquid phase and conceptions of the compressibility of liquids may be derived from teacher alternative conceptions and misleading textbook diagrams and explanations. For example, on the Anrophysics website (Anrophysics, 2012), gas particles are spaced far apart, solid particles are packed together, and the spaces between water particles are intermediate between the two. This conception of the relative spacing between liquid particles was also demonstrated in three different science museums in three different provinces in Canada. The exaggerated spaces between water particles may lead students to conclude that liquids are moderately compressible.

Besson (2004) found that the majority of students (59%) believed liquids are incompressible, 38% believed liquids are compressible, and 12% thought that liquids were compressible, but only to a very small extent. Besson (2004) maintains that many times confusion can occur because some textbooks describe liquids as incompressible, whereas other sources describe liquids as being slightly compressible (Purdue, 2012) and do not qualify that liquids are compressible to such a small extent that the volume change is negligible.

2.10.3 Alternative perceptions of pressure. Basca and Grotzer (2001) developed a pressure unit that addressed the alternate conceptions held by students. Alternate conceptions of pressure and the creation of alternative pressure models identified by Basca and Grotzer (2001) are summarized below:

- students created alternative models based on what they could sense but did not consider variables they could not directly sense;
- students reasoned linearly, considering only one aspect of pressure (internal or ambient) rather than considering the entire system (both internal and ambient pressure);
- students thought of pressure as directional (pushing down) rather than omni-directional; and
- students used pressure and force interchangeably.

2.10.4 Alternate perceptions of air pressure. In 1992 de Berg showed that an alternate conception of students was that enclosed air that is not being compressed exerts no air pressure. In fact, many middle and high school students do not realize that gases exert pressure (Jarrett and Bulunuz, 2009; de Burg, 1995) and that with higher elevation air pressure decreases (Dove, 1998; Basca and Grotzer, 2001; Edwards, personal communication, 2009).

In all four of the previously mentioned scuba sessions, the alternative model "pressure increases with altitude" was also noted. This was derived from experiences observing balloons shrinking as they "flew up" into the air and feeling "pressure in the ears" when flying in an airplane or going up in elevators and hills. These experiences combined with linear reasoning (pressure described as internal or external rather than systematic) appeared to contribute to this alternate model.

2.10.5 Alternative conceptions of Boyle's Law. The alternate conceptions of pressure can affect student understanding of Boyle's Law (Basca and Grotzer, 2001). For example, Anders and Guzzetti (2005) state, "many student have the alternative conception that as pressure increases volume increases." (p. 69). In other words, many students have a linear model of pressure as described by (Basca and Grotzer, 2001). They attribute this alternative conception to previous experiences in blowing up balloons:

> The associated conception results from students' personal experiences in blowing air into a balloon and watching it inflate and grow larger. Students think that the amount of air and its pressure inside the balloon increases, causing the volume of the gas to increase. They do not think about the air pressure outside of the balloon. (Anders and Guzzetti, 2005, p. 93)

de Berg (1995) conducted a study focused on student understanding of volume, pressure and mass. Participating students answered "qualitative" questions that asked them to state whether the mass, volume or pressure of a confined gas increases or decreases. The students then answered quantitative questions where the pressure or volume of a gas was given as a number with units. de Berg found that:

- 34% - 38% of 17 and 18-year old students did not understand the volume and mass of gases in various states of compression.
- Students who scored highly on the qualitative questions were more likely to do well on the quantitative questions.

- Arithmetic averaging (using the average between two given pressures or volumes) to determine the pressure or volume was often used rather than inverse proportion (using the inverse of the pressure or volume ratio) to solve pressure and volume problems. Thus, students who were able to answer questions with a 2:1 inverse ratio could not necessarily answer questions with other ratios (such as 3:1)
- Males performed significantly better than females on 2:1 inverse ratio questions.

Though alternate conceptions are not discussed in this article, it is interesting to note that students who performed well on qualitative questions were more likely to do well on quantitative questions. It may be that in these cases, students' macroscopic and microscopic mental models were more in keeping with scientific models. Also, as all of the students would have taken gas laws previously, it is also important to note that just over one-third of the students still had alternate conceptions. This lends credence to the tenacity of alternate conceptions.

2.10.6 Alternate conceptions of ear physiology. Mak, Yip and Chung (1999) identified that science teachers commonly forgot to address the role and physical placement of the Eustachian tube.

In all four of the previous scuba sessions, two alternate models were observed. First, many students thought that the ear drum was either permeable or behaved like a door and could open and close to let water or air through to the middle ear. Second, students attributed popping ears to the middle ear expanding and then contracting back into place or the ear drum popping back into place rather than the opening and closing of the Eustachian tubes.

Alternate conceptions identified through previous sessions of the scuba project and in the research literature are used to inform and design the teaching intervention as follows:

1. As discussed in the introduction, physical models of the ear were built to directly address alternate conceptions of ear equalization.
2. Discrepant event demonstrations and the order of these demonstrations were chosen based on the suggestions of authors (for example, Grotzer and Perkins, 2003; Basca and Grotzer, 2001; Anders and Guzzetti, 2005) that considered the alternate conceptions of students when designing teaching interventions.
3. Students wrote and discussed their conceptions, and the teacher attempted to challenge experiences and conceptions not in keeping with the target model.
4. Distractors for the two-tiered multiple choice test questions are based on observed and published alternate conceptions.

2.11 The Development of Alternate Conceptions from a Generative Learning Model Perspective

Alternative conceptions are tenacious and difficult to change especially when they are rooted in everyday life experiences. If a concept does not make sense, students tend to hold onto their alternative conceptions (Treagust, Druit and Fraser, 1996). Due to the tenacity of alternative pre-conceptions, many times, conceptual change does not occur in an ideal manner, resulting in various outcomes where students end up with alternative models rather than target or scientific models (Freyberg and Osborne, 1985). Freyberg and Osborne (1985) explain the process of either reinforcing pre-conceptions or generating alternative models as follows:

1. Attention. Students must ignore other environmental inputs and pay attention to the learning activity at hand. This may not happen.
2. Types of input. Many times, teachers state a fact, and expect the students to understand and remember it. However, simply stating a concept to be learned provides "aural input which is simply a set of sounds" (Freyberg and Osborne, 1985, p.83) with no inherent meaning. The information is not necessarily attended to or transferred. Even if other methods are used (demonstrations, activities, and the like), this still may not be enough for the information to be attended to or transferred.
3. Links with memory. Students access memories which "…they consider important" (Freyberg and Osborne, 1985, p.83) and create links with the input to generate a mental model. Since the links to memories are subject to the student's identification of relevance, they may:

- access memories with a common characteristic, but that are not actually helpful in understanding the model;
- ignore memories that may actually be useful for understanding the target model, but are not identified as having a common characteristic; and
- create links that were not intended by the teacher, for example, a student made a link between magnetic flux and soldering flux used by her father (Freyberg and Osborne, 1985).

  Similarly, in a previous session of the scuba project, students were asked to predict what would happen to the volume of a balloon when it is brought to the top of a mountain (assuming temperature stays the same). A student described pressure in his ears increasing when he went flying. The links created were "increased pressure" with "increased altitude". Though pressure and altitude are the common characteristics between memory and the concept, it was not actually helpful in understanding the model.

4. Model construction. Learners access long-term memory stores to actively create meaning from the sensory input. The learner cited in the example given by Freyberg and Osborne (1985) suggested the student may have a mental model for "magnetic flux through a coil" (p. 83) which was not in keeping with the target model intended by the teacher. In the scuba example noted above, students access long-term memories to create a model about pressure. In this case, as the student linked "pressure in the ears" with "increasing altitude", the mental model produced was "pressure increases with elevation".

5. Testing. Learners then test their models against experiences and memory. Freyberg and Osborne (1985) report that the meaning the student made about magnetic flux did not relate to her memories or to the target model discussed in class. Though dissatisfaction was achieved, "The discrepancy was not enough to impress her" (Freyberg and Osborne, 1985; p. 83).

   In regards to the learner discussed who related increased pressure with increased altitude, during the small group discussion, another student mentioned that as balloons go up into the sky, they shrink. Thus, the experience of the learner and peers in the group confirmed that "pressure increases with elevation". Afterward, the teacher explained that, in fact, pressure decreases with elevation, and the balloon would expand. In a later lesson, the teacher gave a demonstration that showed that pressure decreases with elevation. Again, even though the discrepant event contradicted the initial mental model, it failed to impress the learner.

6. Subsuming target model. At this point, the target model may be subsumed into memory. As previously discussed, the target model may either be in harmony with existing conceptions and subsumed or there needs to be comprehensive restructuring before the target model is subsumed. If the target model is not in harmony with existing conceptions, or restructuring of pre-conceptions does not occur, students may adhere to their original metal models, especially if derived from everyday experiences (Treagust, Druit and Fraser, 1996), or they may generate novel alternative models that are not in keeping with the target model.

7. Target model integration. Freyberg and Osborne (1985) explain that initially, the learner subconsciously places some status on the new model. The new model and

previously existing models/ideas are held simultaneously. Over time, the status of one model may increase while the other decreases. Intelligibility, plausibility and fruitfulness (Posner *et. al.*, 1982) as well as emotional (e.g. whether the student is having a good or bad day, self-esteem, mental health) and social factors (e.g. socio-economic effects such as poverty, religion, family dynamics) influence the status of the competing models and ideas (Freyberg and Osborne, 1985). These factors will directly influence the status of an alternative model compared to the target model.

A hypothetical situation can be used to illustrate the influence of other factors that affect model integration. Pretend that a student is a deeply religious Christian and is required to learn the Theory of Evolution. Despite many different attempts to make the concept intelligible, plausible and fruitful, this learner may hold onto the creation of humans as stated in his/her version of the Bible or subscribe to other alternative models such as Intelligent Design rather than the current Theory of Evolution.

Given the myriad of different outcomes for each step in the learning process, a number of different outcomes in regards to model building can occur (Gilbert, Osborne and Fensham, 1982). Freyberg and Osborne (1985) summarized these outcomes as follows:

1. Undisturbed children's science outcome. The alternate conceptions of older students are essentially the same as younger students. Though older students may express their conceptions in a more sophisticated manner, they are essentially the same as younger students. To illustrate this outcome, Freyberg and Osborne (1985) gave an example where a younger student described gravity as getting

stronger the further up a person travels until out of the atmosphere, whereas an adult explained that gravity increased with increased elevation by giving an example where a person jumping down from a higher point above the ground than a lower one will experience a heavier fall from the higher point. Though the adult could give a specific example of his conceptions, essentially, alternate conceptions described by the young student and the adult were the same, i.e. gravity increased with elevation.

2. The two-perspective outcome. Students simultaneously hold two models, one model used for "everyday life" and the other model for school and examinations. The "everyday life" model is an alternative or "older" model that a learner truly believes. However, the learner has also stored in memory parts of the "newer" target or scientific model, which is used in test situations. The two models tend to contradict each other, and there is no attempt to identify or diminish the contradictions (Freyberg and Osborne, 1985). For example, a 17 year-old physics student could site the inverse square law for gravitation, but believed gravity increased with elevation (Stead and Osborne, 1981).
3. The reinforced outcome. Sometimes students unintentionally misinterpret what is taught to support their alternative models. As one example, in a previous run of the scuba project, the teacher (author) described air flow "… through to the middle ear". Some students interpreted this statement as air flowing through the eardrum to the middle ear, which was in keeping with their pre-conceptions, rather than air flowing through the Eustachian tube to the middle ear, which is in keeping with the target model.

4. The confused outcome. Sometimes learners lose confidence in their mental models, but cannot construct better ones. This leads to confusion and incoherence.
5. The unified scientific outcome. This is one of the major aims of science education. Learners are expected to develop a coherent understanding of a scientific or target model that can be used to make sense of the world, successfully applied in different areas, and used in communication with others. For the purposes of this study, students demonstrate understanding of a target model when they can successfully apply the model to various applications, discuss their understanding in terms of the macroscopic, submicroscopic, symbolic and humanistic representations, and discuss/demonstrate how these representations are inter-related.

2.12 Other Sources of Alternate Conceptions

There are many difficulties encountered when learning chemistry. The effective negotiation between the different science representations (macroscopic, submicroscopic, symbolic and humanistic), teacher and student understanding of the use of models in science, and identifying and confronting tenacious alternative conceptions are all potential sources for the building of alternate models.

2.12.1 Alternate conceptions from negotiating between the macroscopic, submicroscopic and symbolic representations. The difficulties of learning chemistry when negotiating between the multiple representations include, but are not limited to the following:

- In order to understand many chemical concepts, learners must deal with three representations simultaneously (Gabel, 1999). This in itself can be difficult.
- The submicroscopic and symbolic representations are abstract and are not experienced first hand (Adadan and Savasci, 2012).
- Learners are seldom introduced to, or familiarized with, the multiple levels of representation (van Berkel, Pilot and Bulte, 2009 as cited in Adadam and Savasci, 2012, p. 518).
- Learners may have limited conceptual knowledge making the three levels of representation difficult to understand. In addition, these learners may also have poor visual-spatial ability, which may make macroscopic and submicroscopic representations difficult to interpret (reviewed in Wu and Shah, 2004).
- Teachers may move between the macroscopic, submicroscopic and symbolic representations without discussing or demonstrating how they are interconnected to form a "complete picture" of a concept (Chandrasegaran, Treagust and Mocerino, 2008).

Adadam and Savasci (2012) suggest that alternative models of chemistry concepts can occur when learners do not understand the role each level of representation plays in understanding a chemistry concept, why they are important, how they relate to each other, and how to move from one form to another effectively. They write:

> Thus, research has shown that students' failure to understand the role and meaning of each level of representation, and their inability to properly translate one form of representation into another, may result in the development of non-scientific, distorted understandings of chemistry concepts (Cheng and Gilbert,

2009; Treagust, Chittleborough, and Mamiala, 2003. (Adadam and Savasci, 2012; p. 518)

2.12.2 Alternate conceptions from inexperience with the use of models. As summarized by Coll, France and Taylor, (2005), the effective use of models may be hindered by a number of factors, including:

- Level of expertise. Younger students generally are not able to describe models in detail and are less critical of models than their older counterparts (Coll, 1999).
- Model as reality. The model is mistaken as a miniature version of reality rather than a representation of reality with limitations (Smit & Finegold, 1995; Farmer, 1994). Instead of learning the concept that the model represents, students learn the model (Thiele and Treagust, 1991, Treagust, 1993).
- Unshared features. Characteristics not shared by the model and concept can cause misunderstanding for students (Thiele & Treagust, 1991; Thagard, 1992).
- Continued use of the simplest model. When given a range of models with increasing levels of detail and complexity, some students will continue to use the most simplified model (Gilbert & Osborne, 1980).
- Application. Some students have difficulty applying the model in different contexts (Gilbert and Osborne, 1980).
- Visual imagery. Some students have difficulties visualizing the model and its applications (Treagust, 1993).
- Mixed models. Some students may mix their models. As previously described, this could lead to two-perspective outcomes and confused outcomes (Freyberg and Osborne, 1985)

2.12.3 Alternate conceptions from observations and experiences. Other sources of alternative conceptions in Adadan and Savasci's (2012) review include:

- Observation and interaction with the world around them;
- Misinterpretation of passages in textbooks;
- Use of everyday language that is misleading;
- Alternative conceptions shown in textbook diagrams;
- Misinterpretation of the teacher's instruction; and
- Teacher alternative conceptions.

2.13 Analyzing Alternate Conceptions: Rationale for the Theoretical Frameworks Used to Analyze Alternate Conceptions

As summarized by Adadan and Savasci (2012), there are two major lines of evidence showing that alternate conceptions may be theory-like or inconsistent. Theory-like alternate conceptions are, " …stable, coherently organized, persistently used, recognized as useful in a number of tasks (Blown and Bryce, 2006; Vosniadou, 2002) " (Adadan an Savasci, 2012, p. 515). In other words, theory-like conceptions do not change for different situations (stable), have a logic and/or method that organizes the concepts that support the model and its use for different tasks (coherently organized), and are used on a regular basis without being altered (persistently used). In relation to the outcomes described by Gilbert, Osborne and Fensham (1982), summarized by Freyberg and Osborne (1985), and as a lens used in the analysis in this study, theory-like conceptions would be used in undisturbed children's models and in reinforced models where stable, tenacious alternate conceptions are used for different tasks.

Conversely, inconsistent conceptions are "…likely to be incoherent, unstable, fragmented (p-prisms) context-bound and transient"(diSessa, 1993; Tytler, 1998 as cited in Adadan an Savasci, 2012, p. 516). These conceptions are used *in situ* (Taber, 2008) by manipulating several concepts to create models specific to one particular context. For example, in the third run of the scuba program, a learner was able to use the target model to determine how ear pressure was equalized while descending, but created a different model for ear equalization while ascending. Furthermore, when explaining reverse block (the inability to equalize pressure while ascending and sometimes descending), a totally different model was used in each of the cases of reverse block while ascending and descending. However, these models could not be applied to ear equalization and reverse block during flight. If the student understood the target model, this model should have been used to explain the outcomes for each situation, rather than applying four different models.

In addition, Taber (2000) showed that there are also stable models built on alternate conceptions that are used to solve different textbook problems (Palmer, 1999 as cited in Adadan and Savasci, 2012). For example, in the first session of the scuba project, two students and a certified diver used the target model of pressure and the target model of ear physiology when describing the effects of increasing and decreasing water pressure (ambient pressure) on the ear drum while scuba diving. Specifically, they were able to show that air entered or exited the middle ear via the Eustachian tube to equalize pressure on either side of the eardrum. The air pressure in the inner ear changed to match that of the ambient pressure. However, when asked about the effects of increasing and decreasing air pressure (ambient pressure) on the ear drum during ascent and descent in a plane, both learners presented an alternate model showing air entering and leaving the middle ear through the ear drum, rather than through the Eustachian tube.

For the purposes of this study, inconsistent conceptions are related to the *two-perspective outcome*, where different models are used for "everyday life" and "examination questions" (Freyberg and Osborne, 1985). The two-perspective outcome has also been expanded to include stable outcomes that are used to answer different problems in texts. Inconsistent conceptions are related to *the confused outcome* where there are fragmented models, and the student experiences utter confusion.

Chu, Treagust and Chandrasegaran (2008) developed a three-tiered method to analyze student learning and beliefs about physics knowledge. Specifically, the authors analyzed:

a) progression from everyday conceptions (pre-conceptions) to unclear scientific conceptions (partial models) to scientific conceptions (understanding the target model) and
b) beliefs about the nature of physics knowledge and how this affected student learning.

2.13.1 First level of analysis: Student conceptions. The authors first identified the pre-conceptions of ten mature physics students in the first year of an undergraduate physics course. Their conceptions were analyzed again at the end of the course. The authors classified the conceptions as follows:

- Scientific Conceptions (SC) using scientific models;
- Unclear Scientific Conceptions (USC) using unclear scientific theory;
- Everyday Conceptions (EC) using everyday experiences and everyday knowledge; and

- Unclear Everyday Conceptions (UEC) using unclear everyday knowledge (Ibid., 2008, p. 116).

2.13.2 Second level of analysis: Definitions of students' conceptions. Based on the framework of Galili and Lehavi (2006), the authors then described student understanding of physics concepts based on how the students explained a concept.

- Theoretical Definition (Verbal) (TDV): Verbal statement clearly based on physics theory (or scientific models);
- Theoretical Definition (Formula (TDF): Symbolic statement defined by a formula;
- Description Definition (DD): Non-formal and casual explanations, related to everyday experiences;
- Operational Definition (OD): Defined by a method of measurement; and
- Instrumental Definition (ID): Mentions the instrument used to measure concepts (Chu, Treagust and Chandrasegaran, 2008, p. 116)

2.13.3 Third level of analysis: students' beliefs about physics knowledge and learning physics. The authors then probed student beliefs about the nature of physics knowledge. Based on the framework of Hammer (1994), these beliefs are analyzed as follows:

- Concepts: Physics knowledge is conceptual and often represented by formalism;
- Weak Concepts: Physics knowledge is conceptual in principal, but conceptual content is not important for a basic understanding;
- Apparent Concepts: Physics knowledge is thought to be made up of a formalism that one can often associate with conceptual content (these conceptual

associations are apparent but not essential, and one makes connections as is obvious or convenient); and

- Formalism: Physics knowledge consists of formulas (Chu, Treagust and Chandrasegaran, 2008, p. 117).

The authors demonstrate that students with dynamic beliefs about physics, that is, students who believe that both conceptual and symbolic understanding are required to understand physics, were able to change their pre-conceptions to scientific conceptions. Students with static beliefs about physics, that is, students who believe that physics knowledge is purely symbolic (formula oriented) or that the goal of physics is to use formulas to solve the problems mathematically, did not appreciably change conceptions. These students spent more time trying to use a formula rather than understanding how it works and how it can be applied to different situations.

For the purposes of this study, the relationship between Freyberg and Osborne's outcomes (1985), stable and inconsistent models (Adadan and Savasci, 2011), multiple representations (Mahaffy, 2006) and the first level of analysis by Chu, Treagust and Chandrasegaran (2008) are viewed as follows:

- Scientific Conceptions (SC) using scientific models. This can be described as *unified scientific outcome*, based on stable, target models, and a clear understanding of the interconnectedness between the macroscopic, submicroscopic, symbolic and humanistic.
- Unclear Scientific Conceptions (USC) using unclear scientific theory. This includes explanations based on partial mental models, which may be stable or inconsistent,

and may indicate the expanded definition of the *two-perspective outcome*. There may be a disconnect between the multiple levels of representation.

- Everyday Conceptions (EC) using everyday experiences and everyday knowledge. These explanations would be *undisturbed children's outcomes*, or *reinforced outcomes.* There may be a disconnect between the multiple levels of representation.
- Unclear Everyday Conceptions (UEC) using unclear everyday knowledge. In relation to Freyberg and Osborne (1985), these would be the result of the confused outcome, where mental models are inconsistent. There is no understanding of the relationship between multiple representations.

For the purposes of this study, the relationship between the second level of analysis and Mahaffy's Model (2006) is viewed in the following manner:

- Theoretical Definition (Verbal) (TDV): Verbal statement clearly based on physics theory. That is, the concept is defined using the four representations.
- Theoretical Definition (Formula (TDF): Symbolic statement defined by a formula. The definition does not include macroscopic, submicroscopic or humanistic representations.
- Description Definition (DD): Non-formal and casual explanations, related to everyday experiences. This description is based on pre-conceptions.
- Operational Definition (OD): Defined by a method of measurement
- Instrumental Definition (ID): Mentions instrument used to measure concepts

For the purposes of this study, the relationship between the third level of analysis and Mahaffy's Model (2006) is as follows:

- Concepts: Physics knowledge is conceptual (macro, micro and humanistic in nature), often represented by formalism (formulas, symbolically).
- Weak Concepts: Physics knowledge is conceptual in principal, but conceptual content is not important for a basic understanding (i.e. physics knowledge is micro and macro and humanistic in nature, but not important for understanding).
- Apparent Concepts: Physics knowledge is formalism that can be associated with conceptual content (i.e. physics knowledge is symbolic and can be associated with the macro, micro and humanistic representations). Conceptual associations (macro, micro and humanistic representations) are apparent but not essential. Connections are made when it is obvious or convenient.
- Formalism: "Physics knowledge consists of formulas" (i.e. physics knowledge is symbolic)

Though probing student understanding and beliefs of the nature of physics knowledge is beyond the scope of this study, the categories used in the third level of analysis serve as the basis for analyzing student responses to questions based on multiple levels of representation.

Chapter 3: Methodology

3.1 Qualitative Research and Case Study Design: Rationale for the use of Interpretive Case Study Methods

Case studies are useful for holistic, in-depth understanding of cognitive processes and behavioural conditions from the participant's perspective (reviewed in Bogdan and Bilkin, 2007). As Zainal (2007) explains:

> Case studies, in their true essence, explore and investigate contemporary real-life phenomenon through detailed contextual analysis of a limited number of events or conditions, and their relationships. (p.1)

3.1.1 Interpretive case studies. As defined by Laws and McLeod (2004), "interpretive case studies are used to illustrate, support or challenge theoretical assumptions prior to gathering data." (p.5) An open coding technique is used to analyze the data (Strauss and Corbin, 1990). That is, the data are read and coded, and the codes are grouped into themes. These themes are compared to a theoretical framework.

In this study, pre-conceptions and post-conceptions are compared to preconceptions reported in the literature and are compared to each other in order to look for resonance. Alternative models expressed by participants at the end of the study are also coded and grouped into themes and compared to model building outcomes described by Freyberg and Osborne (1985) and multiple level of representations (Johnstone, 1991).

3.1.2 Guidelines for designing case studies. In order to be effective, case studies must be carefully constructed. Tellis suggests that when designing a case study, qualitative researchers should consider the following guidelines:

1. It is the only viable method to elicit implicit and explicit data from the subjects.

2. It is appropriate to the research question.
3. It follows the set of procedures with proper application.
4. The scientific conventions used in social sciences are strictly followed.
5. A 'chain of evidence', either quantitatively or qualitatively, are systematically recorded and archived particularly when interviews and direct observation by the researcher are the main sources of data.
6. The case study is linked to a theoretical framework. (Tellis, 1997 as cited in Zainal, 2007, p.2)

The design of this study fulfills the guidelines suggested as indicated below.

1. Though the method utilized is not the only viable method to elicit data from subjects, as the purpose of this study is to examine changes in student mental models and the experiences that contribute to the changes, it is appropriate. As previously discussed, this method is helpful in providing in-depth understanding of cognitive processes, which may not be demonstrated using quantitative methods.
2. The phenomenological design is appropriate to the research questions in that this method provides data that can be used to answer the questions. For example, in the first question, "What are the initial pre-conceptions of students in respect to pressure and Boyle's Law and what experiences shape their mental models, the conceptions and the experiences offered by the students are documented, coded and analyzed for resonance amongst the models and experiences of the different students in the study. This is also compared to pre-conceptions described in the literature as will be further discussed in this chapter.

3. The research design follows a set of procedures, to be outlined, that were accepted by ENREB and the thesis committee.
4. The scientific conventions used in this study are followed.
5. The data are systematically recorded through writing as described in later in the chapter. This is accomplished using Gobert's (2000) "learning to draw" strategy described below, pen and paper assignments, and tests.
6. This case study is linked to the theoretical frameworks described in the literature review.

3.1.3 Limitations of case studies. Two major limitations in case study methods are reliability (or rigor) and validity (or trustworthiness) (Bogdan and Bilken, 2007; Zainal, 2007; Golafshai, 2003; Yin, 1984).

3.1.3.1 Reliability or rigor. As qualitative studies use a small number of subjects, there is little basis for generalization. Rather than looking for statistical generalizations to larger populations, the aim of many case studies is to produce "theory related analytic generalizations" (Yin, 1994, p.2); where data is compared to a theoretical framework, and generalizations (or resonance) can be made in relation to the theoretical framework. For example, in this study, participant data are analyzed to determine if a number of students created models consistent with the *two-perspective* outcome as defined by Freyberg and Osborne (1985). The number of students with two-perspective models in this study cannot be statistically generalized to larger populations, but does indicate whether this is a mechanism used by students and the frequency with which it is used in this cohort.

3.1.3.2 Validity or trustworthiness. Yin (1984) states that "…too many times, the case study researcher has been sloppy, and has allowed equivocal evidence or biased views to influence the direction of the findings and conclusions" (p .21). As information is interpreted by the researcher, bias is a consideration. However, Flybjerg (2012) argues that:

> …case study has its has its own rigor, different to be sure, but no less strict than the rigor of quantitative methods. the advantage of the case study is that it can "close in" on real-life situations and test views directly in relation to phenomena as they unfold in practice. (p. 235).

Furthermore, due to the in-depth nature of case studies, many times hypotheses are found to be false. That is, one observation contrary to the proposition falsifies the proposition, and it must be altered or rejected). In fact, many qualitative researchers have reported that their pre-conceptions and hypotheses were wrong (Flybjerg, 2012). As Flybjerg explains:

> According to Campbell (1975), Ragin (1992) Geertz (1995), Wieviorka (1992), Flyvbjerg (1998, 2001), and others, researchers who have conducted intensive in-depth case studies typically report that their preconceived views, assumptions, concepts, and hypotheses were wrong and that the case material has compelled them to revise their hypotheses on essential points. The case study forces on the researcher the type of falsifications described above (Flybjerg, 2012, p. 235).

Triangulation is a method employed to improve the trustworthiness of a qualitative study (Golafshani, 2003). Researcher triangulation has been used to improve the trustworthiness of this study. Explanations and responses to clarification question written by students are examined by the collaborating teacher, and two external examiners in a manner similar to Zeedyk, Gallacher, Henderson, Hope, Husband, and Lindsay, 2003.

3.1.4 Advantages of case studies. Zainal, 2007, summarizes the advantages of case studies as follows: Examination of the data is contextual; case studies help to explain the intricacies and nuances of real-life situations that may be lost in quantitative methods; case studies help to provide insight into complex cognitive processes; and case studies help to understand unusual cases that may be unethical or problematic to explore using other methods. In regards to this study, the case study method is appropriate as the factors influencing conceptual change are contextual in nature and the building of mental models is a complex cognitive processes.

3.2 Process-folios - Rationale for Use as Both a Learning and Diagnostic Tool

Gobert and Clement (1999) conducted a study where grade 5 students learning about tectonic plates completed drawing exercises to show their mental models after reading pre-determined sections of a text. They found that who used the "drawing to learn" strategy outperformed students who summarized the text.

Gobert (2000) identified three features of student mental models: spatial, causal and dynamic. Students start with spatial models (layers of the earth), then gradually add causal (convection in the mantle) and dynamic (movement in the crust) elements to their models. As student models increase in sophistication (from special to causal to dynamic), the different parts become integrated. That is, students need to think in terms of causal relationships.

This can be related to the multiple representations of science (Johnstone, 1991). Students begin with the macroscopic (what they see) and gradually start to add the submicroscopic and symbolic representations. Understanding occurs when the three become integrated and the model can be successfully applied to different situations.

Thus, Gobert's (2000) strategy is ideal as both a learning strategy and as a source for data in this study because it:

- Creates a written record of prior models, and can be examined by both students and teachers for conceptual change (if any);
- Keeps information coherent; and
- Focuses students on developing models during class.

3.3 Rationale for the Use of Two-Tiered Diagnostic Tests as a Diagnostic Tool

In two-tiered multiple-choice tests, students choose an answer for a question then choose a reason for their answer. The reasons provided in the second tier contain the correct reason and distracters that are based on alternative student conceptions documented in the literature and/or observed in the researcher's previous science classes (Treagust, 1995).

There are many articles dedicated to the use of two-tiered diagnostic tests in chemistry education. These tests have been successfully used to assess student understanding and alternative conceptions for many topics in chemistry, such as solution chemistry (Adadan and Savasci, 2012), chemical equilibrium (Akkus, Kadayifci and Atasoy, 2011), and chemical reactions (Chandrasegaran, Treagust and Mocerino, 2007).

Adadan and Savasci (2012) and Akkus, Kadayifci and Atasoy (2011) summarize the advantages of using a two-tiered diagnostic when compared to traditional multiple choice tests. Such diagnostic tests were found to:

- Limit guesswork (as students must provide a reason for their answer, increased scores due to guessing is minimized compared to traditional multiple choice);
- Provide insight into student alternative conceptions and reasoning;
- Be used to determine the ratio and frequency of alternative conceptions;

- Less time consuming than methods such as concept mapping or using many effective methods in concert;
- Be administered to large groups; and
- Easy to mark (Liu, 2010; Millar and Hames, 2006; Othman, Treagust and Chandrasegaran, 2008 as cited in Adadan and Savasci, 2012).

3.4 Participants in Pressure and Boyle's Law Study

The study included 21 participants from two grade 11 chemistry classes offered in a large suburban high school located in Winnipeg, Manitoba. The high school services an ethnically mixed student body drawn from low, mid and high socioeconomic neighbourhoods. As identified from previous grade 10 science marks and marks from the grade 11 moles unit, these students covered a wide range of academic success. Four students were identified as having English as an additional language (EAL), and two of these four had difficulties understanding basic conversational English. All participating and non-participating students from both classes received pre- and post-instructional assessments based on concepts covered in the scuba program and completed process-folios (Gobert and Clement, 1999; Wolf, Bixby, Glenn, and Gardner, 1991) focused upon these same topics. Students who chose not to participate in the study completed the same assignments and tests given to participants. Eight of the 21 participants went scuba diving.

3.5 Overview of the Teaching Intervention

Students in both chemistry classes were given a pre-test early in the school year at which time baseline levels of science understanding were measured and demographic information was obtained. The treatment followed, and a post-test was administered approximately three days after scuba diving, which equated to approximately four and one-half weeks after the pretest. The chronology of the events and lessons during the four and one-half weeks of the study is described in the 30 pages that follow. The methods used to answer individual research questions are introduced and described on pages 128 through 135.

3.6 Teacher Orientation

Prior to the start of the study, the teacher implementing the lessons developed for the study, hereafter called the collaborating teacher, was involved in an orientation to the study. The orientation was conducted as a series of discussions about the lesson plans that also included information about the theoretical frameworks used to inform the design of the teaching intervention. In particular, emphasis was placed on an awareness and understanding of:

- The use of physical and mental models, and their limitations.
- Multiple representations of science understanding. Note, the name "sub-microscopic" was changed to "microscopic" to shorten the title and because individual atoms can be visualized with modern microscopes.
- Pre-conceptions in the literature, and addressing these pre-conceptions as well as addressing participating students' pre-conceptions brought forth in sessions of the teaching intervention.

3.7 Teaching Intervention

3.7.1 Day 1: Gas pressure, volume and Boyle's Law general knowledge pretest. Students wrote a general knowledge, two-tiered test (Treagust, 1995) based on the concepts of the particulate nature of gasses, pressure, volume and Boyle's Law (Appendix A). The test took approximately 45 minutes.

3.7.2 Day 2: Applications of Boyle's Law to scuba physiology pretest. Students wrote a test based on the concepts of the particulate nature of gasses, pressure, volume and Boyle's Law as applied to scuba physiology (Appendix B). The test took approximately 60 minutes.

3.7.3 Days 3 and 4: Probing student conceptions of the ear and scuba science

At the beginning of the lesson students were introduced to the scuba project. The collaborating teacher explained the intentions of the project. He then administered the third pre-test (Appendix C), which is a diagnostic assessment to determine student conceptions of ear equalization in different situations. Essentially, students answered the question, "Why do your ears pop?" The test took approximately 20 minutes.

A large number of students did not attempt to answer the questions, especially questions addressing the anatomy and physiology of the ear. Upon consultation with the collaborating teacher, it was suggested that the wording of the questions confused and possibly intimidated the students (especially the low functioning EAL students). The next day, an addendum was made that probed conceptions of the ear using simpler language, similar to the cognitive probe administered in the second session of the scuba project (Appendix D).

3.8 In-Class Teaching Sequences

As previously discussed in the literature review, for most of the in-class lessons students participated in a series of pressure and Boyle's Law lessons patterned after Basca and Grotzer (2001). Generally, these lessons had a similar organization and followed the format described below.

1. Students were asked to predict the effects of changing pressure in a described situation or before a teacher led demonstration. Students recorded their individual models through drawings and written explanations and described previous experiences and knowledge used to generate their models.
2. Students then worked in small groups and discussed their models with other students in the group. As their models changed, students recorded their new models, and explained how and why they may or may not have changed. This process was repeated as a whole class activity.
3. Finally, students compared their models to scientifically accepted models. Students recorded the similarities and differences in these models, and were asked which experiences and knowledge they will use to remember the scientifically accepted models. Note: For the purposes of this study, alternate conceptions were address at this time rather than throughout the discussion period, as one objective of this study was to observe students' rationales and model building during small and large group discussions.
4. At the end of each lesson, students were asked to evaluate whether or not the lesson or the demonstration was useful and to give suggestions for improving the lesson and/or demonstration.

3.8.1 Days 4 and 5: Scientific models and the states of matter.

3.8.1.1 Scientific models and the states of matter. Participating students drew models of the three states of matter (Appendix E) and used their models to predict whether liquids and gasses were compressible. Students were also asked by the collaborating teacher to predict the compressibility of liquids and gases and were encouraged to draw models illustrating their thinking on the reverse side of their paper.

Following elicitation of the students' models, the collaborating teacher showed three syringes, one empty (filled with air), the second filled with water, and the third filled with solid carbon. He pushed down on the plunger for each. Only the gas filled syringe was noticeably compressed.

3.8.1.2 Teacher explanations of the particulate nature of matter. The collaborating teacher then described the three states of matter using styrofoam balls to represent the particles. Solids were shown as closely packed particles that vibrated in place. As such, solids are non-compressible and retain their shape. Liquids were shown as closely packed with the spaces between particles similar to those of a solid. Rather than vibrating in place, the particles were shown to "flow" over one another in random motion. Thus, liquids are non-compressible and take the shape of a container, although not necessarily filling the container. Gases were shown to be diffuse with large spaces between particles that moved quickly. As such gases are compressible, take the shape of the container in which they are held, and fill it. The collaborating teacher then showed the relationship between the microscopic and macroscopic visualizations. To address the humanistic orientation, he discussed the use of hydraulic pressure in car brakes and the hydraulic systems of heavy-duty equipment such as excavators. The symbolic representation was not addressed using numbers, but rather as a relationship between greater or lesser compressibility.

The collaborating teacher addressed some of the limitations of the model shown, including solids that are compressible, such as Styrofoam, and mentioning that some liquids may be very slightly compressible. From there, he explained that models were not exact representations of reality, that the models used in the course are simplified, but that models are useful for understanding what occurs in science and for making predictions. For the purposes of the class, both liquids and solids were to be understood as incompressible.

He ended the lesson with a discussion of the relationship between the four dimensions for understanding science (macroscopic, microscopic, symbolic, and humanity), and that to understand a concept, all four orientations must be in agreement. He used a common alternate conception to demonstrate how their microscopic models of liquids with larger spaces between particles did not match with their predictions of compressibility. He then compared these models to the target model to show that in the target model there is agreement between all the representations (to be discussed in greater detail in the Results and Analysis section of this document).

3.8.2 Days 6 and 7: Visualizing air pressure and pressure systems.

3.8.2.1 Visualizing pressure systems (Appendix F). In this demonstration sequence, the collaborating teacher inflated a balloon and held it up in front of the class. Students were asked to explain why the balloon retained its shape and to draw pictures of molecules to explain their models (Appendix F). Students were then asked to predict what would happen to the balloon if brought to a higher elevation (larger, smaller, same size) and to draw the air molecules to explain why their prediction would be what would occur.

3.8.2.2 Teacher explanations of pressure systems. To simulate the microscopic representation, the teacher drew a square on the chalkboard and started pounding his fists quickly inside the square. He then asked the students whether this represented high or low pressure. Then he slowed down his movements and asked students again, whether this represented high or low pressure. He then discussed pressure in terms of a force acting on a unit of surface area. He directly addressed the preconception that pressure is a force (rather than force acting on a defined surface area).

Part 1:Balloon at sea level. The collaborating teacher also discussed pressure systems, and that pressure is a balance between internal (inside, or P_{in}) and ambient (external, outside or P_{out}) forces. When internal and ambient pressures are equal (or $P_{in} = P_{out}$), the balloon maintains its shape. In this case, internal and external pressure were both 1 atm, and the balloon stays the same volume, at 1 L. This represented the macroscopic and symbolic visualizations.

He then described pressure in terms of the average number of collisions on the outside surface of the balloon. In this case, the average number of collisions on the outside surface of the balloon was equal to the average number of collisions inside the balloon. In other words, the force exerted on the outside surface of the balloon (i.e. ambient pressure) was equal to the force exerted on the inside surface of the balloon. The number of particles bouncing off the inside surface the balloon was the same number that he drew bouncing off of the outside surface of the balloon, and all particles exhibited random motion. This represented microscopic visualizations.

Part 2: Balloon on the top of Mount Everest. To represent volume expansion, the collaborating teacher showed the number or ambient particles decreasing and the number of internal particles staying the same. He pointed out that though the number of internal particles stayed the same, the spaces between the particles increased. Thus, the average number of collisions on the inside surface of the balloon would decrease as the particles had a farther distance to travel, but the particles had the same velocity (and random motion) as in the first situation. At this point, external pressure was less than internal pressure, as the average number of collisions on the outside of the balloon were decreased compared to the inside. That is, external pressure was negative, and internal pressure is positive, or $P_{out}<P_{in}$ (or $P_{in}>P_{out}$). Thus, the balloon expanded until the average number of collisions on the inside surface were equal to the average number of collisions on the outside surface, or $P_{in}=P_{out}$ again. In this case, the balloon would have had a volume larger than 1L.

The drawing in this situation showed a larger balloon with less collisions on the outside compared to the inside, and a smaller number of pressure arrows on the outside compared to the inside. The pressure system was described as $P_{in}>P_{out}$ to illustrate how the unequal pressures created a change in volume.

Limitations of models: The collaborating teacher described the limitations of this model (and the drawing of this model) as follows:

- With the equalized balloon, though there are the same numbers of internal and ambient particles and collisions shown, it does not mean that at equalization (i.e. P_{in}=P) there are the same numbers of internal and ambient particles, nor is there the same number of collisions occurring at the exact same place. It is the average force of the collisions over the entire internal and external surface areas of balloon that are the same. That is why the balloon does not change volume.
- When the balloon increases in volume, the change is instantaneous. In fact, to be technically correct, the picture in this case can be drawn to show final, lower ambient pressures and a balloon drawn with a larger volume. In other words, the balloons can be drawn to show $P_{in}=P_{out}$ where the pressures are lower than in the first instance, and the number of collisions on the inside and outside surfaces are equal, but less than those in the first drawing, as this is closer to what actually occurs. The method used

was deliberate as it highlighted that pressures occur in systems, and that when there is an imbalance between ambient and internal pressures, changes in volume will occur (in a flexible container at least) until the two pressures are equal, or equalization has occurred. For notes, tests and assignments, either visualization was acceptable.

He illustrated this concept with a discussion of weather balloons, but stated that at this point in the unit they were to ignore the temperature change, as this would be discussed.

3.8.2.3 Visualizing air pressure. Student understanding of air pressure and changes in air pressure with increased elevation was tested using a series of questions relating their experiences to their models of air pressure (Appendix G).

3.8.2.4 Teacher explanations of air pressure. The collaborating teacher drew pictures showing macroscopic and microscopic particle density at sea level and at an increased elevation. He symbolically described atmospheric pressure as 1 atm at sea level, and less than 1 atm at higher elevations. To address the humanistic representation, the collaborating teacher discussed elevation sickness in terms of his experiences in the Himalayas and differences in physiology between himself and the Sherpas and in Bolivia.

3.8.2.5 Units of pressure. The collaborating teacher delivered a formal lesson on commonly used units of pressure. He discussed the uses in terms of the preferred units of pressure for scuba diving (atmospheres), weather (pascals, kilopascals, bars, millibars), and medicine (millimetres mercury).

The collaborating teacher also told stories about the historical development of our understanding of pressure. These included a narrative about Torricelli running up and down a mountain to check for differences in pressure and a description of one of the first blood pressure experiments where a barometer was hooked up to a major blood vessel in a horse's neck.

Transfer from one unit to another was also taught by asking students to visualize conversions through ratios and proportions. This was not an intended part of the study, and was not tested or analysed.

3.8.3 Days 8 and 9: Student conceptions of pressure systems and vacuums.

3.8.3.1 Visualizing the particulate nature of gases and a vacuum (Appendix H).

Part 1: Bell jar at 1 atm. Students were shown the bell jar vacuum apparatus in the first part of the lesson. This bell jar apparatus was an older hand pump model, with no barometer to show internal pressure. The teacher described the jar as "full" of air, or at 1.0 atm. Students were instructed to imagine they had "magic magnifying googles" so they could visualize the gas molecules in the bell jar. They were asked to draw the internal and ambient gas particles at 1.0 atm (Appendix H).

Part 2: Bell jar at 0.5 atm. With the completion of Part 1, the teacher vigorously pumped the handle of the bell jar apparatus and explained that air was leaving the jar. When he stopped, he explained that about half air was taken out of the jar and asked the students to show relative numbers of air particles, spaces between the particles, and movement of the particles with "half" of the initial volume of air remaining inside the jar (or 0.5 atm). No mention was made of the particulate nature of gases. When students completed their drawings, they shared their conceptions and came to consensus about which drawing best represented the positions and motions of the gas molecules in the bell jar when it was filled with air and when the bell jar was partially evacuated (Appendix H).

3.8.3.2 Teacher explanation of visualizing a vacuum.

Explanation for part 1: Bell jar at 1.0 atm. The collaborating teacher drew particles both inside and outside the bell jar showing relative numbers of collisions on inside and outside surfaces as similar, and both internal and ambient particles having random motion. He also showed that the internal and ambient pressures were equal, identifying each as 1 atm.

Explanation for part 2: Bell jar at 0.5 atm. In the case where air was evacuated from the bell jar, the collaborating teacher showed half the number of particles inside the bell jar relative to the first drawing, and showed half the number of collisions with the inside surface compared to the inside surface of the previous drawing. The internal air particles were described as less crowded, or less dense, with larger spaces between the particles. The average number of collisions on the inside surface were less when compared to the collisions on the outside surface due to the decrease in the number of air particles inside the bell jar. The internal air particles still exhibited random motion, and were drawn throughout the bell jar.

The relative number of ambient particles and collisions were the same for both drawings. In the second drawing, the symbolic representation of ambient to internal pressures was 1.0 atm and 0.5 respectively. Internal pressure was "negative" and ambient pressure was "positive". The collaborating teacher also explained that though there were large differences in ambient and internal pressure, the bell jar was made of material strong enough to withstand the pressure differences.

Addressing alternate conceptions. During the bell jar demonstration, the collaborating teacher also addressed alternative conceptions about the movement and distribution of air particles. As one example, a group of students based their model on a vacuum cleaner, where air was visualized as swirling up the canister both during the process of evacuating the air and after evacuation was completed. Using the target model, the teacher discussed the limitations to the group's model in that no swirling that could be detected after the air is pumped out. Moreover, according to their original model of gases, the gas particles move randomly and fill the container. He then explained how household vacuum cleaners work and how differential pressure causes air to flow into the canister.

3.8.3.3 Pressure systems discrepant event (Appendix I). In the next part of the lesson, a balloon was blown up and placed into the bell jar vacuum apparatus. The teacher asked the students to make predictions as to whether the balloon would get larger, smaller, or stay the same if air is removed from the bell jar and to include macro, micro and symbolic representations in the explanation of their prediction.

The air inside the jar was evacuated, and the balloon increased in volume to the point of almost filling the entire container. Students were asked to provide another set of drawings showing the air molecules outside of the balloon (inside the bell jar) and inside of the balloon. Using these models, students were asked to explain why the balloon increased in volume (Appendix I).

3.8.3.4 Teacher explanation of pressure systems.

Part 1: Balloon at 1.0 atm. For the balloon in the bell jar, the collaborating teacher described the macro, micro and symbolic representations in a manner similar to the explanation given for the inflated balloon shown on day six. He also directly referred to their sea level and Mount Everest visualizations in his explanation.

Part 2: Balloon at 0.5 atm. In the second situation, the teacher drew half the number of air particles inside the bell chamber (and directly external to the balloon) with half the number of collisions on the outside surface of the balloon; and labelled this part of the diagram 0.5 atm.

The number of air particles inside the balloon remained the same, albeit with an increase in spaces between particles. The internal pressure was labelled at 1 atm, to show what was happening "during" equalization. The movement and spacing of the particles was described as follows:

- The number of air particles outside of the balloon decreased and the number of air particles inside the balloon stayed the same.
- Therefore, on average, there are less collisions on the outside surface of the balloon compared to the number of collisions on the inside surface.
- P_{in} is more than P_{out} ($P_{in}>P_{out}$) or P_{in} was positive, P_{out} was negative.
- The volume of the balloon increased until $P_{in}=P_{out.}$
- Internal air particles are less crowded (or less dense) with larger spaces between the particles compared to Part 1.
- Ambient pressure decreased by ½, so the balloon increased 2 times compared to the original.
- Since the original balloon was 2L, the final volume of the balloon following the partial evacuation of the bell jar to 0.5 atm is now 4L in volume.

This model was recorded by the students.

The collaborating teacher discussed the limitations of this drawing, by again stating that the internal changes in "particle crowding" and pressure are instantaneous, while his drawing represented why the volume and pressure changes occurred. A final drawing showing the "end" of the process, would indicate both internal and external pressures at 0.5 atm, and the same number of collisions on the internal and external surfaces on the balloon.

The collaborating teacher also discussed other applications of vacuums and pressure systems such as the mechanics of sipping through a straw (Presidents and Fellows at Harvard College, 2003; Basca and Grotzer, 2001) while showing macro-, micro- and symbolic representations. Symbolic representations were descriptive, showing negative pressure in the mouth and positive ambient/atmospheric pressure pushing against the liquid. He also discussed for a second time the vacuum cleaner example mentioned previously.

3.8.4 Days 10 and 11: Student concepts of pressure systems applied to scuba scenarios.

3.8.4.1 Pressure systems and Boyle's Law in an underwater context. In the first part of this lesson, students used the models they had generated to predict what would occur when a balloon is blown up at the bottom of a pool and then brought to the surface (Appendix J).

3.8.4.2 Teacher explanation of pressure systems and Boyle's Law in an underwater context. Once students shared their conceptions, the collaborating teacher reminded the students to revisit their models of bringing a balloon from the bottom of the hill to the top of a hill (Appendix F) and to relate these models from Day 6 to the pressure systems involved in the discrepant event in the previous class (Appendix I). The teacher then discussed the target models accepted in this scenario.

Part 1: Balloon at 20m depth. The collaborating teacher represented the surface of the water by drawing a wavy line. To represent the microscopic visualization of water, only a few water particles were drawn underneath the surface, as this would save time. Water particles were drawn in this manner for the remaining lessons of the teaching intervention. The particles were drawn close together and "unorganized". He reminded the students of the particulate model of liquids that was previously developed in class (Appendix E). He also drew air particles above the surface of the water and labelled the pressure as 1 atm. He then drew a bar from the surface of the water to the balloon showing water pressure to be 2 atm. The total ambient (or external) pressure was equal to atmospheric pressure plus water pressure or 1 atm plus 2 atm for a total of 3 atm. As the balloon keeps its shape (and volume), pressure inside the balloon must equal the total pressure outside of the balloon; thus the internal pressure of the balloon was 3 atm. The balloon was 2L in volume.

Next, he drew the air particles inside the balloon, consistent with the spacing and motion of gases, and labelled the internal pressure as 3 atm. As it was difficult to show collisions, and as the pressure exerted by the water is hydraulic pressure (which is beyond the scope of the course and was not taught in this study due to time constraints), ambient and internal pressure arrows were used to show equal pressures inside and outside of the balloon. Also, as using arrows to show collisions was incredibly time consuming, this was omitted for this lesson and for all remaining lessons. The collaborating teacher discussed these limitations with the class.

Part 2: Balloon at the surface. The teacher drew a "during equalization" illustration, where the balloon was on top of the surface of the water. The balloon was larger, with the same number of particles as in part 1. To show how the change in internal and ambient pressures affected the volume, more pressure arrows were used on the internal surface of the balloon compared to the external surface. The internal pressure was labelled as 3 atm compared to the ambient pressure of 1 atm. As there was no water surrounding the balloon, ambient pressure was due to atmospheric pressure only. Thus internal pressure was greater than external pressure ($P_{in}>P_{out}$, or positive internal pressure and negative external pressure), and the balloon expanded until both internal and ambient pressures were equal at 1 atm. The ambient pressure decreased by 1/3, so the volume of the balloon increased 3 times. As a result, the final volume of the balloon was 6L.

Students could choose between writing the "during" or "after" model. If their mental models were the same as the target models, students could also choose to write a note to that effect and weren't required to copy down the target model explanation.

To address the humanistic representation, the collaborating teacher talked about deep-sea salvage techniques where large balloons are attached to objects and used to float these objects to the water's surface.

3.8.4.3 Application of Boyle's Law to scuba diving. Students were asked to determine what would happen to the lungs of a scuba diver if he ascended from 30m to the surface while holding his breath (Appendix K). To save time, students discussed but did not describe or illustrate their small group and whole class models.

3.8.4.4 Teacher explanation of pulmonary barotraumas

Part 1: Diver lungs at 30m depth. The collaborating teacher described internal and ambient pressures, and drew macro-, micro- and symbolic representations similar to those in the balloon exercise (Appendix J). The water surface, water particles and air particles were drawn as previously described for "Balloon at 20m depth". However, a lung with bronchus was drawn instead of a balloon. Also the total ambient (or external) pressure was equal to atmospheric pressure plus water pressure or 1 atm plus 3 atm for a total of 4 atm. As the diver is breathing in air from the scuba tank, the lungs were also at 4 atm pressure. As in the previous scuba balloon example (Appendix J), pressure arrows were used to show equal pressures inside and outside of the lungs.

Part 2: Diver lungs at the surface. The collaborating teacher drew a "during equalization" picture, where the lung was on top of the surface of the water. The internal pressure was labelled as 4 atm compared to the ambient pressure of 1 atm. Internal pressure was greater than external pressure, (P_{in}>P_{out}, or positive internal pressure and negative external pressure) so the lung expanded until both internal and ambient pressure were equal at 1 atm. The ambient pressure decreased by 1/4, so the volume of the lung increased by 4 times. As the previous scuba balloon scenario (Appendix J) was analogous to what happens to a scuba diver's lungs while breath holding upon surfacing, the teacher referred to and made comparisons between the balloon and the balloon metaphor for the diver's lungs throughout his explanations.

The teacher also explained that lungs are not nearly as elastic as a balloon, and that a change of one meter (three feet) below the surface is enough to cause injury and create tears in the lung lining. In this hypothetical case, the lungs would have been torn. Gas bubbles would be released into the body and, depending on the location, would cause various injuries such as air embolisms (air entering the bloodstream via alveoli) and pneumothorax (lung collapse). The teacher described this condition as "hamburger lung" and explained that a diver with such a condition would surely die. He then emphasized, for those students who would be scuba diving, that, "…you should never hold your breath when going up…"

3.8.5 Days 11 and 12: Formal lessons in scuba science and pulmonary physiology. In this two-day lesson students completed a formal set of notes by filling out the table in Appendix L. In these notes, macro, micro- and symbolic representations were addressed.

The collaborating teacher showed pictures of the scuba tank and second stage regulator and explained that the scuba tank was at very high pressure and would "blow up" a person's lungs. The second stage regulator reduces the air pressure so that air can be taken in easily, and it ensures that lung pressure is equal to ambient pressure during a dive. This way, breathing would feel more or less "natural".

He also explained the two cardinal rules for diving:

1. Never hold your breath when ascending.
2. Do not rise faster than your bubbles.

To end the lesson students watched a short video clip from the television program *Mythbusters* titled *Dumpster Diving Episode 19* (Mallet, 2010) that showed the consequences of rapid depressurization when deep-sea diving (diving greater than 40m and requiring a specialized suit).

3.8.6 Day 13: Formal lesson in flight science - cabin pressurization. Students received a formal lesson about flight and cabin pressurization, and they wrote formal notes (Appendix M).

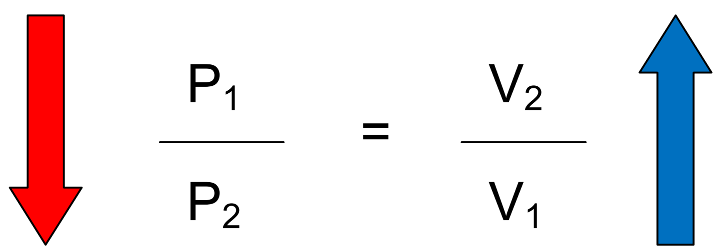
The collaborating teacher then had students examine the case of the Helios Flight 3522 air disaster and watch the video *Mayday: Ghost Plane* (Bambrick, 2007) that explained the events leading to the crash and the resultant safety precautions that came from it.

Comparisons were be made between the role of the second stage regulator and cabin pressurization.

3.8.7 Days 14 and 15: Formal lesson on Boyle's Law and the first formal assignment.

3.8.7.1 Compression of gases and introduction Boyle's Law. Students observed the "Gas Laws Program" (Abraham and Gelder, 2000), a computer simulation that simulates gases in a piston (similar to the syringe set-up), and subsequently developed Boyle's Law by answering a series of questions while the collaborating teacher manipulated the simulation (Appendix N).

The teacher explained Boyle's Law in terms of pressure systems (ambient vs. internal) and particle collisions while showing the computer simulation. He described Boyle's Law as an inverse relationship, with symbolic memory cues as follows:



$$\frac{P_1}{P_2} = \frac{V_2}{V_1}$$

Figure 3.1. Memory cue used for Boyle's Law equation.

3.8.7.2 Formal assignment: Finding volumes using Boyle's Law. Students were given a formal assignment on Boyle's Law. This was set of problems that the collaborating teacher normally gave when teaching grade 11 chemistry (Appendix O). However, rather than only providing the answers to mathematical formulas, students were also asked to show the macroscopic and microscopic representations. These instructions were given verbally and written on the board. Some students wrote down the instructions, others did not.

The teacher emphasized that in order to answer the questions correctly the macroscopic, microscopic and symbolic representations should all be in agreement. If only one of the representations wasn't in agreement, then there was a problem with understanding. The students were given one class to complete the assignment. The assignments were marked by the researcher and retuned to the students the next day.

3.8.8 Day 16: Second formal assignment: Finding pressures and volumes using Boyle's Law (Appendix P). It was observed from the first assignment that many students did not draw microscopic and macroscopic representations when answering their questions. The teacher discussed this with the students and reported that students did not complete macroscopic and microscopic drawings for a number of reasons. These were as follows:

- Some students did not have macroscopic and microscopic understanding.
- Some students did not write the instructions and forgot they had to show more than the symbolic representation.
- Some students didn't realize they would lose marks, because they had not been required to include all three forms of representation in the past.
- Some students were "burned out" as it was coming close to the end of the term, and there was a lot of writing in this study. They completed what they could, given that showing symbolic representations was all that was normally necessary.

This led the researcher and collaborating teacher to create another assignment where:

- Instructions were included at the beginning of the written assignment indicating that macroscopic, macroscopic and symbolic representations must be shown, and that a final statement should be included indicating whether the three representations were in agreement.

- The students analyzed the pressure and volume of a balloon in different hypothetical scenarios involving a balloon, similar to the first assignment given.
- Eight questions were developed similar to a split-test design, where students solved two questions representing each variable in Boyles Law. Thus, there were two questions asking students to determine initial volume (V_1); two questions to determine final volume (V_2), two questions to determine initial pressure (P_1), and two questions where students determined final pressure (P_2).

The first assignment with comments and formal marks given was returned to the students. The collaborating teacher again discussed the importance of showing all three representations and that agreement between the representations was crucial to demonstrate understanding.

3.8.9 Days 17 and 18: Boyle's Law syringe experiment. On day 17, students conducted a Boyle's Law Syringe Experiment (Appendix Q). Part of day 17 and part of day 18 were dedicated to writing the laboratory report of the syringe experiment..

3.8.10 Day 18: Introduction to the ear and scuba physiology.

3.8.10.1 Developing student concepts of ear anatomy and physiology. In the first part of the lesson, students reviewed their initial conceptions of what occurs when they "pop" their ears in relation to scuba diving during descent. Then students were then given an outline sketch of the ear with parts of the ear labelled (Figure3.2). A brief review of the parts of the ear and the connections between each part was given. The function of each part of the ear was not discussed.

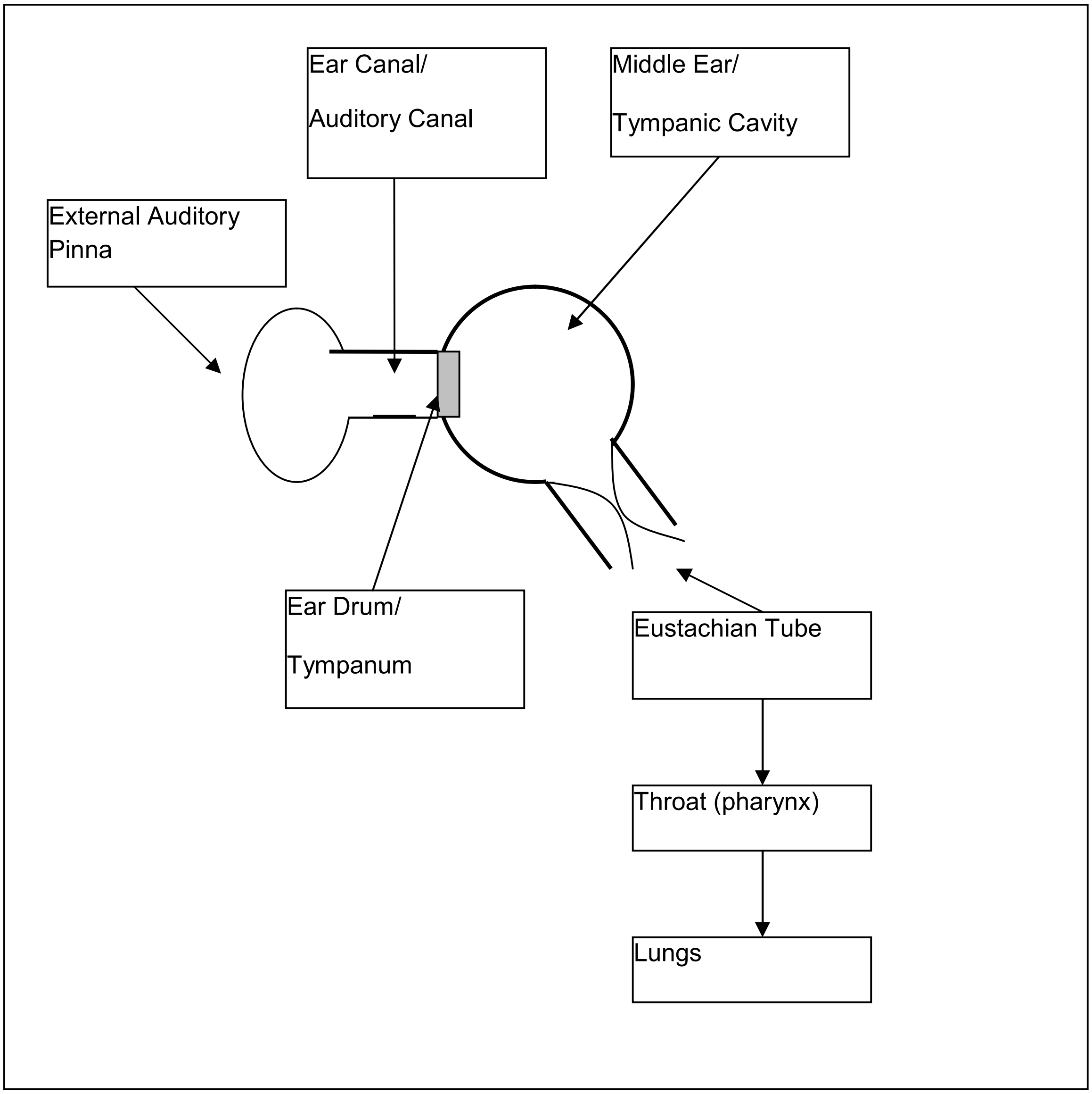


Figure 3.2. Sketch model of the anatomy of the ear.

Students drew new models of the inner ear based on the information that they received, and they predicted what happens to the inner ear while scuba diving (Appendix R).

3.8.10.2 Introduction to the physiology of the ear and dive theory. A formal lesson about ear physiology and ear barotraumas is given, with formal note taking (Appendix S).

In this lesson, macrocroscopic, microscopic, and symbolic representation were to explain ear squeeze while scuba diving. In this formal lesson, students were shown a plastic model of the ear that revealed the actual orientation of the ear drum and other parts of the ear omitted from the pen and paper model. The students also watched a computer simulation of ear barotrauma on the Med Imagery website (Med Imagery, 2007). This simulation showed macroscopic and symbolic representations and was compared to the pen-and-paper model. Lastly, YouTube videos of the tympanum (northwestENT, 2009) and ear drum perforations (drrahmatorlummc, 2010) from real, not animated, people were shown. Thus, students could see the differences in the pen-and-paper model when compared to the 3D plastic replica, the computer simulation and the video of "live" examples.

The three orientations were also used to explain how scuba divers equalize their ears, the appropriate methods for equalization while diving, and the consequence ("reverse block") of failing to equalize while ascending.

3.8.10.3 Introduction to mask squeeze. The collaborating teacher introduced and explained mask squeeze. Students were shown a picture of a diver that suffered from severe mask squeeze that had also been used in the second two-tiered test (Appendix B). Using macroscopic, microscopic and symbolic representations, he explained why mask squeeze generally occurs during descent and how to blow air into the mask through the nose to equalize mask pressure.

3.8.11 Day 19: Introduction to the scuba demonstrations and experiments. The collaborating teacher discussed the demonstrations, experiments, dive procedures and safety procedures for the day of the dive.

3.8.11.1 Boyle's Law cylinder experiment: Student predictions. This pre-lab was used to prepare students for the actual lab activity and write-up for the scuba session. The teacher had students predict what would happen in a hypothetical cylinder experiment, then write formal notes as shown in Appendix T. Students also viewed the demonstrations and experiments portrayed in the video produced in the second "pilot" session of the scuba project.

3.8.12 Day 20: Scuba demonstrations and experiments. Students participated in a half-day field trip to Seven Oaks pool where they conducted the scuba diving demonstrations and experiments (Appendix U). Ten students in the class participated in the scuba activity in the morning, and the remaining 11 students dove in the afternoon. The lessons for the day were as follows:

3.8.12.1 Discover Scuba course. The "Discover Scuba Course" was conducted by instructors from Underworld Scuba. Instructors taught students about the dive equipment, dive techniques, and safety regulations according to the guidelines set out by the Professional Association of Diving Instructors (PADI), the international regulatory and licensing body for scuba instruction.

In the explanations, the function of the scuba tank and the regulator were discussed. The dive master demonstrated that air from the tank was under high pressure by opening the valve and "blasting" a student's hair. The diver explained that as the air pressure directly from the tank is too great to breathe in, the second stage regulator is required to ensure appropriate airflow so that lung pressure is equal to ambient pressure thus allowing the diver to breathe easily and properly.

The Underworld Scuba instructors then discussed ear squeeze and the appropriate techniques for equalization and mask squeeze and the appropriate techniques for mask equalization. These explanations did not include multiple levels of representation. They also stressed the importance of ascending properly, and reminded the students on a number of occasions to, "Never hold your breath while ascending" and to "Never beat your bubbles to the top".

Students who did not scuba dive were part of the surface crew. They helped prepare equipment, record data, and kept safety watch. As each demonstration and experiment occurred, the researcher described the science behind each demonstration and experiment.

Participants that choose to scuba dive practiced basic scuba skills in the shallow end of the pool for approximately 45 minutes and then practiced these techniques in the deep end of the pool. When all participants were comfortable with basic diving techniques, the students watched a set of underwater demonstrations similar to the demonstrations shown in class, and conducted an underwater Boyle's Law Cylinder Experiment. This took approximately one-and-a-half to two hours.

Dive masters of Underworld Scuba took pictures and videotaped the scuba session as mementos for the students.

3.8.12.2 Skin diving demonstration. A two-litre pop bottle was filled with air and capped at the surface of the pool. Students observed what happens to the volume of the pop bottle during descent to the bottom of the pool and what happens during re-surfacing.

This demonstration was used to explain what happens to a person's lungs during a deep dive. The capped off bottle at the surface represented a person's lungs when holding their breath just before performing a deep dive. The change in lung volume during descent and ascent was explained using the pop-bottle model and Boyle's Law (Appendix S).

3.8.12.3 Pulmonary barotrauma demonstration. In this demonstration, students squeezed a capped two-litre pop-bottle at the surface of the pool. Then the bottle was brought to the bottom of the pool. Once at the bottom, the dive master filled the bottle with air from his/her regulator, then re-capped the bottle. The bottle was then brought back to the surface of the pool, and students squeezed the bottle again.

This demonstration was used to show the change in lung volume when a diver holds his/her breath while ascending. During descent, the pop bottle collapses. When filled with air from the regulator, the bottle regained its original shape and firmness. During ascent, the pop bottle became slightly larger, and much firmer to the touch, as the gas expanded during surfacing.

The pop bottle represented the diver's lungs. As in the previous demonstration, the "lungs" decreased in volume (or collapsed) because of the increase in water pressure. At the bottom of the pool, the extra air added by the regulator demonstrated how the scuba equipment works to equalize the pressure between the lungs and ambient (water) pressure. When the pop bottle was capped and returned to the surface, it represented what happens to a divers' lungs when they hold their breath while surfacing. The pop bottle simulated lung overexpansion, a form of pulmonary barotrauma. In worst case scenarios, air embolisms or pneumothorax occur; and in the worst case scenario, death.

3.8.12.4 Squeeze, equalization and reverse block demonstrations. The dive master showed and explained the parts of a stylized model of the ear made from a cylinder, balloon, and air valve as shown in Figure 3.3.

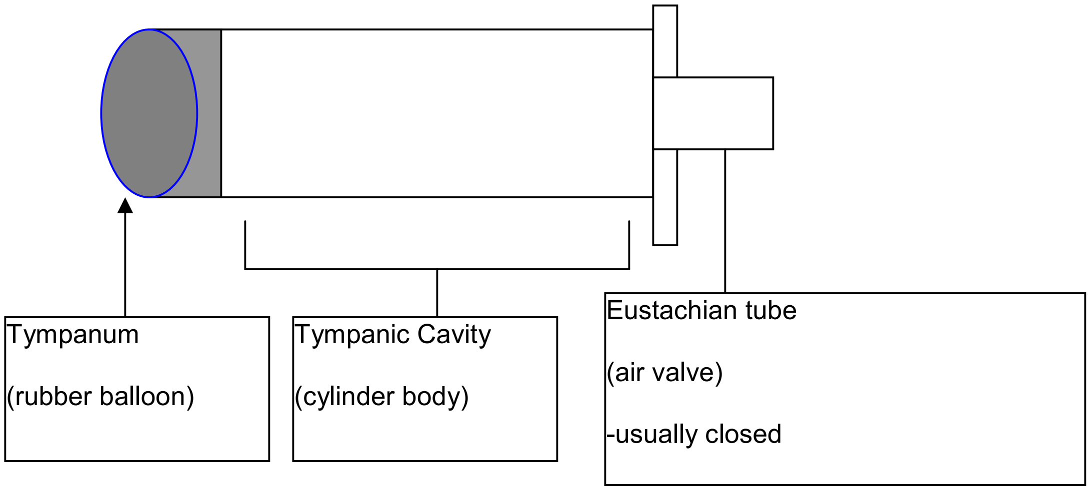


Figure 3.3. Model ear for scuba demonstration.

The students and scuba master dove to the bottom of the pool with the ear model. Students observed the tympanum during descent. The unequal pressure and movement of the tympanum, called "squeeze", is commonly described as "pressure in the ears", and feels similar to the pressure experienced during an airplane flight. In this case, students were feeling ear squeeze directly while watching the simulated ear underwater. Students were encouraged to relate the demonstration to their own bodies, and think about what is happening to their own ears and how it felt as they descended (Figure3.4).

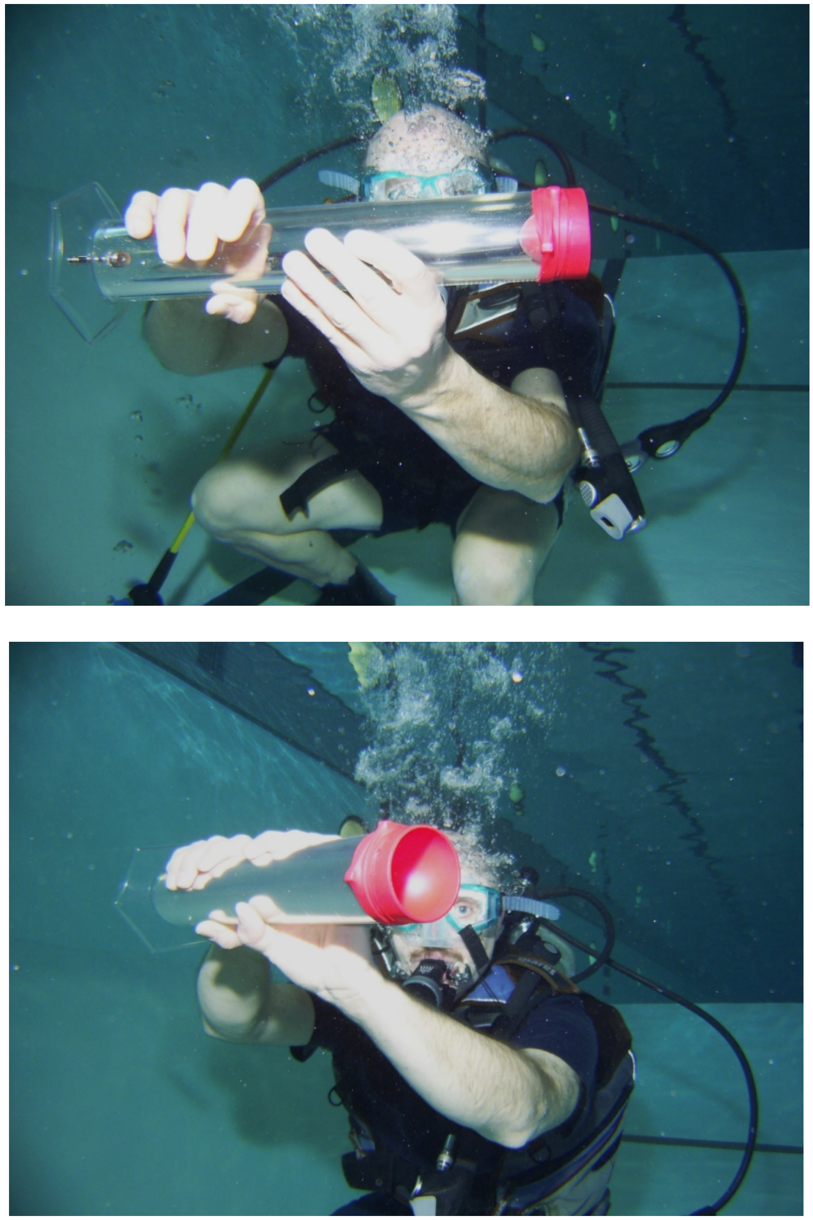


Figure 3.4. Model ear during descent. Photograph given with permission, D. Alderson and Underworld Scuba & Sport, copyright © 2010.

At the bottom of the pool, the dive master filled the Eustachian tube with air until the tympanum pops backed in place, level with the rim of the cylinder (Figure 3.5).

(a)

(b)

(c)

Figure 3.5. Ear equalization demonstration. Photographs used with permission, D. Alderson and Underworld Scuba & Sport, copyright © 2010.

(a) Dive Master preparing to equalize the model ear, tympanum is concave due to increased ambient pressure.

(b) and (c) Equalization occurs once air enters the model "middle ear" through the "Eustachian tube".

Each time the student divers equalized their ears (most student divers accomplished this by plugging their noses and gently blowing, or wiggling their bottom jaws), their Eustachian tubes opened, and air was added into the middle ear. The internal pressure (air pressure in the tympanic cavity/middle ear) and ambient pressure (water pressure outside the tympanum) became equal (or were "equalized'), thus, restoring the tympanum to its original position. The equal pressure on either side of the tympanum relieved the pain or "squeeze".

During ascent, the Eustachian tube normally opens automatically when the air pressure in the tympanic cavity is too great, sending the extra air back into the throat. However, in this part of the demonstration, the air valve (or "Eustachian tube") on the model remained locked, and simulated what happens if a diver has a cold, and cannot open his/her Eustachian tubes because of swelling. This condition is called "reverse block. In this case, the air pressure in the tympanic cavity increased due to the expanding gas as the water pressure decreased. The tympanum became convex, and in real-life situations may burst (Figure 3.6).

Figure 3.6. Demonstration of reverse block using the ear model. Photograph given with permission, D. Alderson and Underworld Scuba & Sport, copyright © 2010.

3.8.12.5 Boyle's Law experiment. Students performed the Boyle's Law experiment as described in Appendix U.

3.8.13 Day 21: Scuba demonstrations and experiments write-up. Students, with the help of the collaborating teacher, wrote up the Day 20 demonstrations and experiments with partners as a formal assignment (Appendix U).

3.8.14 Day 22: Ear squeeze and flight.

3.8.14.1 Ear squeeze during flight cognitive probe. In the first part of the lesson, a model ear made from a can, pen, and balloon was placed in the bell jar vacuum apparatus (Appendix V).

Students were asked to show the movement of air particles, and explain why the tympanum was in its current position. Then students were asked to predict what would happened when air was evacuated from the bell jar, and to draw macroscopic and microscopic representations of their predictions (Appendix V). Student models were discussed and debated until class consensus occurred. To save time, the teacher reported the class consensus to the researcher and students did not have to describe and illustrate the class model.

The air was evacuated from the bell jar, and the latex tympanum bulged outward (convex position). Once the demonstration was completed, the student models were discussed and compared to the scientifically accepted model. The teacher related this demonstration to what happens when a person's ears hurt while ascending in an airplane.

Students were also asked to relate their own ear squeeze experiences due to changes in elevation (such as on a flight, going up a hill, in an elevator, etc.) to the model and video in order to explore the human aspect (Mahaffy, 2006) of the demonstration.

3.8.14.2 Ear squeeze during flight formal lesson. Afterwards, the collaborating teacher delivered a formal lesson that explained what occurs when people feel pain in their ears during an airplane flight (Appendix W).

Addressing alternate conceptions. The teacher stressed that when people feel "pressure in their ears" they are, in fact, feeling pain due to a pressure imbalance on either side of the ear drum. The pain experienced is the same whether ambient pressure increases (as in descending while scuba diving) or ambient pressure increases (such as ascent in an airplane). He showed macroscopic, microscopic and symbolic representations of both cases, and demonstrated that the pain felt was the same. He emphasized that this explanation should not be used to support the idea that pressure increases with elevation. They should understand it as pressure differences and these difference in pressure causing ear pain due to the stretching of the eardrum to a convex or concave position.

3.8.15 Days 23 and 24: Study sessions. Students were given two days and the weekend to study for the post-test. For review, students were given "real-life" problems dealing with ear and lung physiology in the contexts of scuba diving and flight. Unfortunately, student responses to the review problems were confidentially shredded before analysis by the researcher could occur.

3.8.16 Day 25: Gas pressure, volume and Boyle's Law general knowledge post-test (post-test 1). Post-test 1 was given (Appendix A).

3.8.17 Day 26: Applications of Boyle's Law to scuba physiology post-test (post-test 2). Post-test 2 was given (Appendix B).

3.8.18 Day 27: Probing students' conceptions of the ear post test (post-test 3). Post-test 3 was given (Appendix C).

3.8.19 Day 28: Pre/post test analyses (Appendices X and Y) and compiling process- folios. After post-test 3, students reviewed their answers for each pre-test and post-test question. Students had the opportunity to review their original pre-tests and to compare their answers on the pre-test answers to those on the post-tests. Students analyzed their learning using the questions in Appendix X as a guideline. In essence, students explained why they thought the differences occurred (or did not occur) between the first time and the second time they wrote pre and post-test 1 (Appendix X) and pre- and post-test 2 (Appendix Y). Students also evaluated the scuba activity (Appendix Z) and in-class lessons (Appendix AA).

3.8.19.1 Overall evaluation and member checks. Students compiled their process-folios, which included pre- and post-tests and the cognitive probes. This also enabled students who agreed to participate in the study to check, add or withdraw information before final submission to the researcher.

3.8.19.2 Student Debriefing. All students, whether they were participants in the study or not were debriefed with the collaborating teacher present. The researcher gave a verbal summary of tenacious alternate conceptions found during the process, student experiences that influenced conceptual understanding, and discussed evidence of learning. This was followed by a question and answer period, and general class discussion.

3.9 Teacher Interviews

Each week, the participating teacher met with the researcher and was asked to describe how a lesson was taught and to evaluate the lesson (Appendix BB). The times and locations for the face-to-face interviews varied but occurred three or more times a week. Debriefing also occurred throughout these sessions.

3.10 Dive Master Interviews

Dive masters participating in this study were asked to respond to a series of questions to help evaluate the scuba program (Appendix CC). The times and locations for the interviews were determined by negotiation between the dive masters and researcher. The dive masters also had the option of e-mailing responses to questions throughout the weeks of the study.

3.11 Research Instruments

3.11.1 Two-tiered multiple choice pre- and post-tests 1 and 2 (Appendices A and B)

Two-tiered multiple-choice test items were developed according to guidelines established by Treagust (1995). In two-tiered multiple-choice items, students choose an answer for a question, then, choose a reason for their answer. The reasons provided contain the correct explanation and distracters that are based on alternative student conceptions documented in the literature or observed in the researcher's previous science classes. In the

Pre-tests 1 and 2 and the Post-tests 1 and 2 questions, distracters were generated from student conceptions established in the literature (for example, Anders and Guzzetti, 2005; Ardac and Akaygun, 2004; Ciu and Liang, 2004; Grotzer and Perkins, 2003; Basca and Grotzer, 2001; Mak, Yip, and Chung, 1999; de Burg, 1995; Benson, Wittrock and Baur, 1993; Grosslight, *et. al.*, 1991) and those identified from the processfolios of students who participated in the scuba program in 2008 and 2009.

See Figure 3.7 as one example of such a two-tiered item.

Which of the following statements about air pressure is true?

a) Air pressure pushes down only.
b) Air pressure pushes in all directions.
c) Air does not create pressure.

Because…

a) air particles exhibit random motion.
b) air particles move downward due to gravity.
c) air particles do not hit surfaces.
d) air pressure is the same as force.

Figure 3.7. Multiple choice test item developed from student conceptions.

Questions 6-11 requiring symbolic representation were designed by de Berg (1995, p. 874-875) and adapted for the two-tiered multiple choice format. These questions were used to determine if students understood that Boyle's Law is an *inverse* relationship. In fact, if students understood the inverse relationship of this law, students would not require the use of calculators. Though calculators were allowed, many students did not use therm. Also, the researcher was initially interested in determining if students also used arithmetic means reasoning for 1:3 rations rather than inverse reasoning required by Boyle's Law as had been reported by de Berg (1995). Questions 12 - 17 are adapted from de Berg's questions (1995) for the scuba context.

To increase confidence in content validity, concepts were broken down into propositional statements, These were simple concept statements such as "gas molecules are in constant motion". These propositional statements were organized on a specification grid that was used to ensure all of the propositional knowledge statements were represented by test items, and that the number of test items for a particular propositional knowledge statement was proportional to the time spent on that concept during instruction (Treagust, 1995).

To increase reliability, a split-test design was incorporated. This required that each question be re-worded and presented again (McMillan, 2008). The split-test design for each test is summarized in Tables 3.1 and 3.2 below.

Table 3.1.

Question correlations for pre and post test number 1 split-test design.

Question Number	Duplicate Question	Concept
1	22	Cause of air pressure
2	21	Changes in air pressure with elevation
3	20	Effects of pressure imbalance
4	19	Pressure system of a balloon
5	18	Boyle's Law
6	12	Boyle's Law/ Ambient and internal pressure systems of a syringe
7	13	Boyle's Law/ Ambient and internal pressure systems of a syringe
8	15	Predicting volume with decreased pressure – outside data set (#8 syringe, #17 scuba)
9	14	Predicting volume with increased pressure – within data set (#9 syringe, #14 scuba)
10	17	Predicting pressure with decreased volume – outside data set (#10 syringe, #16 scuba)
11	16	Predicting pressure with increased volume – within data set (#11 syringe, #17 scuba)

Table 3.2.

Question correlations pre and post test number 2 split-test design.

Question Number	Duplicate Question	Concept
1	4	Basic ear physiology
2	7	Position of the tympanum
3	35	Squeeze
5	33	Proper timing for ear equalization while scuba diving
6	34	Mask squeeze
8	19	Ear squeeze caused by increased ambient pressure (#8 scuba, #18 flight)
9	20	Equalization at increased ambient pressure (#9 scuba, #20 flight)
10	17	Ear squeeze caused by decreased ambient pressure (#10 scuba, #17 flight)
11	18	Equalization at decreased ambient pressure (#11 scuba, #18 flight)
12	30	Reverse block - scuba context
13	29	Boyle's Law balloon activity - scuba context
14	28	Pulmonary barotrauma
15	27	Proper breathing technique during ascent
16	26	Function of the second stage regulator
21	25	Reverse block - flight context
22	24	Physiological effects of rapid cabin depressurization (Helios Flight 522)
23	36	Function of cabin pressurization
31	32	Action to take if difficult equalization - scuba context

The original pre-instruction/post-instruction test was edited by three teachers (Gertley, Edwards, Datzkiw, personal communications, 2009), three grade 12 students and two university students. Word problems that would be difficult for EAL students were identified and re-written. It was determined that those writing the test would suffer from test fatigue. Based on the suggestions from teachers and students, the test was divided into two parts that were to be administered on consecutive days. Part I tested students' understanding of pressure and Boyle's Law (Appendix A). Part II tested diving applications of these laws (Appendix B). The two tests were administered to sixteen grade 11 students and fifteen grade 12 students for comment and both tests were amended on the basis of the feedback provided. The final versions of these tests were submitted to scuba teachers and tertiary level educators for expert feedback.

Part I is composed of 22 test items and focuses upon the following topics: the particulate nature of gases; pressure; and Boyle's Law. Part II is composed of 36 test items and focuses upon the following topics: ear physiology, ear barotrauma/ equalization, dive theory and flight.

The pre- and post-instructional diagnostic instruments and instructional sequence were largely based on student conceptions observed during the four previous sessions of the scuba project, beginning in April 2008, and on the diagnostic instruments established by educational researchers Basca and Grotzer (2001), Benson, Wittrock and Baur, (1993) and Stavy (1991).

3.11.2 Conceptions of the ear (Appendices C and D). After an intensive literature search, there appeared to be no previously published, pre-instructional diagnostics in this area of study. The diagnostic used in the study was developed by Gertley (2008) with recommendations from experts in the fields of education and scuba diving including Alderson, Bush, Dann, Dubois-St. Jacques, Edwards, Leuthwaite, Lukie and McMillan (personal communications, 2008). The diagnostic was edited four times, based on observations by teachers and students who used or responded to it in previous scuba sessions. Gertley and Datzkiw edited the first version utilized in this study. As previously discussed, an addendum was written based on the second session of the scuba project in 2008.

3.11.3 The nature of matter (Appendix E). This diagnostic was developed by Gertley in conjunction with Datzkiw (2009). It is based on Mahaffy's (2006) representations of science understanding.

3.11.4 Student conceptions of atmospheric pressure and changes in atmospheric pressure (Appendices F and G). As previously discussed, many middle and high school students do not realize that gases exert pressure (reviewed in Bulunuz, Jarrett and Bulunuz, 2009; reviewed in de Burg, 1995) and that with higher elevation, air pressure decreases (Basca and Grotzer, 2003; Edwards, personal communication, 2009). The questions posed in Appendices F and G were to determine student conceptions of pressure systems and atmospheric pressure.

3.11.4.1 Predicting changes in volume with elevation (Appendix F). This diagnostic was adapted from Groter and Perkins (2003) and Stavy (1990) to determine if students' models of the particulate nature of gases were consistent with scientific models, and to determine if students could use their models to predict what would happen to a balloon brought to a higher elevation (Appendix E).

3.11.4.2 Student models of atmospheric pressure (Appendix G). This diagnostic was developed by Gertley in conjunction with Datzkiw (2009). Pedagogically, it would be reasonable to reverse the two diagnostics. In other words, have students think about air pressure first (Appendix G), then learn about changes in air pressure (Appendix F). However, for the purposes of this study, this teaching sequence was used to avoid influencing initial conceptions of air pressure and changes in air pressure expressed by students in Appendix F.

3.11.5 Effects of decreasing atmospheric pressure (Appendices H and I). In previous scuba sessions, teachers observed that a tenacious alternative conception held by some students was believing that atmospheric pressure increased with increased elevation (Gertley, and Edwards, 2009 and 2010 personal communications). The two activities immediately below were added to challenge these conceptions, and their design was based upon activities developed by Benson, Wittrock and Baur (1993), Basca and Grotzer, 2001 and Anders and Guzetti (2005). These activities were discussed again in the context of flight and scuba diving later on in the intervention.

3.11.5.1 Bell jar evacuation (Appendix H). For this activity, the demonstration and diagnostic tool were taken from Benson, Wittrock and Baur (1993, p. 589).

3.11.5.2 Discrepant event demonstration: Balloon in a bell jar (Appendix I). This augmentation activity/discrepant event was based on Basca and Grotzer, (2001) and Anders and Guzzetti (2005).

3.11.6 Scuba and flight science (Appendices J, K, L, and M). These demonstrations, activities and diagnostics were used to develop the understanding of what occurs in the lungs while scuba diving. Throughout these activities, extreme emphasis is placed on the motto, "Never hold your breath..."

3.11.6.1 Student conceptions of pressure systems with scuba balloons (Appendix J). This diagnostic was developed by Gertley and is the scuba-based version of the Groter and Perkins' (2003) and Stavy's (1990) diagnostic (Appendix F). It is analogous to the bell jar evacuation demonstration (Appendix H) and was one of the demonstrations students observed while scuba diving. The activities in Appendices H, I and J are analogous to what happens to the lungs of a scuba diver who breath holds during ascent.

3.11.6.2 Pulmonary barotrauma (Appendix K). This activity was developed by Gertley and edited by Datzkiw (2010). It was used to create connections between the activities in Appendices H, I and J and the real-life consequences of breath holding during ascent while scuba diving. The activity was developed using Mahaffy's (2006) modes of representation.

3.11.6.3 Pulmonary physiology: scuba and flight applications (Appendices L and M). The notes for the formal lessons were developed by Gertley and edited by Datzkiw (2010) They were based on multiple representations of science understanding (Johnstone, 1991).

3.11.7 Boyle's Law (Appendices N, O, P and Q). The lesson immediately below and the three assignment lessons were developed by Gertley and Datzkiw (2010). They were based on activities, questions and teaching sequences created by Grotzer and Perkins (2003), Basca and Grotzer (2001), and De Burg (1995).

3.11.7.1 Introduction to Boyle's Law (Appendix N). This lesson was adapted from a pre-lab designed by Gertley in 2000, Bishop (2003), Buffie and Matter (date unknown), Schneider (2009), and edited by Datzkiw in 2010.

3.11.7.2 Boyle's Law practice questions assignment 1 (Appendix O). As previously discussed, this set of practice questions was designed by Datzkiw (date unknown) and had been given for practice in his grade 11 chemistry course for a number of years.

3.11.7.3 Boyle's Law practice questions assignment 2 (Appendix P). As previously discussed, another set of practice questions modeled after a split-test design was given. Upon consultation with Datzkiw, the questions were based on balloon scenarios as in the former set of practice questions.

3.11.7.4 Boyle's Law syringe experiment (Appendix Q). This lab was adapted from the Boyle's Law lab used by Datzkiw, with questions adapted from Basca and Grotzer (2001), Grotzer and Perkins (2003) and de Burg (1995).

3.11.8 Ear squeeze (Appendices R and S). These set of activities described immediately below were developed by Gertley in 2008 in consultation with Alderson, Remillard, Bush, Edwards and Datzkiw over successive runs of the scuba project from 2007 - 2010.

3.11.9 Pre-lab: Student predictions of Boyle's Law scuba experiment (Appendix T). This pre-lab was initially developed by Gertley and Matwyczuk (2007). The computer simulation was created by students in Matwyczuk's 2002-2008 computer science classes. The computer science students used the "Principals of Digital Learning" (Gee, 2000; Matwyczuk, 2009) as a pedagogical framework for the simulation. The computer simulation was incompatible with the programs used at the participating school and could not be shown. As a result, a pen-and-paper model was created.

The final question in the pre-lab was developed to alleviate confusion observed in students who completed the Boyle's Law scuba experiment. These students did not see a clearly defined inverse curve similar to the graph produced during the Boyle's Law syringe experiment when graphing the results of the scuba experiment.

3.11.10 Underwater experiments and demonstrations (Appendix U). Boohan (2002) suggests that, "Models are simplified representations of the real world." (p. 117) Models can exaggerate certain features (and simplify others) to emphasize these features. By doing so, these features can become more apparent in a world real context. Models can also help students make sense of the very large or very small (Ibid., 2002). Good models are useful in the sense that they can be used to explain observed phenomenon and to make predictions (Ibid., 2002). The lung and ear models used during the scuba demonstrations were selected based on these features.

3.11.10.1 Demonstration: Lung physiology while skin diving and scuba diving (Appendix U). A 2L pop bottle was used as a lung model to demonstrate what occurs to lungs while skin diving and scuba diving. They are analogous to the demonstration and activities in Appendices I, J and K, and reinforce the concepts taught in Appendix L. A 2L pop bottle was found to be the least expensive and sturdiest model that was flexible enough to show the effects of increased ambient pressure and lung barotrauma.

3.11.10.2 Demonstration: Ear squeeze while scuba diving (Appendix U). The scuba ear model was designed by Gertley, Alderson (divemaster) and Remillard (divemaster) using the pedagogical framework described by Boohan (2002) and Jonassen, Pick and Wilson (1999). The model exaggerated the size and movement of the tympanum and the size of the middle ear. The tympanum was positioned perpendicular to the middle ear cavity, rather than at an angle, and the Eustachian tube was represented by a valve, from which students could view the addition or release of air. All other parts of the ear were omitted or de-emphasized.

Thus parts of the ear not directly involved in equalization (for this level) were not part of the model.

As demonstrated by student and staff comments in April, 2008 (Edwards, Alderson and Richards, personal communication, 2008), this demonstration was particularly useful, most likely because the ear simulation compliments first-hand experience. Not only could students see what happened to this model under pressure, but they should have felt the effects in their own ears at the same time.

A plastic model of the ear that better shows relative positions and all the parts of the ear, and a video directly showing the inside of the ear was shown so students could relate their models to the real context. A computer simulation of these events that illustrated the macroscopic and microscopic representations was used to more accurately show the ear in different environments (Medical Imagery, 2007).

3.11.10.3 Boyle's Law cylinder experiment (Appendix U). This experiment was developed based on the Boyle's Law syringe experiment (Appendix Q) and in consultation with Bush, Alderson, Remillard, Edwards, Datzkiw and Gertley.

3.11.11 Demonstration: Ear squeeze during flight (Appendix V). This model was designed by Gertley and Edwards (2007), and based on the pedagogical framework described by Boohan (2002) and Jonassen, Pick and Wilson (1999) as discussed above. The model simulates and exaggerates the movement of the tympanum during take-off.

3.11.12 Formal lesson: Ear squeeze during flight (Appendix W). The notes for this lesson were based on the ear squeeze during scuba diving lesson (Appendix S) and on the macroscopic, microscopic and symbolic representations of Mahaffy (2006).

3.11.13 Student, teacher and dive master evaluations (Appendices X to CC). The questions for these evaluations were designed by Gertley (2010).

3.12 Qualitative Analysis

This study is based on a qualitative, interpretive case study method design. Open coding technique was used to analyze the data (Strauss and Corbin, 1990). The data were read initially and coded, then the data were read again, and the codes were grouped into themes.

3.12.1 Process-folios. To determine changes in student conceptions and to discuss activities that students deemed beneficial to learning, students produced a process-folio. The process-folio was a structured sampling of student work that provided a written record of student perceptions throughout the teaching sequence (Gobert and Clement, 1999; Wolf *et.al.,* 1991). The process-folios consisted of work from the three pre-posttests (Appendices A-C), and work from E to K, O to R, T to V, and X to Y.

The process-folios were developed using guidelines established by Grotzer and Perkins (2003) and in consultation with Alderson, Bush, Dann, Datzkiw, Dubois-St. Jacques, Edwards, Datzkiw, Lewthwaite, Lukie and McMillan (personal communications, 2008).

As students built their process-folios, for each cognitive probe students were asked how they thought their perceptions had changed (or had not changed), why these changes occurred (or did not occur) during each section of the teaching sequence, and if they found the lesson helpful. If there were questions about student reasoning or understanding, the researcher responded with written questions to which students responded in writing. These responses were also added to their process-folios.

The process-folios were analyzed for content and qualitative themes in a manner similar to those used by Zeedyk, Gallacher, Henderson, Hope, Husband, and Lindsay (2003). Initial conceptions and changes in conceptions (if any) before and after each diagnostic tool were coded. Themes generated by the coded data were identified and named by the researcher and colleagues. Themes were compared to the theoretical frameworks discussed below.

To provide inter-rater validity, students' responses were classified by the researcher and two external examiners. There were six external examiners in total who helped with the analysis of different parts of the study. One of the external examiners was the collaborating teacher. Four of the external examiners were high school teachers with a minimum of five years teaching experience. All of these teachers had received grants and awards for their projects in education. One external examiner was a Faculty of Education instructor with a position at a university in western Canada.

Interpretations of student responses were discussed with the researcher and external examiners. All differences or disagreements were resolved by discussion. This process required hundreds of hours of analysis by the researcher and examiners.

3.13 Methods Used to Answer the Nine Research Questions

3.13.1 Question 1: What are the initial pre-conceptions of students in respects to pressure and Boyle's Law and what experiences shape their mental models?

Initial conceptions and experiences written by students (Appendices E, F, G, H, I, J, K, R and V) were analyzed by the researcher by meeting with two external examiners individually, or two external examiners simultaneously. Student conceptions were coded with the external examiners; and compared to conceptions found in the literature and conceptions observed in previous sessions of the scuba project by the researcher. Also, conceptions noted and addressed by the collaborating teacher that may not have been recorded in written form by the students were also included.

3.13.2 Question 2: What information about student understanding of Boyle's Law can be obtained from assignments based on multiple representations of science understanding (Johnstone, 1991)?

Assignments 1 and 2 (Appendices O and P respectively) were analyzed to determine if students understood Boyle's Law from symbolic, macroscopic and microscopic perspectives.

The researcher analyzed both assignments to determine student understanding of congruency between the three representations (Treagust, Chittleborough and Mamiala, 2003) without external examiners. Then the researcher met with two external examiners individually. Each examiner would give his or her opinion, and the researcher would discuss her opinion. Any disagreements were discussed until consensus was met.

3.13.3 Question 3: What alternative models do students have at the end of the teaching intervention?

Post-tests 1 and 2 were analyzed to determine if there was conceptual understanding from a multiple representations perspective (Mahaffy 2006; Johnstone 1991). The types and development of alternate models were also compared to the teacher-student outcomes framework (Freyberg and Osborne, 1985) and applicable parts of the three-tiered analysis framework (Chu, Treagust and Chandrasegaran (2008).

3.13.3.1 Analysis of post-test 1.

Identifying stable alternate conceptions. Post-test 1 was first analyzed on its own (that is, without looking at any other tests or assignments) by the researcher. Each pair of analogous questions was checked for consistency, and a tentative list of stable, alternate conceptions was developed. The researcher then met with two external examiners individually. Each examiner would first give his or her opinion, after which the researcher would provide her opinion. The researcher and external examiner would then compare responses from assignments 1 and 2, analysis of student analysis of post-test 1 and responses from the process-folios to support interpretations. Any disagreement in interpretations was discussed until consensus occurred.

3.13.3.2 Identifying model building outcomes for post-test 1(Freyberg and Osborne, 1985).

Unified Scientific Outcome. Students were identified as having a unified scientific outcome if they showed only one or two stable alternate conceptions that did not appear to impede overall understanding. Generally, these students scored a minimum of 85% on post-test 1.

Children's undisturbed outcome. Children's undisturbed outcomes were identified by comparing stable alternate conceptions demonstrated in post-test 1 to the literature to see if they had been identified in younger students.

Reinforced outcome. A reinforced outcome was determined by the researcher and co-operating teacher by analyzing limitations to the models the teacher presented and test answers compared to target and scientific models. Evidence from class discussions and pen-and-paper "scientific models" written by students in class were used to designate a reinforced outcome.

Confused outcome. Students who didn't regularly answer analogous questions in a consistent manner (indicating unstable, p-prism, fragmented and contextual alternate conceptions) and showed a number of stable alternate conceptions were thought to present with a confused outcome. These students did not improve from pre-to-post test scores (less than 5%) and received less than 50% on the post-test.

3.13.3.3 Analysis of post-test 2.

Identifying stable alternate conceptions. Post-test 2 was analyzed for alternate conceptions that were categorized using the outcomes perspective (Freyberg and Osborne, 1985) in a similar manner to post-test 1. Post-test 2 was first analyzed on its own (that is, without looking at any other tests or assignments) by the researcher. Each pair of analogous questions was analyzed for consistency, and a tentative list of alternate conceptions was developed. Later, post-test 3 (Appendix C) was analyzed for alternate conceptions and a tentative list of these conceptions was made. Questions numbers 8, 9, 19 and 20 were then compared to the analogous long-answer written responses in post-test 3 to check for consistency between written and multiple-choice answers.

At this point, the first external examiner analyzed post-test 2 with the researcher. The external examiner first gave his/her interpretation; afterwards, the researcher shared her opinion. Questions 8, 9, 19 and 20 were also compared to the analogous questions in post-test 3 by the external examiner in a similar manner. If there were discrepancies with interpretation, other evidence provided by written answers from the conceptions of the ear post-test (Appendix C), student analysis of post-test 2, and analysis of post-test 1 were used to support or refute the differing interpretations. If consensus could not be achieved, multiple interpretations were recorded. This process was repeated with the second external examiner.

Only stable alternate conceptions that were agreed upon with confidence by the two external examiners and the researcher are presented. The minimum requirement for identifying an alternative conception was agreement in either part 1 or part 2 in each of the analogous two-tiered multiple-choice items. For example, in questions 2 and 7 of post-test 2, part A asks the student to identify the "normal", macroscopic position of the tympanum using a written explanation (Appendix V, question 2) or a diagram (Appendix V, question 7). Part B of each question asked the students to identify the microscopic (Appendix V, question 2) and symbolic (Appendix V, question 7) justifications for the normal position of the tympanum. If a student answered that the normal tympanum position was "convex" in part A of both questions, but identified different symbolic and microscopic rationales in part B, the "normal convex tympanum" was identified as an alternate conception. When possible, evidence was gathered from the conceptions of the ear post-test (Appendix C), post-test 1, and the student analysis of post-test 2 to confirm or refute interpretation of alternate conceptions of the ear during scuba descent and flight ascent. As the scuba experiments were completed in small groups, these were not used as a basis for comparison, as in many cases one person did all of the work.

3.13.3.4 Identifying model building outcomes for post-test 2 (Freyberg and Osborne, 1985). Student models were analyzed through the lens of Freyberg and Osborne's outcomes (1985) as described below.

Unified Scientific Outcome. Students were identified as having a unified scientific outcome if they showed only one or two stable alternate conceptions that did not appear to impede overall understanding. Generally, these students scored a minimum of 85% on post-test 2.

For example, one student could use her knowledge of pressure systems and Boyle's Law to answer most questions correctly. However, the student could not identify "positive" vs. "negative" pressures. Though the student could identify and understand which space had "greater" pressure and which space had "less" pressure comparatively, determine the physiological effects of unequal pressure systems and explain equalization, she could not place the labels "positive" and "negative" when there was a pressure imbalance. This was confirmed by the post-test analysis. Regardless, this student was identified as having a unified scientific outcome, even though the "positive" and "negative" labels were not used, because she understood the differences and determined outcomes in keeping with target models.

Children's undisturbed outcome. Children's undisturbed outcomes were identified by comparing stable alternate conceptions demonstrated in post-test 2 to those of post-test 1 and alternate models and experiences identified by the participants and recorded in class. These conceptions were then compared to the literature to see if they had been identified in younger students.

Some participants had persistent, tenacious alternate models based on previous experiences that were demonstrated throughout the teaching intervention and did not change despite instruction. This was also thought to be an "undisturbed outcome" as the alternate model did not change, or remained "undisturbed".

Reinforced outcome. A reinforced outcome was determined by the researcher and co-operating teacher by analyzing limitations to the models the teacher presented and test answers compared to target and scientific models. Evidence from class discussions and pen-and-paper "scientific models" written by students in class were used to designate a reinforced outcome.

Confused outcome. Students who didn't regularly answer analogous questions in a consistent manner (indicating unstable, p-prism, fragmented and contextual alternate conceptions) and showed a number of stable alternate conceptions were thought to present with a confused outcome. These students did not improve from pre-to-post test scores (less than 5%) and received less than 50% on the post-test.

3.13.4 Question 4: Do students find model building activities useful for understanding pressure and Boyle's Law?

3.13.5 Question 5: Do students find the tetrahedral orientation (Mahaffy, 2006) useful for learning pressure and Boyle's Law ?

3.13.6 Question 6: Do students find the scuba activity useful for learning pressure and Boyle's Law?

Students were asked to discuss the demonstrations, lessons and activities they found useful, whether they thought small and large group discussions were helpful, and if the four orientations assisted their understanding of pressure and Boyle's Law (Appendix AA). Individual answers to these questions were compared against understanding demonstrated in the post-tests. This information was then compared to student pre-and post-test analyses (Appendices X and Y) where they were asked to discuss the experiences that helped them pick correct answers on post-tests 1 and 2. Student answers were categorized and the frequencies of their answers were recorded.

In the overall evaluation (Appendix AA), students were also asked if they found the scuba activity useful (or not) (Appendix Z), which demonstrations or activities they found particularly useful and why they were useful, which demonstrations or activities they did not find useful and why they were not useful, and to suggest improvements. Students who did not dive were asked why they chose not to dive, and after watching their peers dive, would they try if given the opportunity? The answers were categorized and frequencies of the answers were recorded.

3.13.7 Question 7: Does the collaborating teacher find model building activities useful for understanding pressure and Boyle's Law?

3.13.8 Question 8: Does the collaborating teacher find the tetrahedral orientation (Mahffy, 2006) useful for teaching and evaluating science understanding (for the concepts of pressure and Boyle's Law)?

3.13.9 Question 9: Does the collaborating teacher find the scuba activity useful for learning pressure and Boyle's Law?

These questions were asked in the interviews with the collaborating teacher (Appendix BB). In order to ensure validity, the teacher was given a draft of the results and analysis section that he could edit or delete at his discretion.

Chapter 4: Initial Student Conceptions of the Particulate Nature of Matter, Pressure and Boyle's Law

Students' initial conceptions at the beginning of particular lessons within the study are described in this chapter. Thought there were 21 participants in this study, feedback from all 21 participants for each lesson did not occur. Students missed lessons for reasons such as illness, appointments, and field trips. They were not asked to provide conceptions for missed lessons.

4.1 Conceptions of the Particulate Nature of Matter

Nineteen student responses were analyzed to determine student conceptions of the particulate nature of matter (Appendix E). Of these nineteen participants, only one student (36494) was able to provide diagrams of the relative spacing of particles close to the target models of solids, liquids, and gasses. However, this student did not provide explanations of the movement of these particles. One other student (36843) did not provide diagrams and gave few written explanations.

A majority of students either didn't provide explanations of the movement of the solid, liquid and gas particles or only provided explanations of one or two of the phases of matter. The students that did provide explanations of the movement of particles are discussed below.

4.1.1 Spacing and movement of solid, liquid and gas particles. Sixteen students drew particles of solids close together, liquids further apart (larger spaces between particles compared to solids) and gas particles with the largest spaces between particles. Figure 4.1 is a representative example of the models drawn by the 16 students.

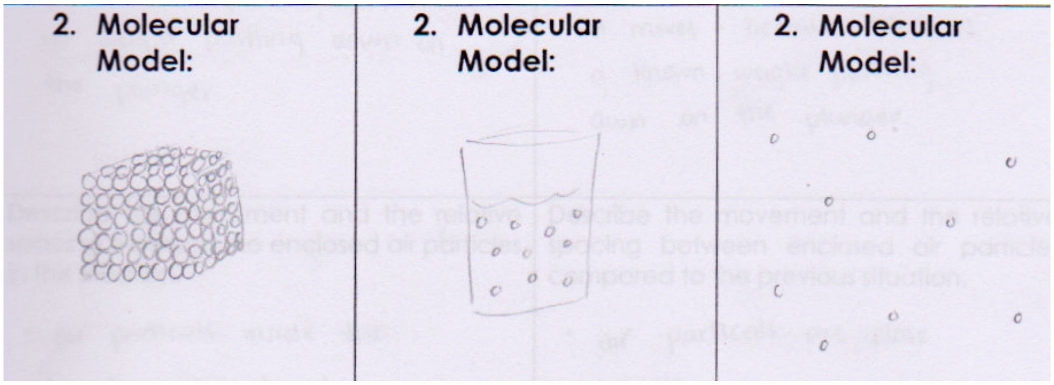


Figure 4.1. Microscopic visualizations of a solid (left), liquid (middle) and gas (right). Drawn by Student 59932.

As discussed in the literature review, the exaggerated spaces between particles forming a liquid may have been the result of a reinforced outcome (Freyberg and Osborne, 1983) such as misinterpretation of teacher instruction (Freyberg and Osborne, 1983) or the learning of alternative conceptions teachers themselves may hold (Besson, 2004).

4.1.1.1 Movement of solid particles. When describing the movement of solid particles, five students (11252, 22724, 30913, 34988 and 84816) thought that solid particles did not have any movement. One of these students thought that there were, "strong ionic bonds between particles" so they were held in place. Another student thought that the particles forming a solid were so "compacted" that the particles could not move. One student (36843) described the movement of particles forming a solid as "less than a liquid or a gas" but, as mentioned above, did not provide a diagram illustrating this. Twelve students did not describe the spacing or movement of solid particles.

4.1.1.2 Movement of liquid particles. Eight students (26951, 27563, 30913, 34988, 36843, 59932, 62533 and 84816) described the movement of particles in a liquid as "moving freely" and having more movement compared to solids. The other students did not provide a description of the movement of the particles in a liquid state.

Student 84816 thought that compressed liquids and gases had similar spacing to those of solids, and that solid particles were "jammed together" with no spaces between them. This alternate conception re-appears in the next diagnostic described below.

4.1.1.3 Movement of gas particles. Five students (29425, 30913, 34988, 36843 and 84816) described the movement of particles in gases using descriptors such as "random", "moving freely" and "chaotic".

One student (62357) thought that both liquids and gases in a syringe moved in a circular motion, then in a downward motion upon compression (Figure 4.2). This alternate conception was tenacious, and will be discussed later in this chapter.

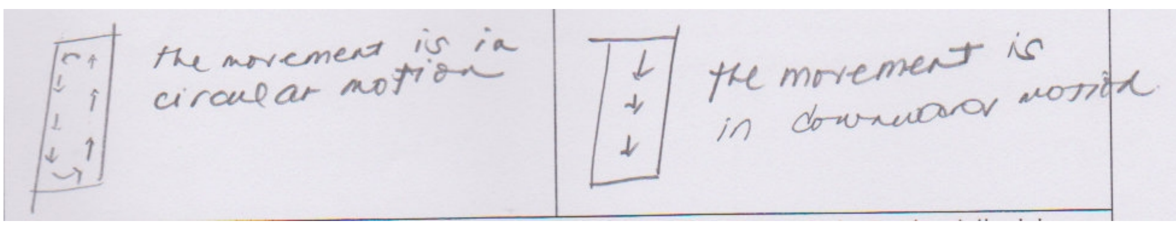


Figure 4.2. Circular motion of liquid in a syringe (left) and upon compression (right). Drawn by Student 62357.

4.1.2 Student conceptions of liquids and gases in a syringe. Eight of the 15 students predicted that both liquids and gases would be compressible. Given the large spaces between liquid and gas particles as compared to solid particles, the prediction that liquids as well as gases would be compressible is congruent between microscopic and macroscopic visualizations.

Three students (27563, 36843 and 66774) predicted that gases would be compressible, and that liquids would not be compressible. These three students used the rationale that "water is not compressible". In this case, the macroscopic prediction that water or liquids are not compressible was incongruent with their microscopic visualizations. The spaces between water particles drawn by these students would imply compressibility. No experiences were cited by these students, whether it be a information learned from school or first-hand experiences.

Five students (26951, 30913, 38667, 69297 and 81886) predicted that both gases and liquids would be incompressible. Though these students initially drew models of gases with particles far apart, when asked to describe the relative spacing of air particles in a syringe, these students described gas particles as "compacted together", "crammed" or "packed" in their written explanations.

This common alternate conception was described by Benson, Wittrock and Baur (1993). In a similar manner, their students drew liquid particles with smaller spaces between them (Figure 4.1), however, the liquid particles in a syringe were also described as "packed". Moreover, Benson, Wittrock and Baur (1993) described a common alternate conception where the structure of gases was viewed as similar to the structure of liquids. Thus it would appear that these students thought that as the gas particles were packed tightly in a syringe, the liquid particles would be as well.

This simple change from a microscopic drawing with no real-world context (i.e., a picture of gas or liquid particles bounded by a frame, typically used in textbooks) to a microscopic drawing in a real-world context (i.e., a picture of gas or liquid particles in a syringe) supports the idea that the effective use of models may be hindered by the difficulty in applying models in different contexts (Coll, France and Taylor, 2005).

4.1.3 Student experiences for model building. Only one student (30913) described an experience that helped him build his model of the compression of liquids and air. This student had initially drawn particulate models of solids, liquids and gases similar to Figure

4.1. However, when describing the spacing of gases (and liquids) in a syringe, he described the particles as "compacted together", and thought that both gases and liquids were incompressible. The experience cited was difficulties with an air pump. As he explained, "An air pump wouldn't pump smoothly when I used it. I had to use so much force." This experience was addressed by the collaborating teacher who explained that the pump was not working and, in fact, the mechanism was stuck rather than the air particles being compacted. This alternate conception appeared to have been resolved for this student at the end of the lesson.

4.2 Conceptions of Boyle's Law: Volume Changes in a Balloon at Increased Elevation

Eighteen students responses were analyzed to find student conceptions of changes in the volume of a balloon from sea level to the top of a mountain (Appendix F). Ten students predicted that at a higher elevation, the balloon would decrease in size. Five students thought the balloon would stay the same volume. Three students predicted that the balloon would increase in size. One of the students who predicted the balloon would increase in volume provided a partial scientific model.

Explanations included linear reasoning of pressure, specifically internal pressure orientations (or only thinking of pressure in terms of changes in internal pressure and not considering external pressure) and external pressure orientations (thinking of pressure changes externally and not considering internal pressure) as described by Basca and Grotzer (2001). Students also applied systematic reasoning (considering both internal and external pressures) to form their models. The students' alternative models are described below.

4.2.1 Volume decreases. Students used internal, external and systematic pressure reasoning to predict that the balloon would decrease in volume. Two students were identified as holding the alternate conception that pressure increased with altitude (Basca and Grotzer, 2001).

4.2.1.1 No explanation. Students 11252 and 36494 drew a balloon of smaller size at increased elevation, with no microscopic, symbolic or written explanations. Student 11252 was identified as EAL with conversational difficulties.

4.2.1.2 Decreased volume with internal pressure orientation reasoning. Four students (29425, 38667, 62357 and 97608) predicted that the volume of the balloon would decrease based on internal pressure orientations (Basca and Grotzer, 2001).

Students 29425 and 97608 drew a smaller balloon, with internal particles drawn only (Figure 4.3). In this case, there was no discussion of the role of decreased ambient pressure, Upon clarification, both student indicated that the particles were moving randomly, inside the balloon, and this did not change at increased elevation. The explanations only described the particles inside of the balloon. The drawings and explanations indicated an internal pressure orientation as described by Basca and Grotzer (2001).

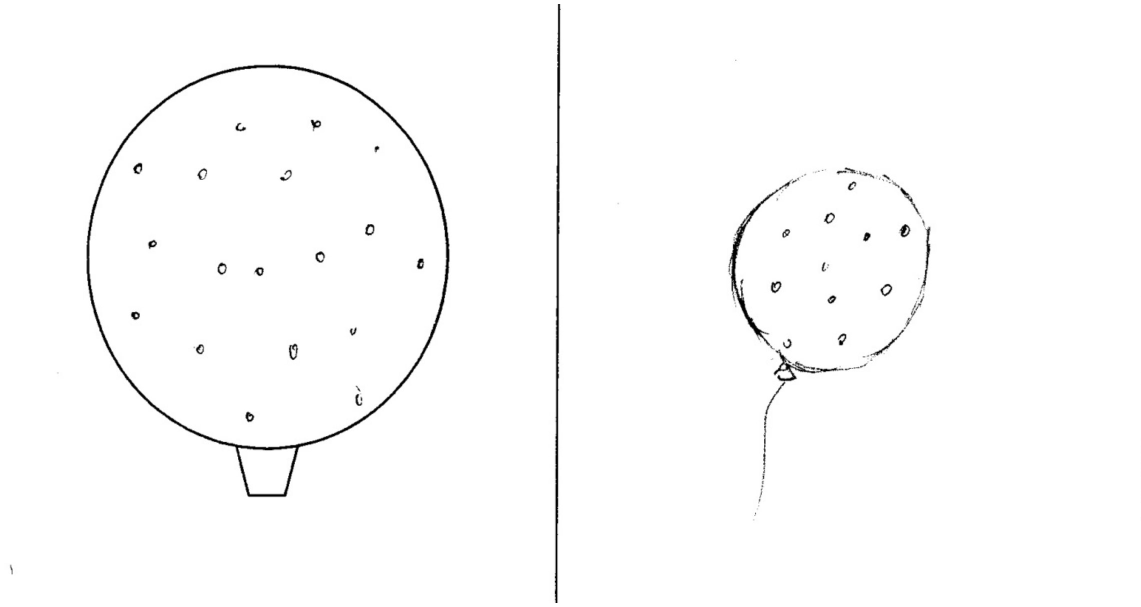


Figure 4.3. Balloon volume at increased altitude, representative diagram of volume decrease with linear reasoning of pressure. Internal pressure emphasized.

Student 62357 also predicted that the volume would decrease with increased elevation. This student thought that air molecules moved in a circular motion to maintain the balloon's circular shape (Figure 4.4). This circular model was described by the student previously (Figure 4.2) and did not change with instruction in the preceding class. The experience she cited in forming this model was, "looking at balloons".

The roundness of the balloon and her model of circular gas particle movement appear to have a common characteristic that is not actually helpful in understanding the scientific model (Freyberg and Osborne, 1985). At this particular time, the student did not disclose that she attributed her understanding that gas particles travelled in a circular motion to a previous teacher's description of air particles moving in a circular manner in air currents. This would have helped to establish her alternative conception.

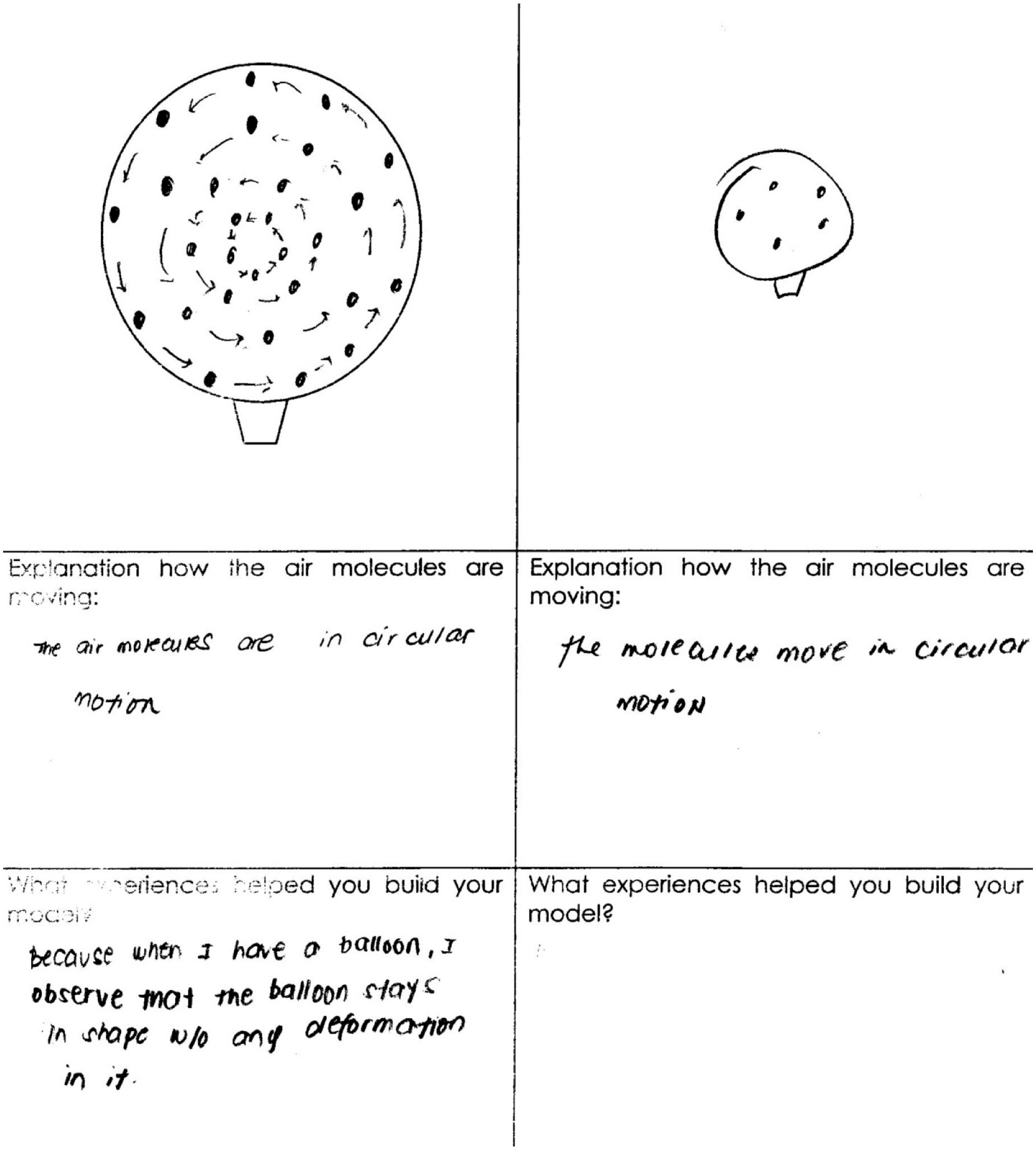


Figure 4.4. Balloon volume at increased altitude, volume decrease with internal pressure orientation and circular movement of air particles.

4.2.1.3 Experiences cited in forming a decreased volume model using an internal pressure orientation. Student 97608 described blowing up a balloon as the experience used for her model of a balloon at sea level, and seeing a balloon shrink outside when it is cold for her model of a balloon at the top of a mountain where it is not only at a higher altitude but is also normally a lower temperature.

4.2.1.4 Decreased volume with external pressure orientation. Student 84816 demonstrated an external pressure orientation when explaining why a balloon maintains its shape at sea level (Figure 4.5). When explaining why he predicted the balloon would shrink, he provided an external pressure orientation, discussing external pressure only. He thought the pressure at the top of the mountain was so great that the internal air particles would become packed together. He also thought that, "The balloon pops because there is a lot of pressure [sic] at the top."

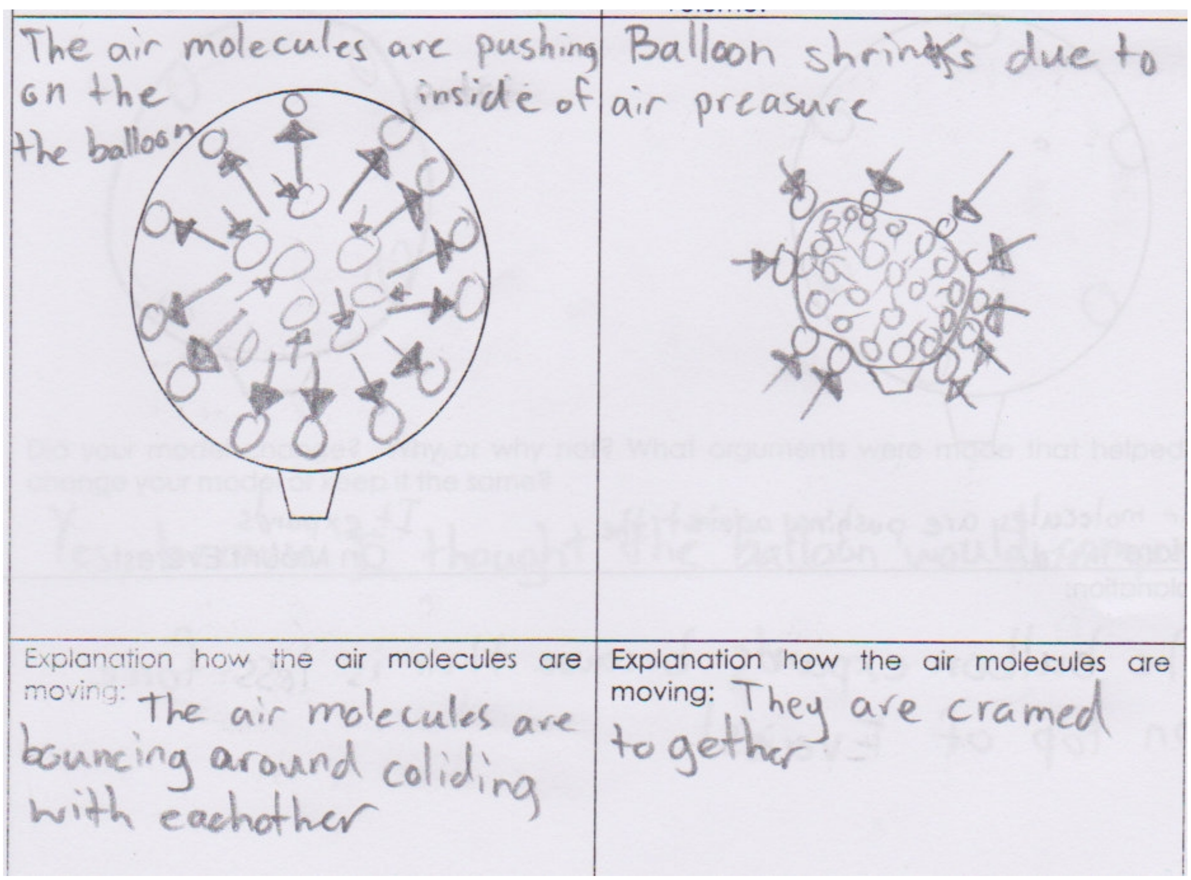


Figure 4.5. Balloon volume at increased altitude, volume decrease using external pressure reasoning.

***4.2.1.5 Decreased volume with systematic reasoning*.** Student 36843 explained that the balloon would shrink due to increased ambient pressure (Figure 4.6). Though external particles were not drawn, the explanation shows an attempt at systematic reasoning, taking into account internal and ambient pressures. The student thought that there was, "...more movement inside the balloon but more pressure outside." It is unclear as to why the student thought there would be more movement, and how this would affect volume. This student cited releasing a balloon into the air as the experience used to build her model.

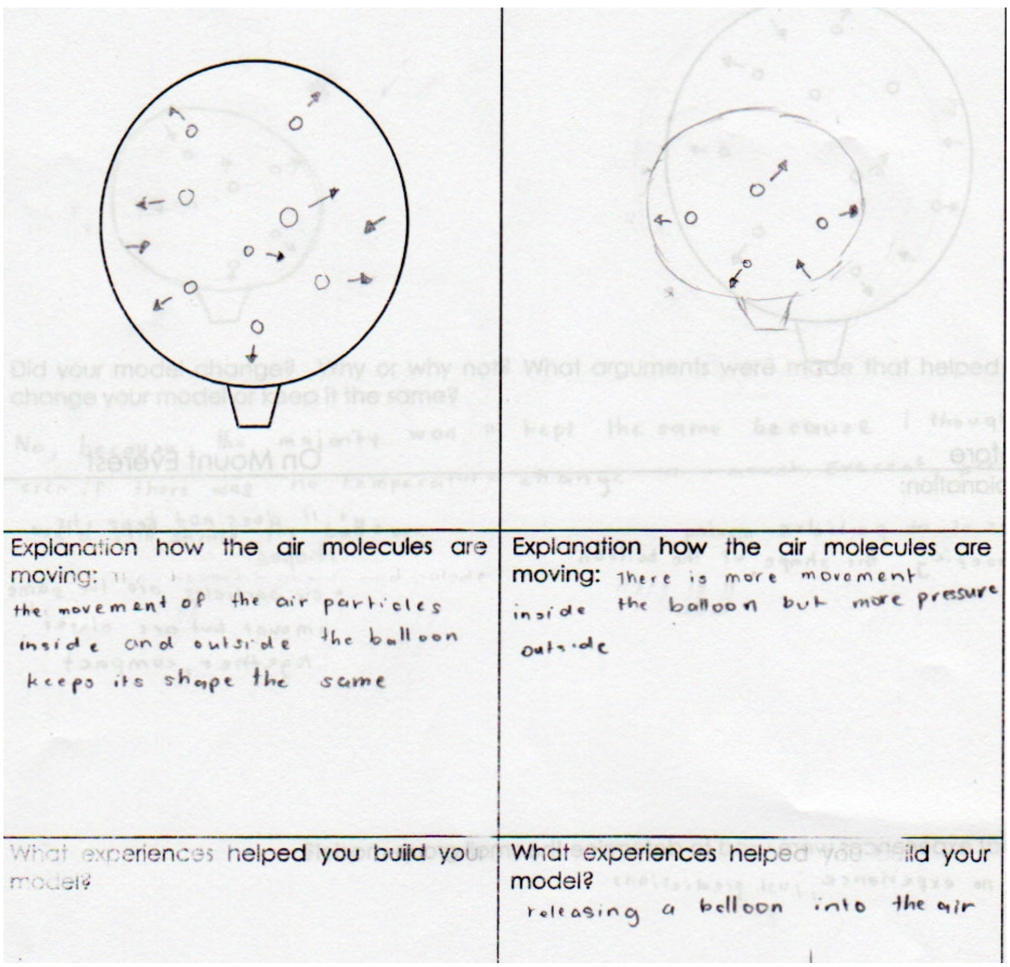


Figure 4.6. Balloon volume at increased altitude, decreased volume with systematic reasoning though no ambient particles drawn.

Students 46628 and 77079 also predicted that the balloon would shrink due to increased atmospheric pressure, and provided a systematic explanation (Figures 4.7 and 4.8).

Upon clarification, Student 46628 explained that though the picture showed air particles close together, she thought that both internal and ambient air particles moved with random motion, and showed surface particles to indicate pressure was caused by collisions with internal and external surfaces (Figure 4.7).

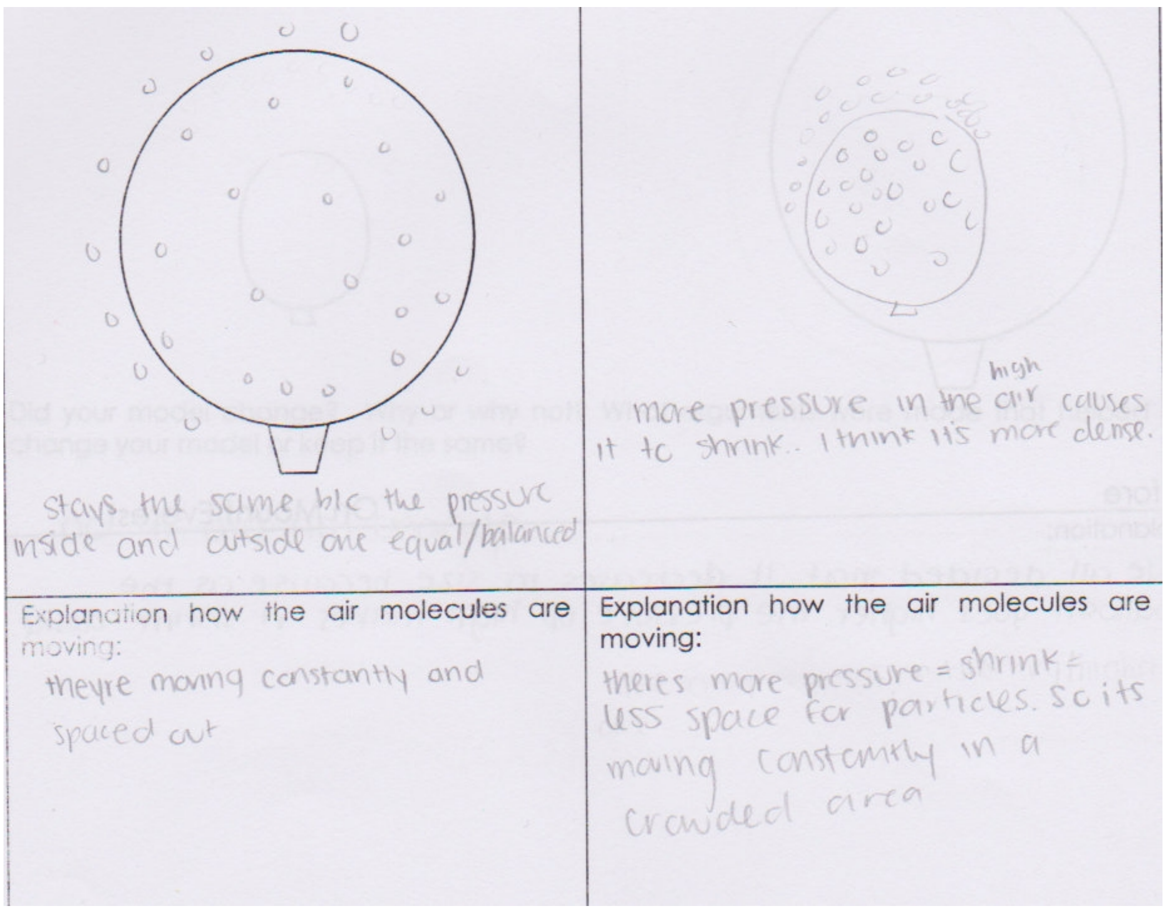


Figure 4.7. Balloon volume at increased altitude, alternate conception of increased air pressure and density with increased elevation, systematic explanation. Drawn by Student 77079.

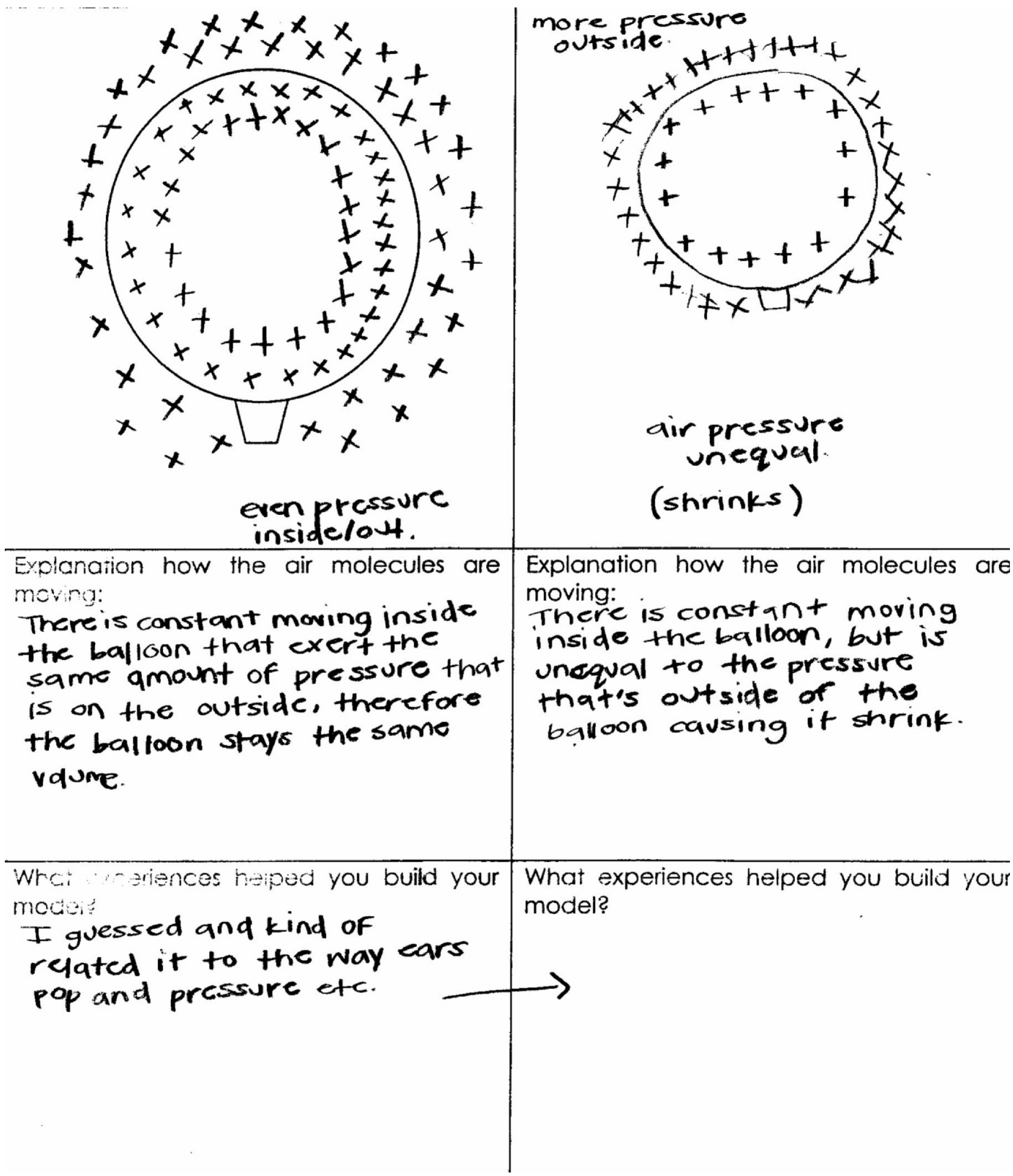


Figure 4.8. Balloon volume at increased altitude, alternate conception of air pressure at increased elevation, systematic explanation. Drawn by Student 46628.

4.2.1.6 Decreased volume, indeterminate model. Student 81886 drew diagrams that implied internal and external reasoning, however, the written explanation only described the internal movement of the air particles. In this case, the student thought that air particles moved around the balloon at sea level. With increased altitude, air particles moved towards the bottom of the balloon (Figure 4.9). No responses were given to questions that asked for clarification.

This may demonstrate another example of unclear everyday conceptions (Chu, Treagust and Chandrasegaran, 2008). However, it was difficult to determine her model with certainty. She was identified as EAL and may not have responded because of difficulties with written English.

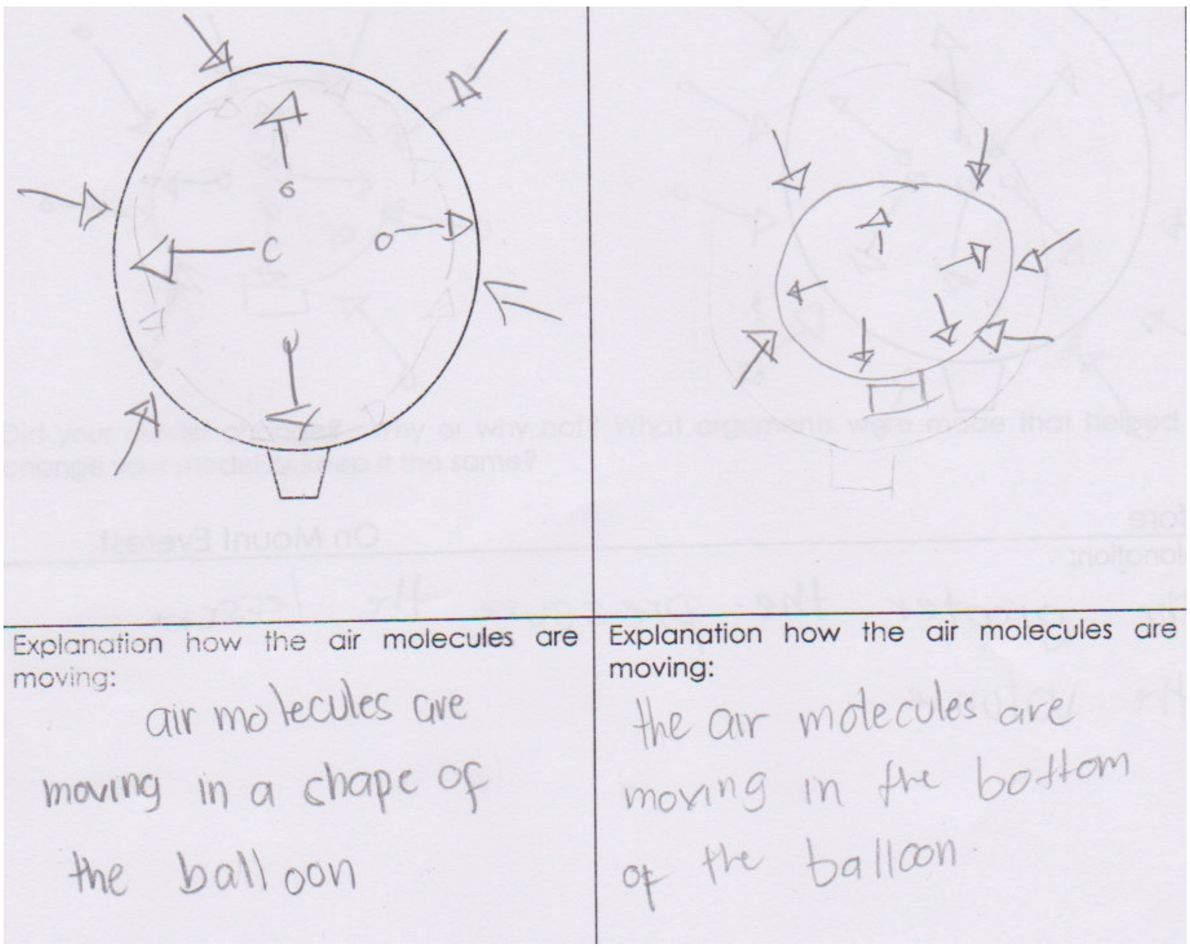


Figure 4.9. Balloon volume at increased altitude, indeterminate model of volume decrease.

4.2.1.7 Experiences cited for decreased volume, systematic explanation model. Student 46628 used the experience of her ears popping under pressure to build her model. It may be that the student built her model using a rationale that was also cited by previous participants of the scuba program. In previous sessions of the scuba program, students who described the ear popping experience explained that during a flight or while climbing a mountain, the person felt "pressure" in his/her ears, thus air pressure increased with increased elevation. If air pressure increases with increased elevation, then the balloon should shrink when brought to the top of a mountain. Student 46628 did not elaborate to this extent on how experience applied to her model, but her rationale may have been similar to other participants in previous sessions of the scuba program.

4.2.2 Volume remains constant. Five students predicted the balloon would stay the same with respect to volume. The alternate conceptions used to form their models included internal pressure orientations (Basca and Grotzer, 2001) and imprecise scientific conceptions (Chu, Treagust and Chandrasegaran, 2008).

4.2.2.1 Constant volume, internal pressure orientation. Students 22724, 66774 and 69297 thought the balloon would remain the same volume as the number of internal air particles did not change. Student 69297 also added that the air particles would be moving at the same speed in either situation, thus, there would be no change in volume.

There were no drawings of external air particles nor was the role of ambient pressure discussed or drawn, which is consistent with the internal pressure orientation identified by Basca and Grotzer, (2001). Student 22724 showed spacing and movement of internal air particles in keeping with scientific models.

Student 66774 also drew a model showing the circular movement of air particles similar to Student 62357 discussed previously (Figure 4.10).

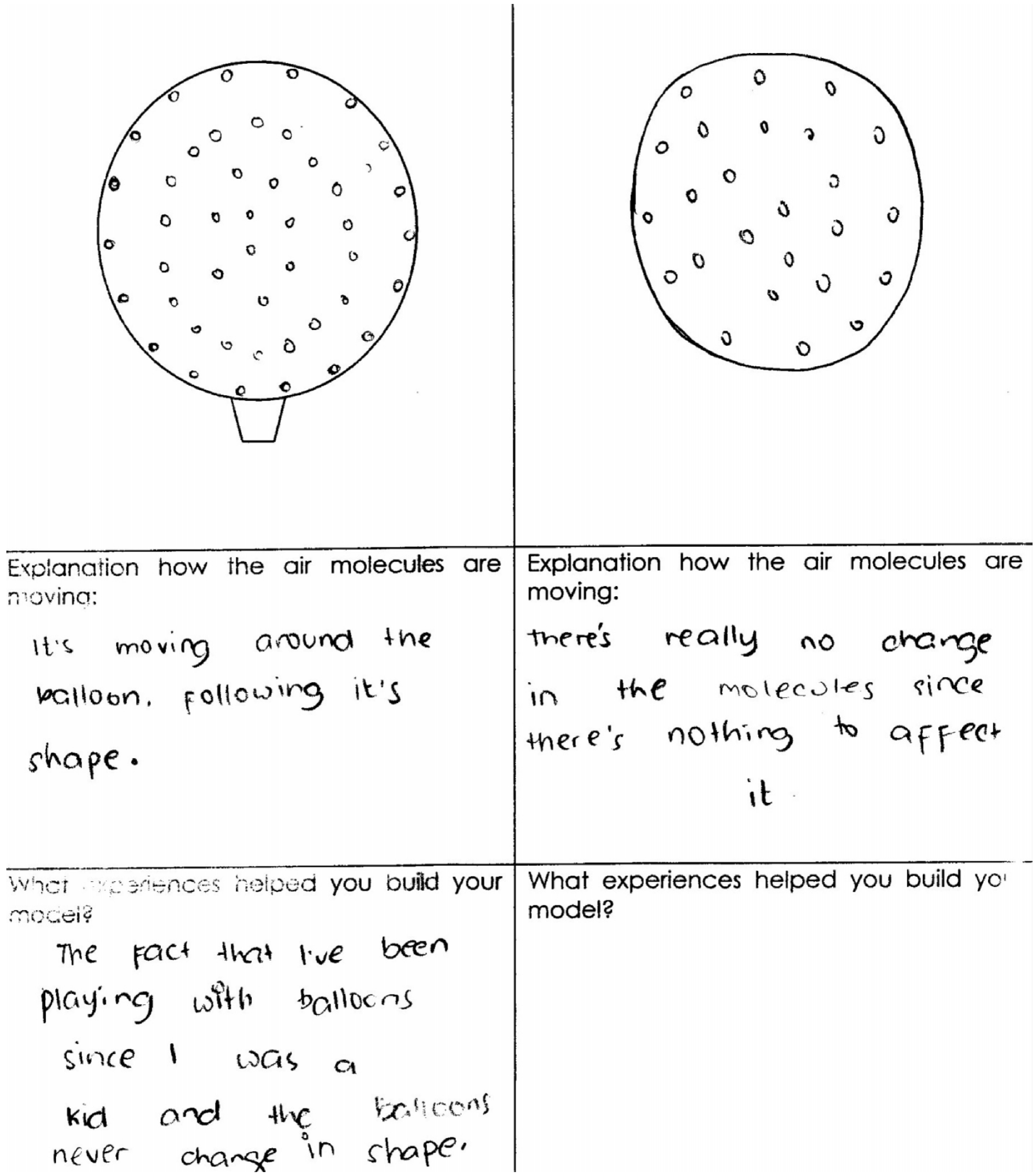


Figure 4.10. Balloon volume at increased altitude, constant volume prediction based on internal pressure orientation and circular air particle motion.

4.2.2.2 Constant volume, indeterminate model. Student 34988 thought the balloon would stay the same size. Though she did not draw the balloon as being the same size in her illustration, clarification questions and later written statements confirmed she believed volume of the balloon remained constant. There was an attempt to discuss internal and ambient pressure, but there was no clear indication that she understood the relationship between ambient and internal pressure.

Though the microscopic drawings appear to indicate that internal air particles are absent from the centre and only move towards the inside surface of the balloon, possibly in a circular motion. It appears the student believed that ambient particles move around the balloon, and at a higher elevation, it appears that the air particles move around more quickly. No responses were given to clarification questions.

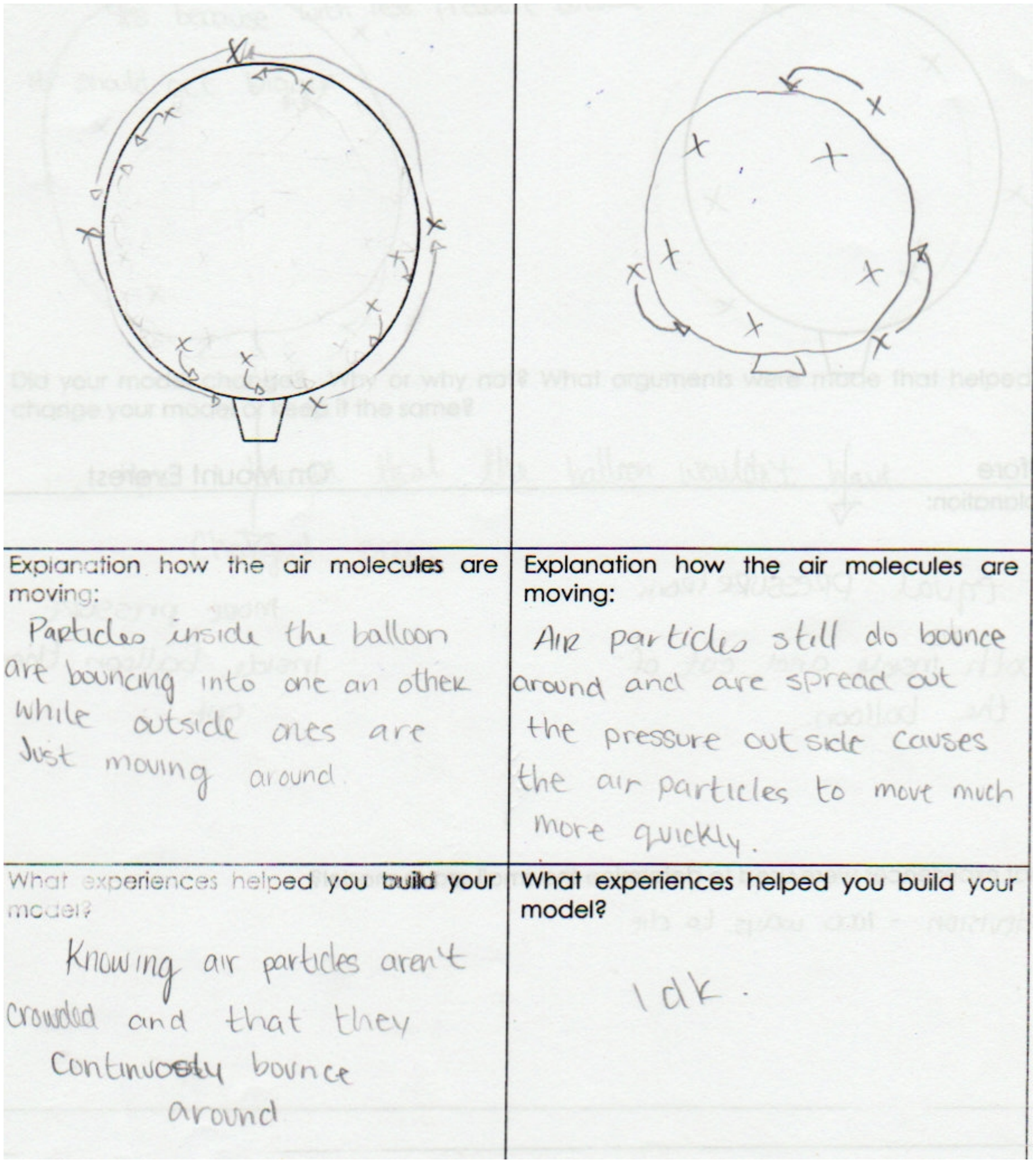


Figure 4.11. Balloon volume at increased altitude, indeterminate constant volume model. Drawn by Student 34988.

4.2.2.3 Experiences cited to form constant volume models. Student 22724 cited blowing up a balloon as the experience used to help build her model.

4.2.3 Volume increases. Two students predicted the balloon would increase in size based on internal pressure reasoning. One student provided a scientific explanation. These models are described below.

4.2.3.1 Volume increases, internal orientation. Student 30913 thought that the balloon would expand because the air particles inside the balloon would move faster (Figure 4.12). There was no mention of a specific experience that helped form this alternate conception.

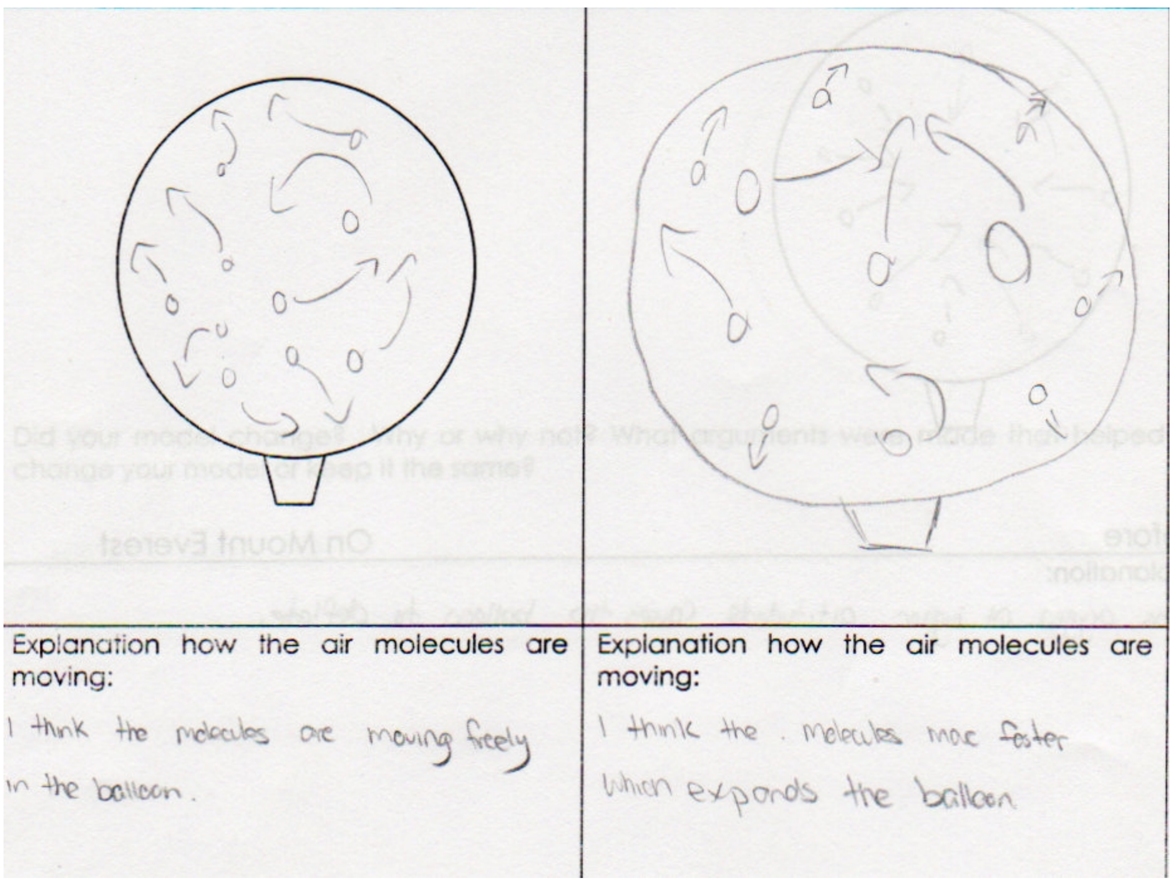


Figure 4.12. Balloon volume at increased altitude, volume increase with linear reasoning of pressure. Internal pressure emphasized.

Student 59562 (Figure 4.13) also predicted the balloon would expand based on the internal pressure orientation, although the movement of the air particles was not described.

As will be discussed later in the chapter, this internal pressure orientation was an anchoring alternative conception for this student and remained with the student throughout the teaching intervention when faced with different contexts.

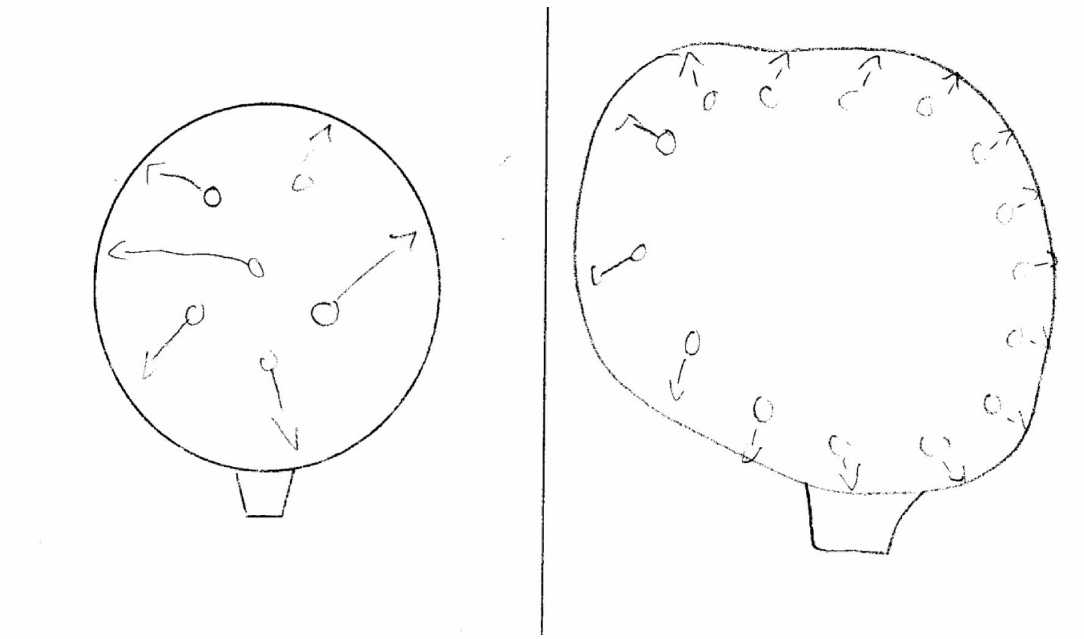
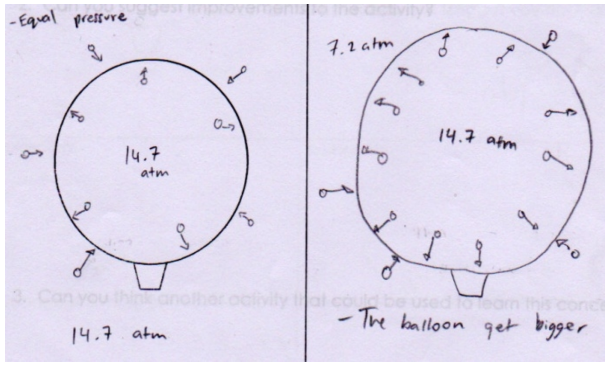


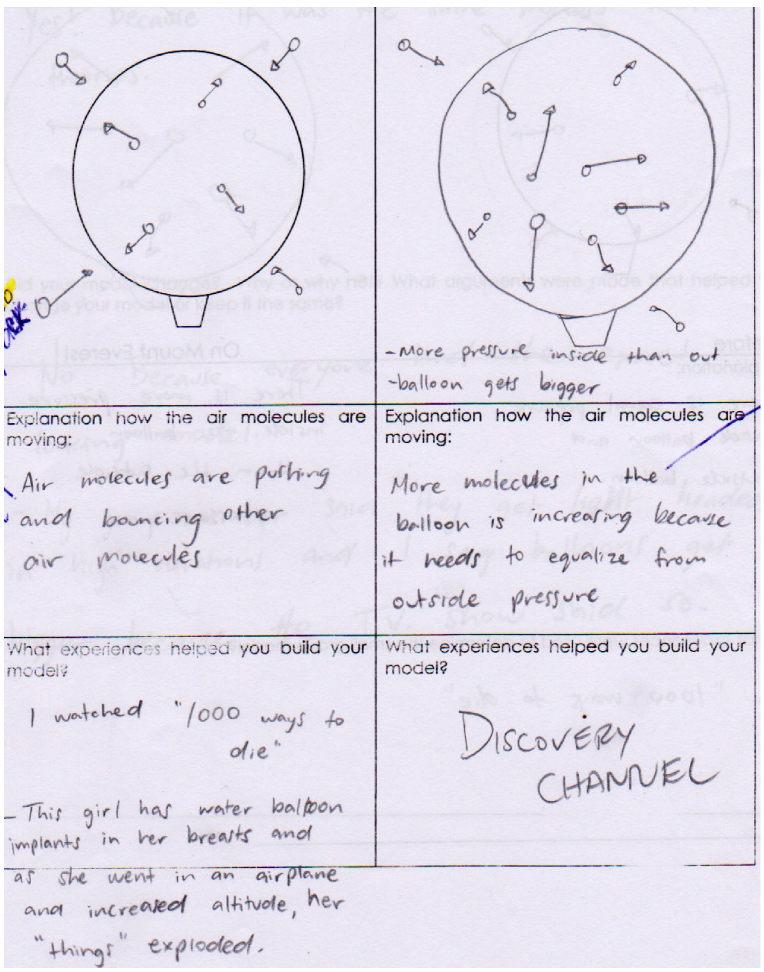
Figure 4.13. Balloon volume at increased altitude, volume expansion, internal pressure orientation, particle movement may be uniform.

4.2.3.2 Volume increases, systematic model explanation. One student (26951) explained that the balloon would expand using pressure systems. Upon clarification, microsopic explanations implied that the student thought that air particle movement was random, and air particles collided with internal surfaces and each other (Figure 4.14).

4.2.3.3 Experiences cited to form systematic models. Student 26951 cited a television show, where, "This girl has water balloon implants in her breasts and as she went in an airplane and increased altitude, her "things" exploded."



a) Symbolic representation of pressure systems.



b) Microscopic, macroscopic and humanistic (experiential) orientations of pressure.

Figure 4.14. Balloon volume at increased altitude, systematic pressure orientation model close to target models. Drawn by Student 26951.

4.3 Conceptions of Atmospheric Pressure at Different Elevations

Students were asked to determine if air exerted pressure in the following three situations: in a room, at the bottom of a mountain, and at the top of a mountain (Appendix G). Twenty students responses were analyzed to determine student conceptions of air pressure at different elevations.

Alternate conceptions identified by Basca and Grotzer (2001) and de Berg (1995) were demonstrated by participants in this study. The alternate conceptions identified were as follows: air does not cause pressure (Basca and Grotzer, 2001; de Berg, 1995), and air pressure increases with altitude (Basca and Grotzer, 2001). Alternate conceptions about the air density and movement of air particles were also identified and will be described below.

4.3.1 Air pressure in the classroom. Nineteen of the 20 students stated that there would be air pressure in the classroom. One student (69297) thought that air did not exert pressure around her, even though she drew microscopic diagrams showing air particles and described them as "moving freely".

Two students (62357 and 66774) thought that the air would move in a circular motion. Both students had previously demonstrated a circular motion model (Figures 4.4 and 4.10) in the context of air in a balloon. This alternate conception was tenacious. Although the two previous lessons included discussions of the random movement of air particles, these motions weren't considered all that was necessary for an inflated balloon to have the shape that it has.

Upon further discussion with the instructor, it was determined that these students had the same middle school teacher who described air particles as moving in a circular motion with air currents. This is an example of an alternate conception through a reinforced outcome (Freyberg and Osborne, 1985). Students may have misinterpreted the teacher's lesson, or the teacher may have taught an alternate conception that he/she believes. The instructor directly addressed this alternate conception with these students, and compared their models to the target model he was teaching. Students 66774 and 62357 changed their microscopic models to air movement in random motion when discussing pressure at the bottom of a mountain.

4.3.2 Air pressure at the bottom of a mountain.

Two students thought that air pressure was not present at the bottom of a mountain. Student 26951 gave macroscopic and microscopic explanations of air pressure in the classroom. The experience he quoted was a story the collaborating teacher told about, "...millions and trillions of air molecules are being hit and bouncing around".

In his explanation of air pressure at the bottom of a mountain, the student clearly showed air particles moving in random directions and bouncing off of a person. However, there seemed to be some confusion as to whether air pressure actually occurred at the bottom of a mountain. This student thought that there may not be air pressure at the bottom of the mountain because "...atmospheric pressure is equal to the ambient pressure." Yet, he used symbolic and microscopic representation to show greater pressure at the bottom of the mountain compared to the top (Figure 4.15).

Clearly, this student understood that pressure works in systems, and tried to apply this concept in this particular situation, when a description of atmospheric (or ambient) pressure was all that was asked for. This intermediate model may be a result of the student making inappropriate (but related) connections, or the student having two competing models as described by Freyberg and Osborne (1985).

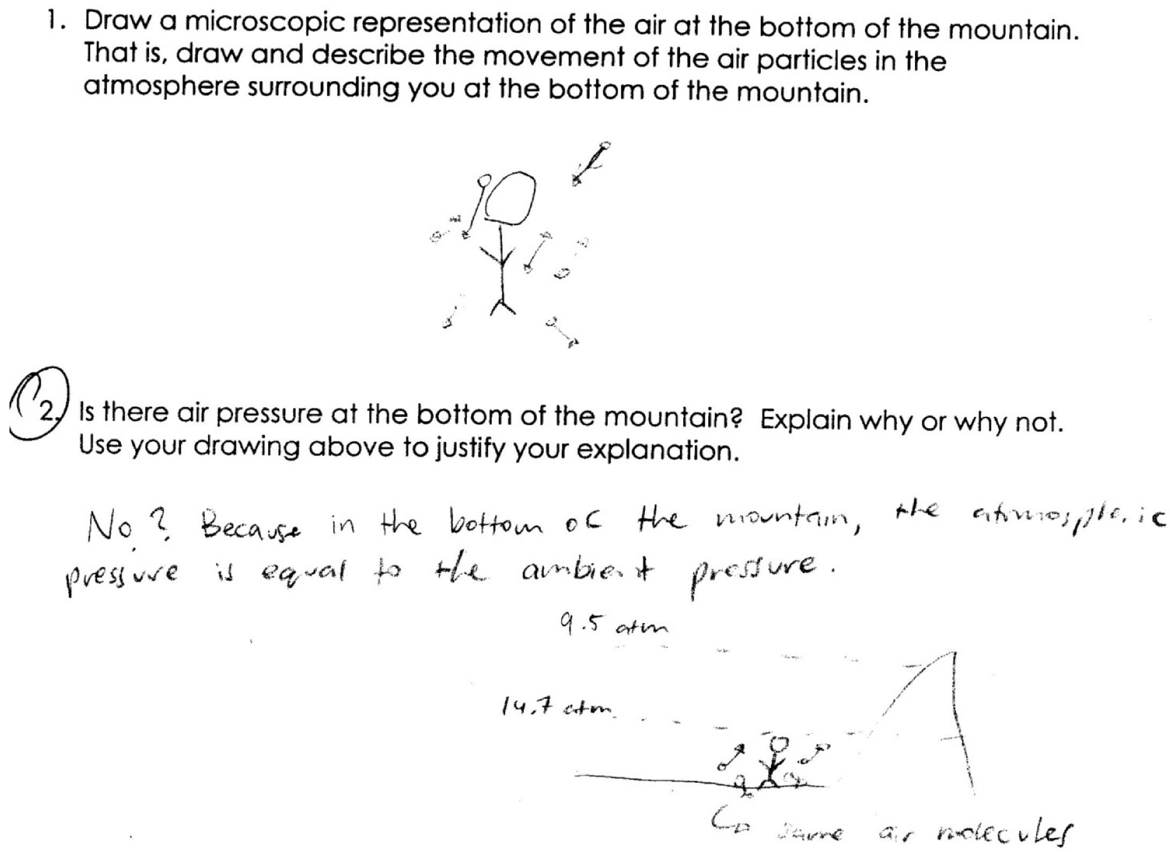


Figure 4.15. Air pressure at different altitudes, contradiction between symbolic and microscopic drawings and written explanation.

Student 69297 also drew air particles at the bottom of the mountain, but stated there was no air pressure at the bottom of the mountain, "because you're standing at sea level and are at lower altitude." This alternate conception was previously described in Basca and Grozer (2001) and de Berg, (1995).

4.3.3 Air pressure at the top of a mountain.

4.3.3.1 Increased air pressure. Despite the previous lesson addressing the concept that air pressure decreases with altitude, Students 11252, 36494, 36843 and 69297 believed that pressure increased with elevation. Three of these four students, 11252, 36494, and 36843, previously held this pre-conception.

Student 36843 explained that she thought air pressure increased at the top of the mountain because, "There are more air particles moving. There is less room between the air particles and has more air pressure." She also showed random movement of the air particles. This student previously gave the experience of releasing a balloon into the air to build her model of increased air pressure with increasing altitude.

Student 69297 explained that there was no air pressure at the bottom of a mountain, but high air pressure at the top of a mountain. Her drawings showed few air particles at the bottom of the mountain, and densely packed particles at the top. As she explained, "...you are at a higher altitude. More pressure."

This anchoring conception (Clement, 2000) or persistent alternative conception was described by Basca and Grotzer (2001).

4.3.3.2 Decreased air pressure, no clarification. Students 38667, 62357 and 66774 thought that air pressure decreased at the top of a mountain due to a decreased number of air particles that were spaced further apart. However, the movement of the particles was not explained.

4.3.3.3 Decreased air pressure based on alternate conceptions. Student 29425 suggested that there was decreased air pressure at the top of a mountain because, "There is more wind/cooler at the top of the mountain than the bottom." The drawing provided clearly showed a decrease in air particles at the top of the mountain compared to the bottom. There was no response to clarification questions. Thus, it was difficult to determine how "more wind" and decreased temperature would contribute to decreased air particles with increased elevation.

4.3.3.4 Decreased air pressure, scientific model. Seven students (46628, 59562, 66774, 77079, 81886, 84816 and 97608) provided models in keeping with scientific models. However, Student 81886 provided diagrams without a written explanation. As previously mentioned, this was an EAL student with difficulties speaking and writing in English.

Student 30913 thought that air pressure was greater at the bottom of a mountain compared to the top because gravity pulls air particles down, keeping the particles close to the earth's surface (Figure 4.16). Previous questions indicated that he thought air particles exhibited random motion, and the arrows were used to exemplify the force of gravity acting on air particles. The experience cited for this model was a "guess".

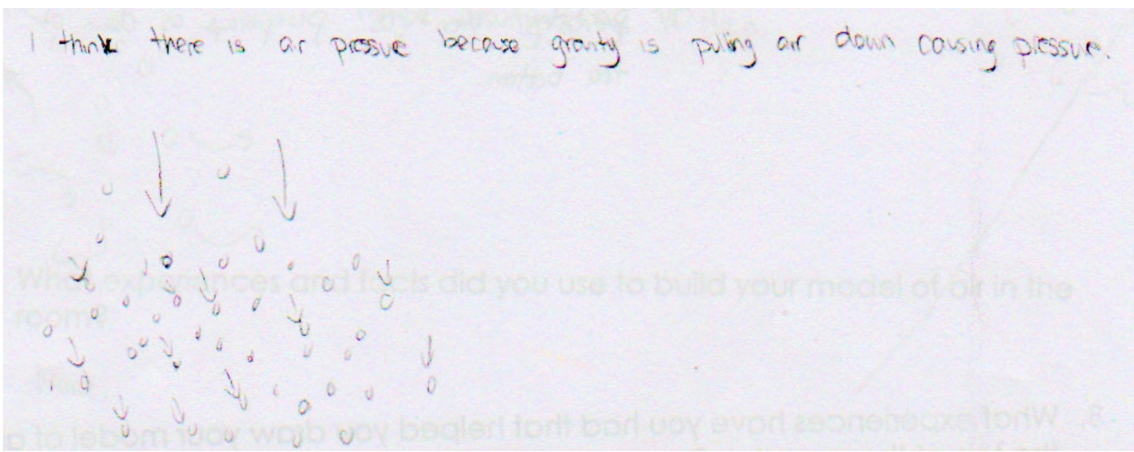


Figure 4.16. Air pressure at different altitudes, student conception of the influence of gravity on air pressure at different elevations.

Experiences used to build scientific models. Students 27536, 46628 and 66774 cited the previous balloon lesson (Appendix E) as the experience that helped shape their models. Student 66774 also cited difficulty breathing in high places due to fewer air particles as evidence helping her to create the model. Student 84816 cited grade nine science lessons and his experience on a mountain where the air was thinner. The humanistic aspect, as described by Mahaffy (2000), of these experiences on a mountain may help to reinforce these scientific models.

4.4 Student Visualizations of a Vacuum

When visualizing air particles in a vacuum (Appendix H) many participating students either (a) drew fewer randomly distributed particles in a flask with larger spaces between them, (b) drew particles in one area of the flask (either top or bottom) or (c) drew particles condensed in the middle of the flask. These results are consistent with Benson and colleagues (1993). One notable exception in this study was that none of the students shaded in the flask, then erased the middle, as reported by Benson, Wittrock and Baur (1993).

Twenty student responses were analyzed, and three general models were observed. These models included a skewed distribution of gas particles, partial scientific models, and scientific models.

4.4.1 Skewed distribution. Six students created models where their air particles were localized in either the top or middle of the vacuum chamber.

4.4.1.1 Air particles localized to the top of the bell jar. Students 11252 and 81886 visualized a vacuum as a removal of air particles from the bottom part of the bell jar only, where the hose through which the evacuated the air flowed was attached. In both cases, the bell jar had air particles spaced closely together, or were "packed". (The collaborating teacher reported that to save time, students were asked to only draw a few particles if they thought the container was full of particles for part 1.) The remaining air particles stayed localized in the top of the bell jar (Figure 4.17).

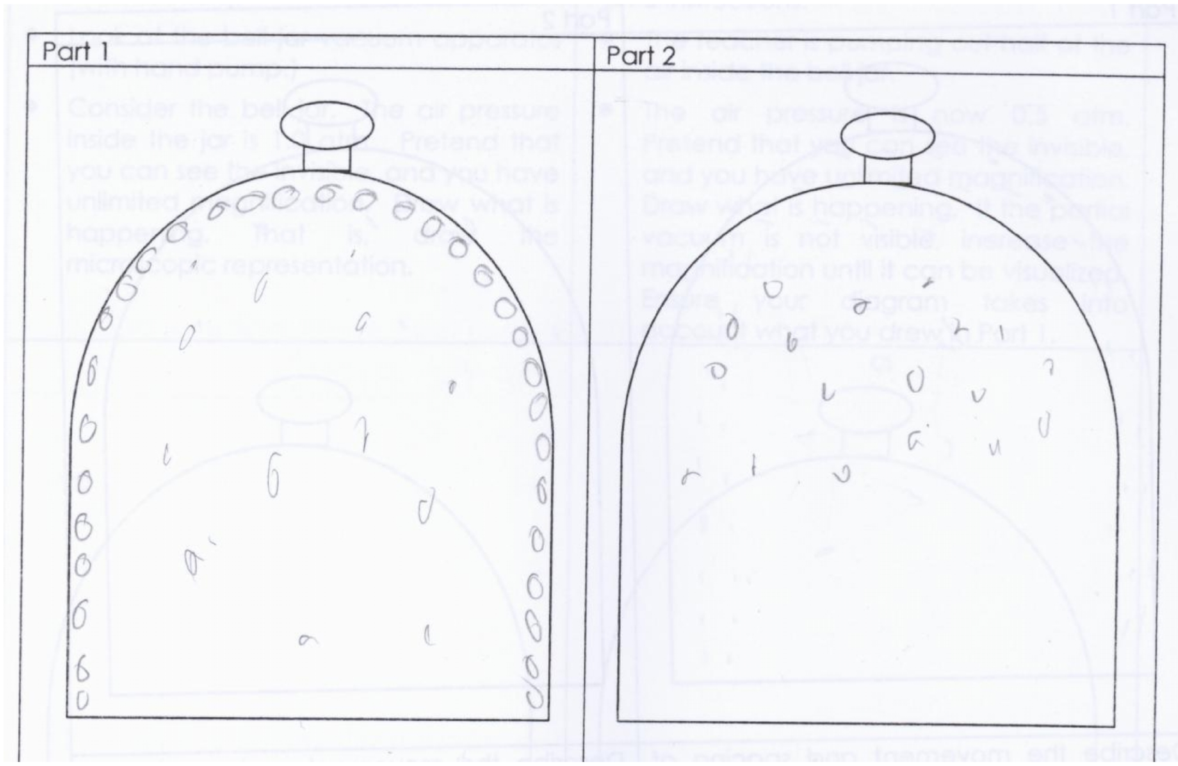


Figure 4.17. Visualization of a vacuum, representative diagram of particles localized to the top. Drawn by student 81886.

Student 22724 visualized that the particles would be absent from the top of the bell jar. She also explained the differences in the movement of the particles. In this case, she explained that normally, "The particles collide on the inside of the container". When describing the spacing and movement in the evacuated bell jar, she wrote that there were, "less particles", "more spacing" and "[t]he air particles will move towards the direction of which way the air is being pumped out." (Figure 4.18). This student cited cleaning (specifically the use of a vacuum cleaner) to help develop her model.

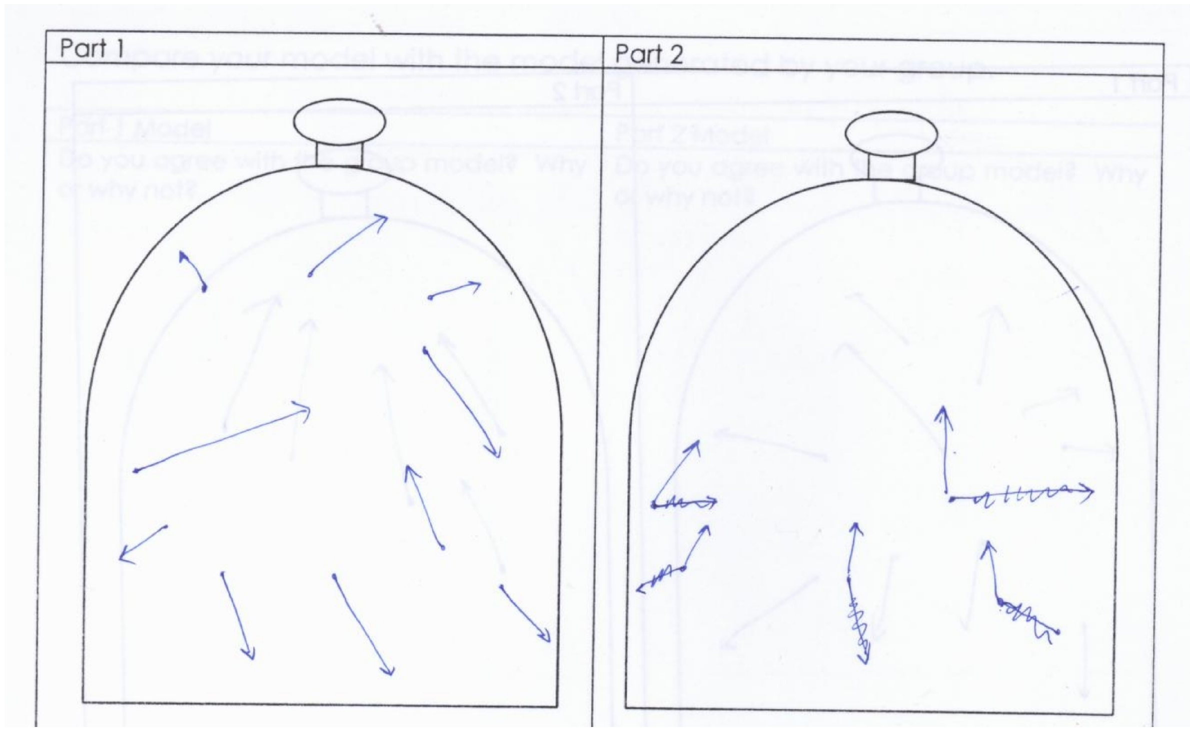


Figure 4.18. Visualization of a vacuum, alternate conception of a vacuum based on experiences with a vacuum cleaner. Drawn by Student 22724.

4.4.1.2 Condensed vacuum model. Three students (38667, 59932 and 97608) thought that air particles would have large spaces between them before evacuation. Following partial evacuation, they believed that the particles would become more dense or closer together rather than further apart. In fact, these particles condensed towards the centre of the bell jar chamber (Figures 4.19 and 4.20). No experiences were cited from these students.

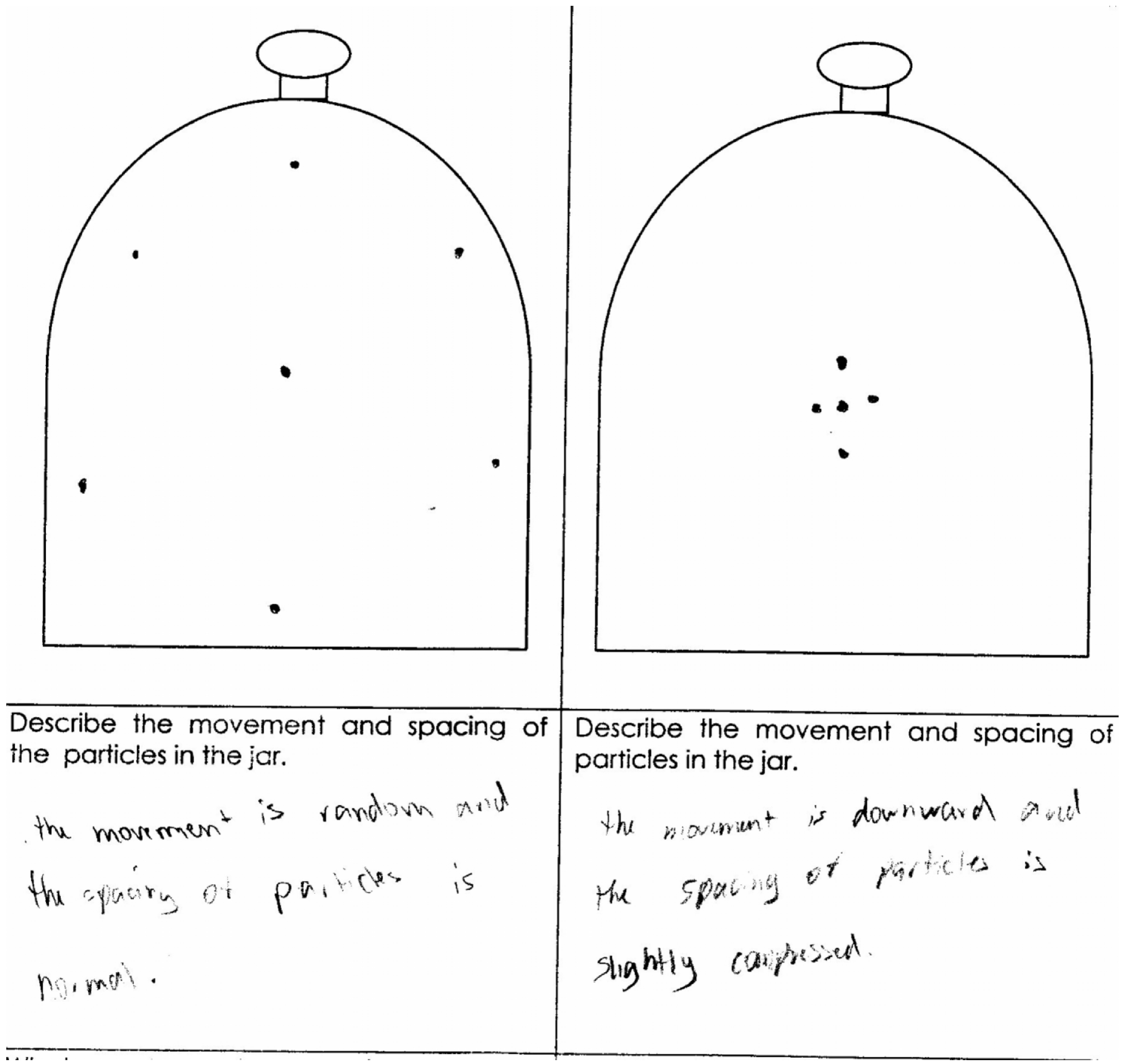


Figure 4.19. Visualization of a vacuum, compressed air model.

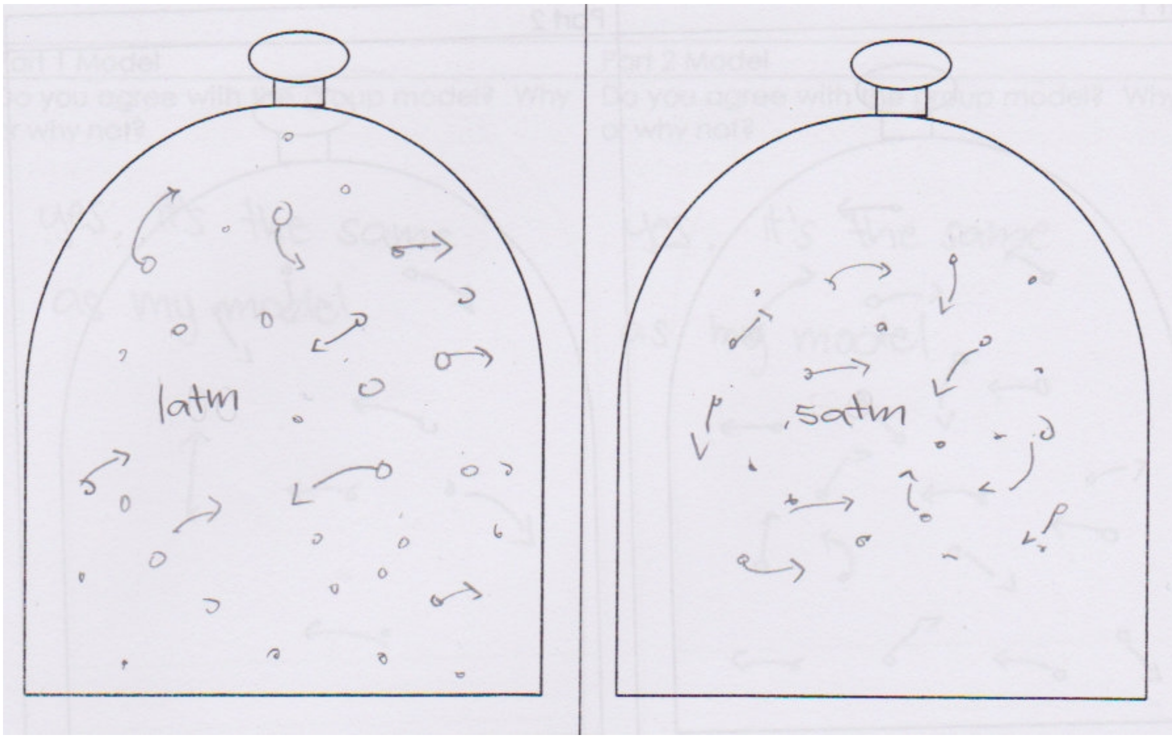


Figure 4.20. Visualization of a vacuum, compressed air model with symbolic representation.

4.4.2 Potential scientific model or skewed distribution model. Student 36843 (Figure 4.21) potentially gave full macroscopic, microscopic, and symbolic diagrams in keeping with scientific models; or thought that air was evacuated from the middle of the bell jar, similar to students who shaded in the a vacuum flask then erased the middle to represent a vacuum as described by Benson, Wittrock and Baur (1993). The explanation provided in part 2 indicated that that there are "less spaces" between air particles which contradicts the drawings. However, when comparing the scientific model to her model, a dash was put in the box indicating there were no differences between the two models.

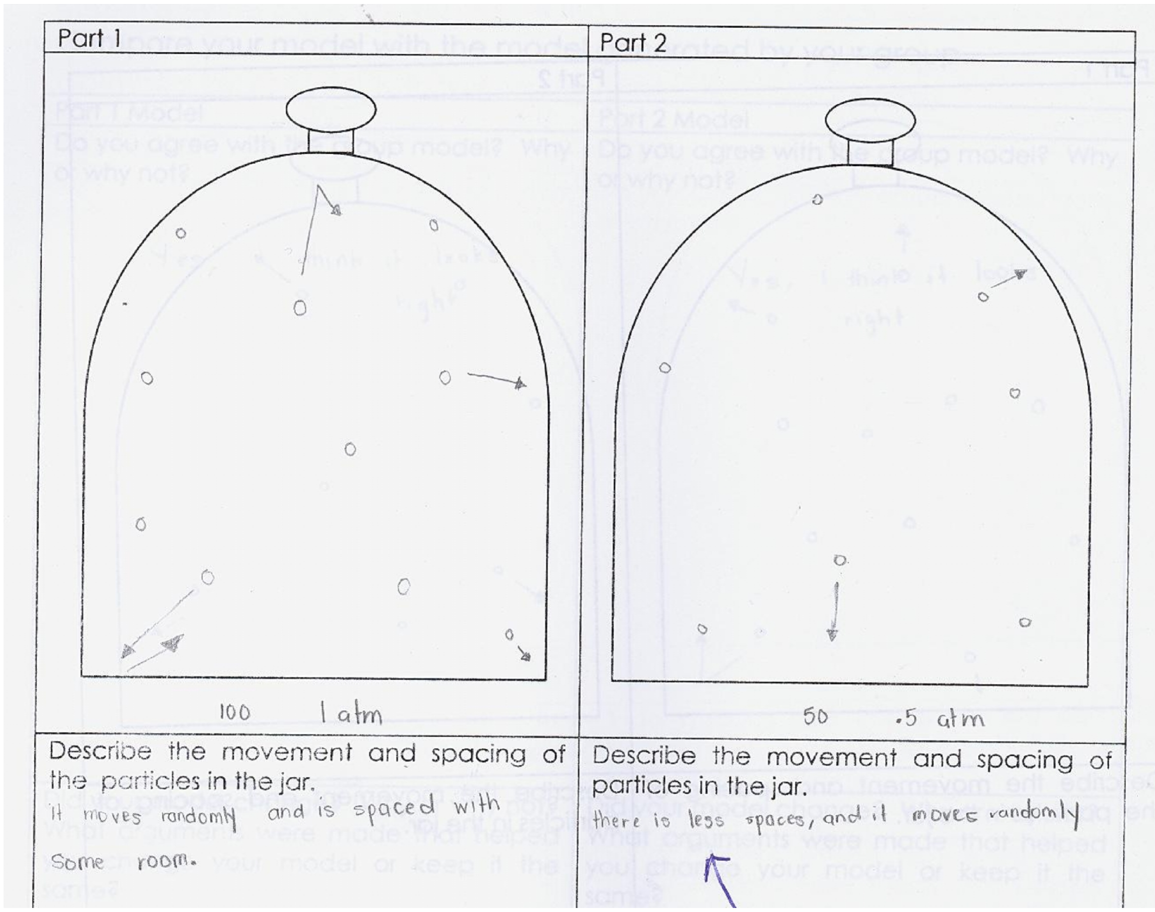


Figure 4.21. Visualization of a vacuum, potential scientific model or skewed distribution model. Drawn by student 36843.

4.4.3 Partial scientific model. Thirteen students (26951, 22753, 29425, 30913, 34988, 36494, 46628, 59562, 62357, 66774, 69297, 77079 and 84816) provided explanations in keeping with scientific models. Though these student showed fewer particles and random movement, there was no symbolic representation indicating that the air pressure was less, or decreased by one-half. Below is a representative example of a partial scientific model (Figure 4.22).

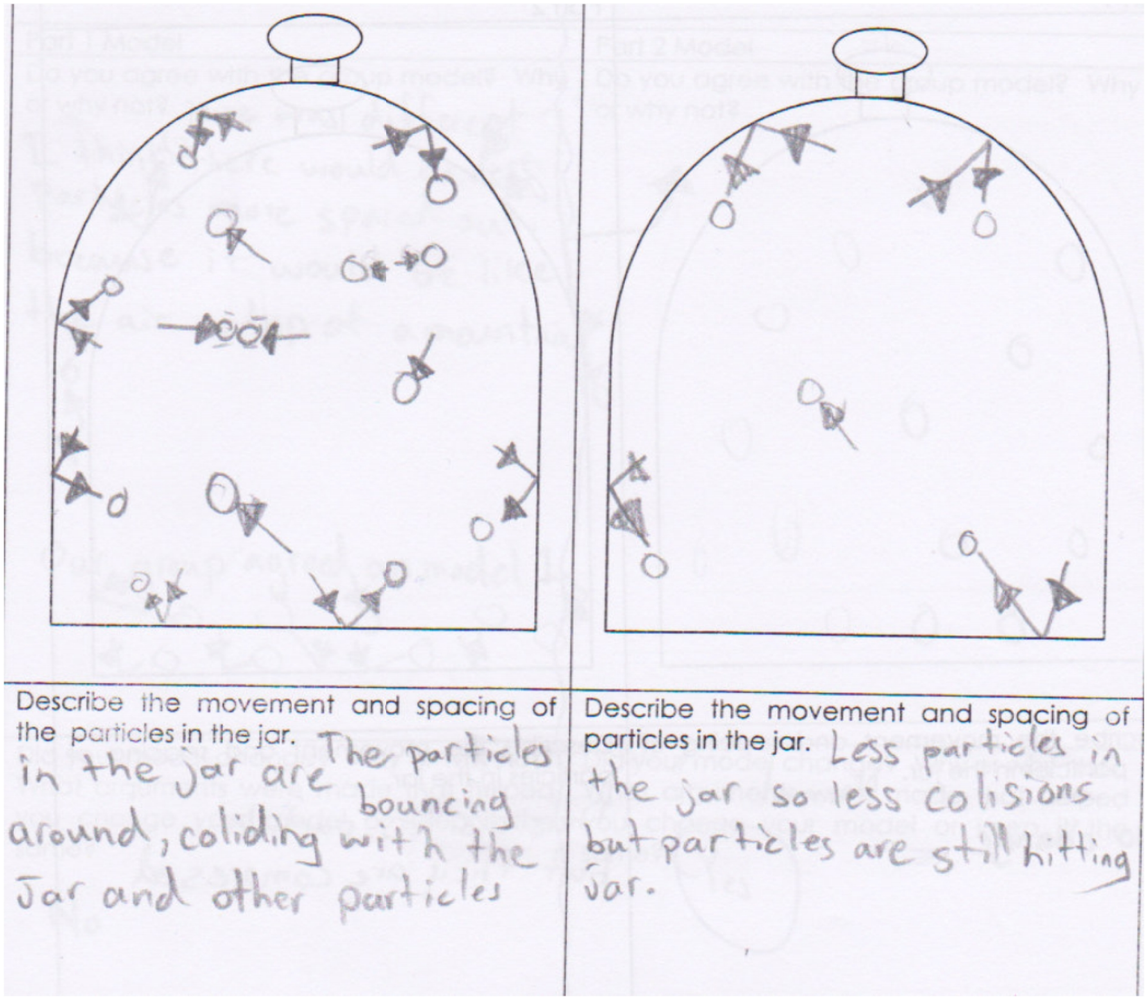


Figure 4.22. Visualization of a vacuum, partial scientific model with no symbolic representation.

Five students (22753, 3091, 36494, 69297 and 77079) that gave scientific models when visualizing a vacuum in the bell jar, did not accurately predict what would occur if a balloon was placed in the jar and air was evacuated (Appendix H). As the transfer of their vacuum models resulted in alternate models when applied to a related context, these students may have had unclear scientific conceptions based on unclear scientific models, as described by Chu, Treagust and Chandrasegaran (2008).

At this point, the students who presented the circular model of air movement in the previous diagnostic (Appendix F) appeared to have changed their models to scientific models.

4.4.4 Experiences used to build models. Student 26951 provided an indeterminate model, and cited the lecture from the previous class as the experience used for his model in this context. Student 46628 provided a partial scientific model (without symbolic representation) and cited the previous lesson on air pressure as the experience from which she formed this model.

4.5 Balloon in a Vacuum Demonstration

Twenty participant responses were analyzed to determine student conceptions of the balloon in a vacuum demonstration (Appendix I). Four students predicted that the balloon would contract, 14 students predicted that the balloon would expand, and two students presented models that were difficult to interpret.

4.5.1 Decrease in balloon volume. Four students believed that a balloon would shrink when ambient air pressure decreased from 1.0 to 0.5 atm.

4.5.1.1 Decrease in balloon volume, internal pressure orientation. *Internal particles evacuated, condensed vacuum model.* As previously discussed, Student 11252 held the alternate conception that a balloon would shrink with increased elevation and that when air is evacuated from a bell jar vacuum apparatus, air particles are absent in the region of the bell jar from which the air is evacuated. Despite copying down the target model for both these exercises, this student used both alternate anchoring conceptions in her prediction of the balloon volume after decreasing ambient pressure by half (Figure 4.23). In this case, she predicted that the balloon would shrink. She also drew fewer air particles in the balloon than inside the bell jar when evacuated.

It is unclear if Student 11252 thought that air particles are closely spaced or packed together. Their movement was also not clearly described. No responses were given to clarification questions.

It is difficult to assess if this particular student still has an internal orientation of pressure, and equates "less air particles" with "less volume" despite the fact that air particles external to the balloon were evacuated rather than internal to the balloon. No response was given to the question concerning whether the smaller number of air particles in the second part of the demonstration was intentional or not.

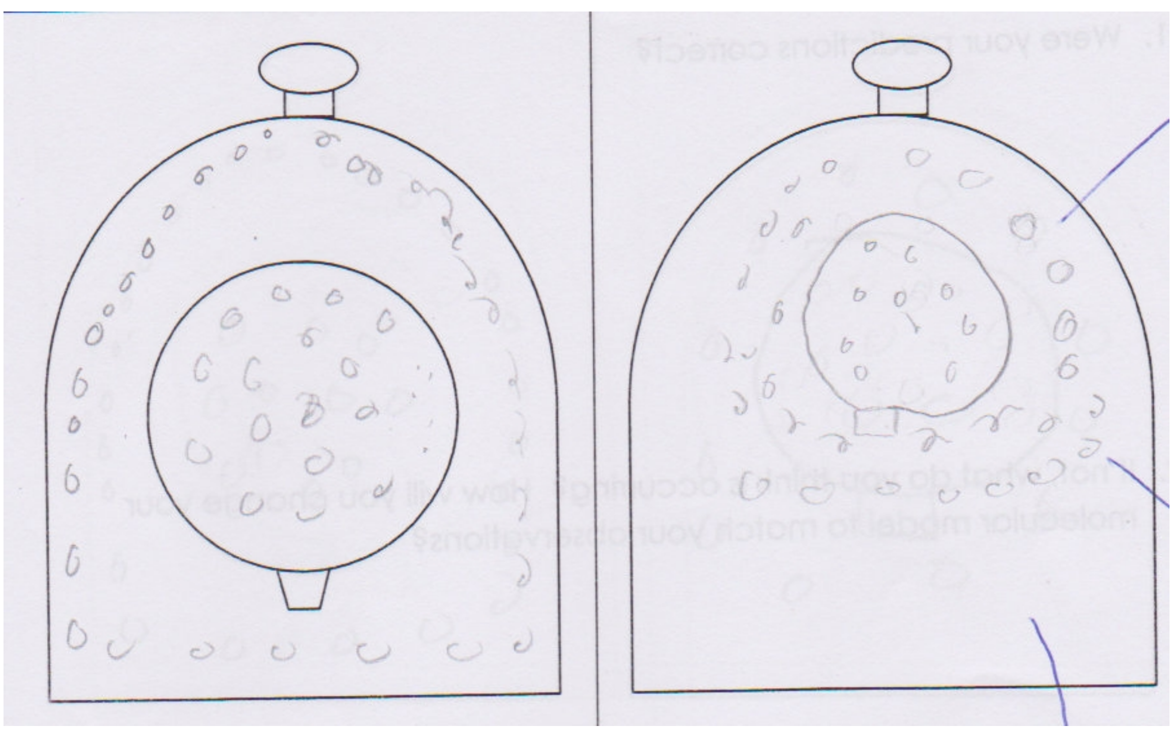


Figure 4.23. Student 11252 model of balloon volume before (left) and after evacuation (right).

Evacuation of ambient and internal particles. Student 69297 thought that the decrease in pressure also meant a decrease in the number of both external and internal air particles, thus causing the balloon to shrink (Figure 4.24). This is an example of an internal pressure orientation as described by Basca and Grotzer (2001) and Anders and Guzzetti (2005). Despite the discussions of pressure in terms of internal and ambient systems, and that Student 69297 gave a scientific explanation of what occurs when air is evacuated from the bell jar, she did not consider pressure systems in her model.

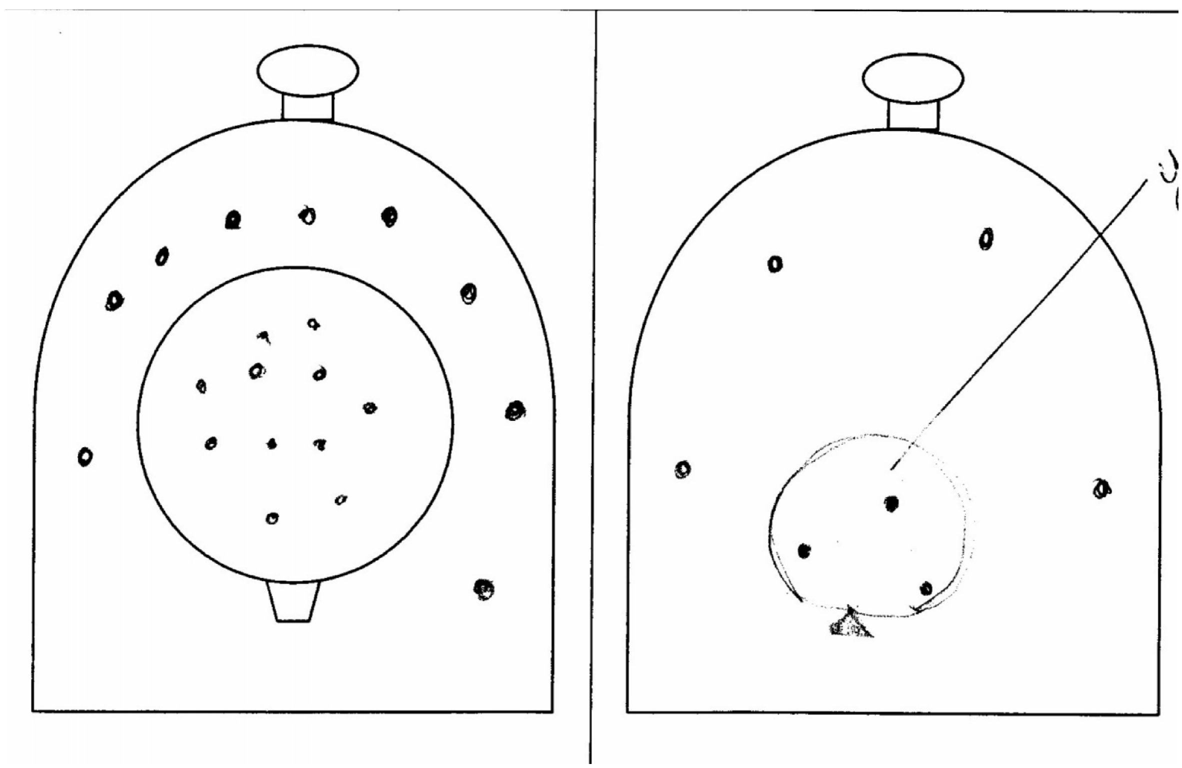


Figure 4.24. Balloon in a vacuum, volume decrease with internal pressure orientation rationale.

4.5.1.2 Decrease in balloon volume, external pressure orientation. Student 36494 previously drew models of a vacuum in keeping with target models. When applied in this context, the student believed that the balloon would shrink because of the "low pressure" (Figure 4.25). In contrast to the above model, the number of internal air particles remained relatively consistent. It appears that though this student drew internal and ambient particles, he used an external orientation of reasoning (equating low pressure with smaller volumes) in his prediction (Basca and Grotzer, 2001; Anders and Guzzetti, 2005).

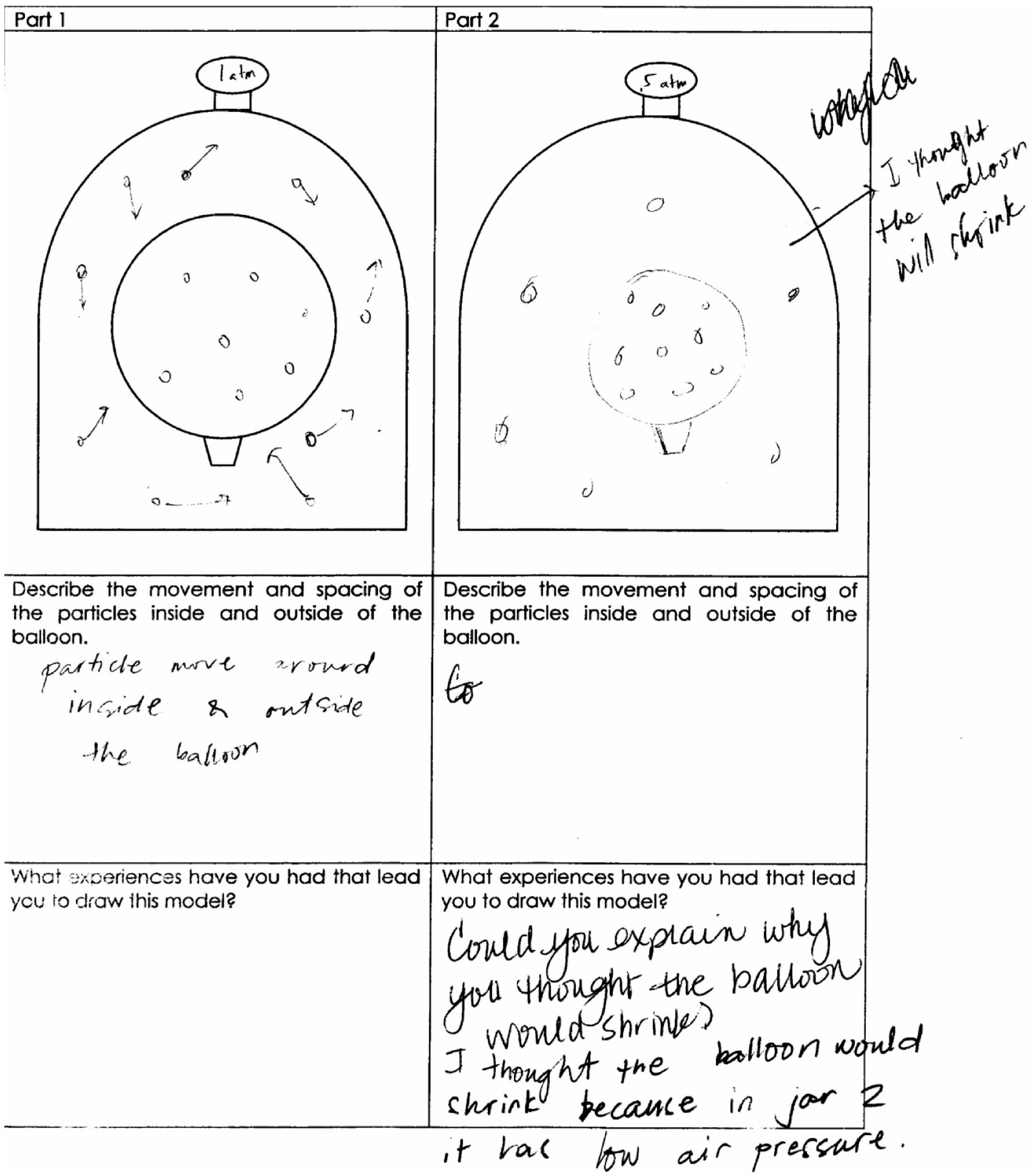


Figure 4.25. Balloon in a vacuum, predicted decrease in volume potentially based on external pressure orientation.

Student 30913 predicted the balloon would pop due to ambient air particles compressing the balloon even though there would be fewer ambient air particles once the air was evacuated (Figure 4.26). In this case, emphasis was placed on the change of the external pressure and was not compared to the internal pressure. This is an example of external pressure orientation as described by Basca and Grotzer, (2001).

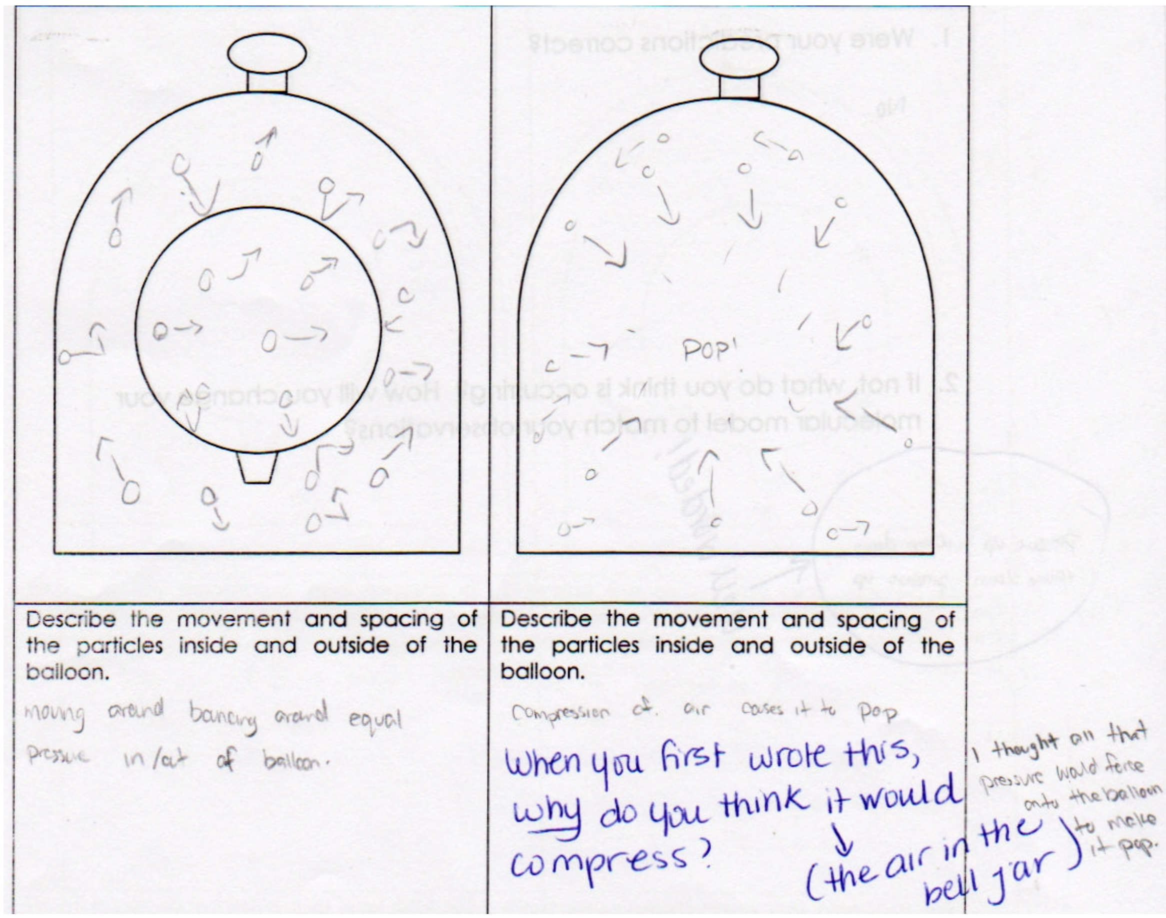


Figure 4.26. Balloon in a vacuum, compression model.

4.5.2 Indeterminate models. Some models presented by students were difficult to analyze. For example, Student 59562 showed a collapsed balloon after evacuation (Figure 4.27). However, it was unclear if the student thought the balloon expanded and burst, was compressed, or deflated. No written explanations were provided, nor were responses given to clarification questions.

This may be an example of a model based on unclear everyday conceptions (Chu, Treagust and Chandrasegaran, 2008), where the student used unclear knowledge to form his model.

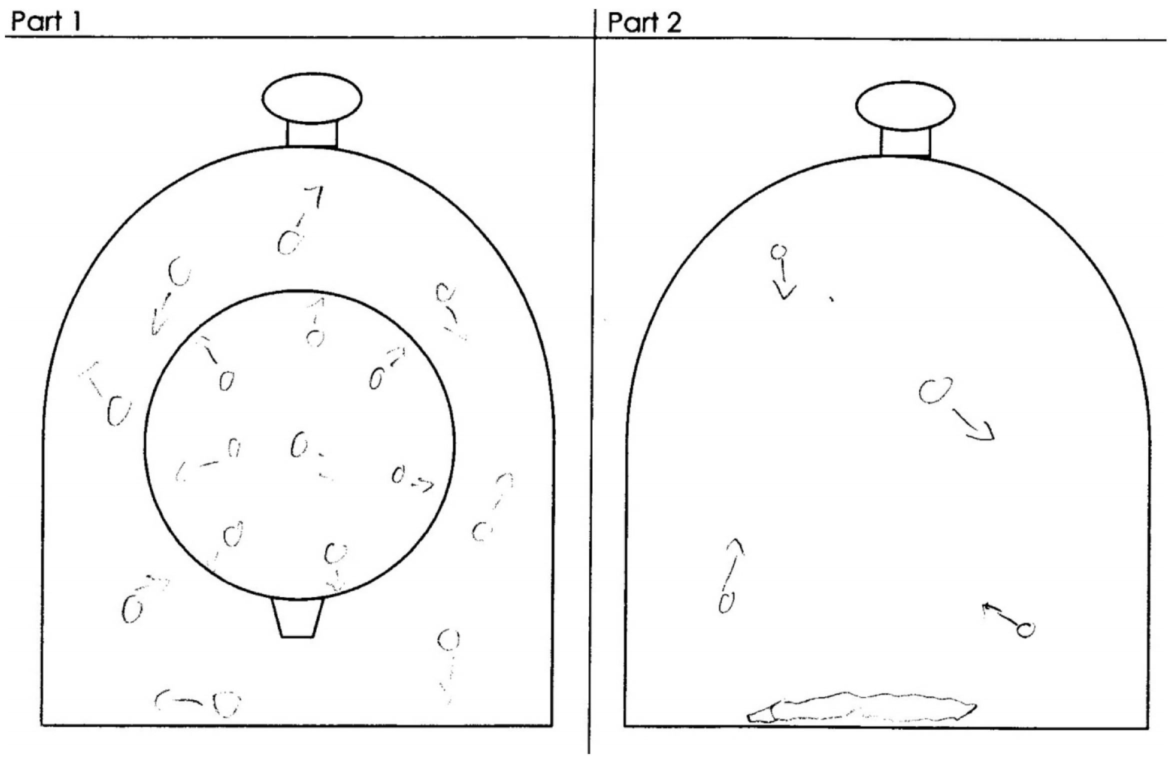


Figure 4.27. Indeterminate model of a balloon in a vacuum chamber.

Student 36843 drew a model where the diagram suggested that in her initial conceptions, the balloon would stay the same size and air would be evacuated out of the balloon rather than the bell jar (Figure 4.28).

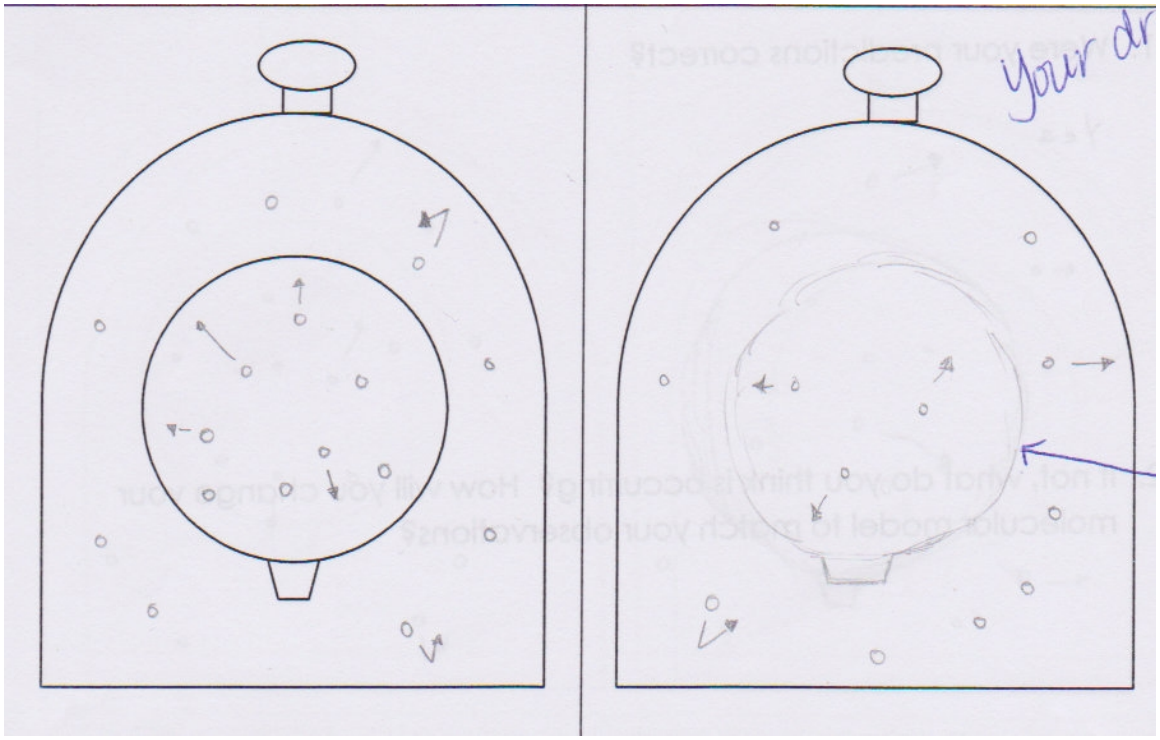


Figure 4.28. Indeterminate model of a balloon in a vacuum chamber, contradictions between diagram and written explanation.

In her response to clarification questions, she thought that the balloon would expand (based on a "wild guess") and thought that, "...the air particles in and out of the balloon were the same." The discrepancy in the diagrams and explanation made analysis of the model difficult.

4.5.3 Scientific model. Fourteen students (22724, 26951, 27536, 29425, 34988, 36498, 38667, 46628, 59932, 62357, 66774, 81886, 84816 and 97608) drew models in keeping with the scientific models (Figure 4.29). Symbolic representations were missing in seven of these fourteen models. In order to show pressure differences, students were allowed to show the internal pressure the same as at the beginning. However, this was also described as a limitation to the model by the collaborating teacher, and in fact, the internal and external pressures would be equal.

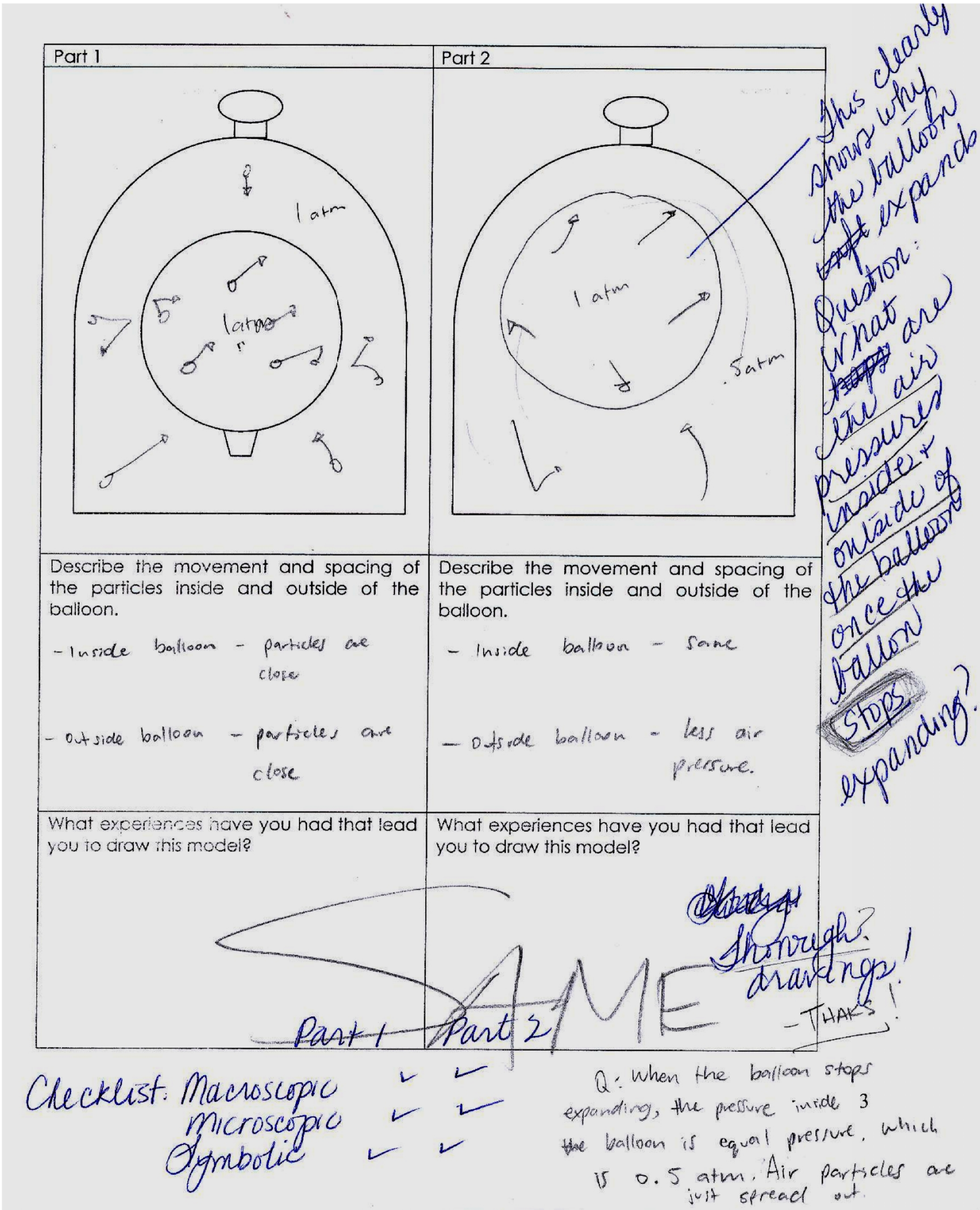


Figure 4.29. Balloon in a vacuum, representative drawing by student 26951 with target model explanations.

4.5.4 Student evaluations. Eleven students evaluated this lesson on the use of the three representations, the demonstration itself, writing conceptions, the use of group discussions, and suggestions. For the most part, the students found this process to be helpful in their learning of pressure systems and Boyle's Law.

All eleven students stated that the three representations were useful for understanding science concepts. Only thee provided comments that indicated the three representations were "interesting", and that the "real life" applications and use of the representations made concepts easier to understand. Nine of the eleven students found the demonstrations useful (no comments provided), and one student did not. Ten students found writing thoughts during each step of the process helpful, and one student thought the continual writing was "tedious" and "time consuming". Nine students found the group discussions of use. One student commented that comparing ideas was helpful. Another student thought that group discussions helped by learning from mistakes and sharing ideas with other students. The students offered no additional comments or suggestions.

The collaborating teacher also found this process useful. He agreed that writing models was beneficial to student learning, but too time consuming and tedious for students when required too frequently. He suggested that though the progression of the demonstrations was useful, having students discuss their models and only writing about their models for a few, not all, of their demonstrations would save time and mental exhaustion. Another suggestion was to have the students draw their initial conceptions and the scientific model, but not to record group models.

4.6 Student Conceptions of an Underwater Balloon Brought to the Surface

In the previous demonstration, students observed the volume of a balloon increasing with decreased ambient pressure (Appendix I). In this case, the same concept was repeated with a change in context. The students were asked to predict what would happen to the volume of a balloon submerged in water then brought to the surface. In this case, as elevation increased, ambient pressure decreased, thus the balloon would expand. The concepts in the previous demonstration (Appendix I) and this thought experiment (Appendix J) were the same (as ambient pressure decreases with elevation, volume increases), albeit with a slight change in context. That is, ambient pressure was caused by water rather than air.

Seventeen student responses were analyzed for student conceptions of the effect of decreased ambient temperature in a scuba-like context. Discussions with the collaborating teacher revealed that as there was little time, students were asked to draw, "…a few representative particles". This could have many different interpretations by students including (amongst others) the following: drawing external particles for just one part of the exercise, drawing water particles similar to those of gases and using pressure arrows to indicate particles creating pressure assuming that the motion of these particles was random.

In all of the drawings submitted, none of the students drew water particles close together, and the collisions of water particles against outer surfaces of the balloons were drawn similarly to those of gases. It is unknown if these students perceived a difference in the relative densities of liquid and gas particles, if they thought that liquid and gas particles behaved in a similar manner (Wittrock, Benson and Baur, 1993) or, as mentioned above, if they drew representative particles using a variety of understandings of motion and densities not expressed in the written responses. As a consequence, student visualizations of the relative densities and movement of water particles compared to air particles were not analyzed.

4.6.1 Volume decreases. Six students predicted that the volume of the balloon would decrease.

4.6.1.1 Balloon decreases in volume, internal orientation. Five students (11252, 29425, 36843, 69297 and 84816) predicted that the balloon would decrease in volume. These students maintained an internal pressure orientation, with no discussion of external pressure (Figure 4.30).

Students 36843 and 69297 stated that internal and ambient particles collided with the internal and external surfaces of the balloon, indicating that there was some awareness of external particles. However, it appears that these students still did not take into account ambient pressure in their models.

This may show evidence of mixed models (Coll, France and Taylor, 2005) where students have learned that at lower ambient pressure, internal air particles become less dense. However, given that these students may think of pressure only in terms of an internal orientation, then less pressure would be equated with less volume (Anders and Guzzetti, 2005).

An alternate interpretation is that these students believed that pressure increases with elevation. As no discussion of external pressure was given, the researcher and external examiners remained divided on the interpretation of the alternate conceptions used by these students.

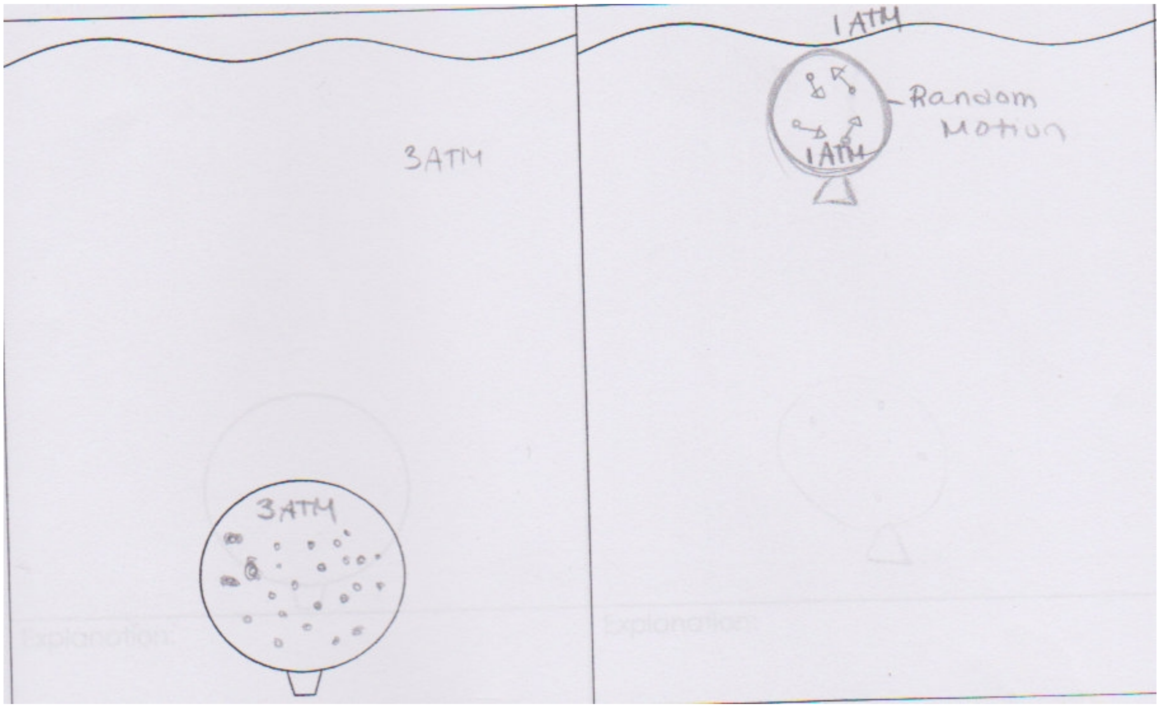


Figure 4.30. Underwater balloon rising to surface, volume decrease using mixed alternate models.

The diagram from student 29425 also indicated an internal pressure orientation (Figure 4.31). However, the explanation was difficult to interpret, and the researcher and external examiners could not decipher what "pushing down the balloon with 1 atm" and "it is pushing up the balloon" meant . It may be that this student had an alternate conception similar to those of Students 62357 and 97608, where water particles appear to move in uniform motion apparently causing pressure downwards in at depth and upwards during ascent. This alternate conception is described later in the chapter (Figure 4.31).In this case, the references to “pushing up” and “pushing down” are, unknown, as no explanations nor responses to clarification questions were provided.

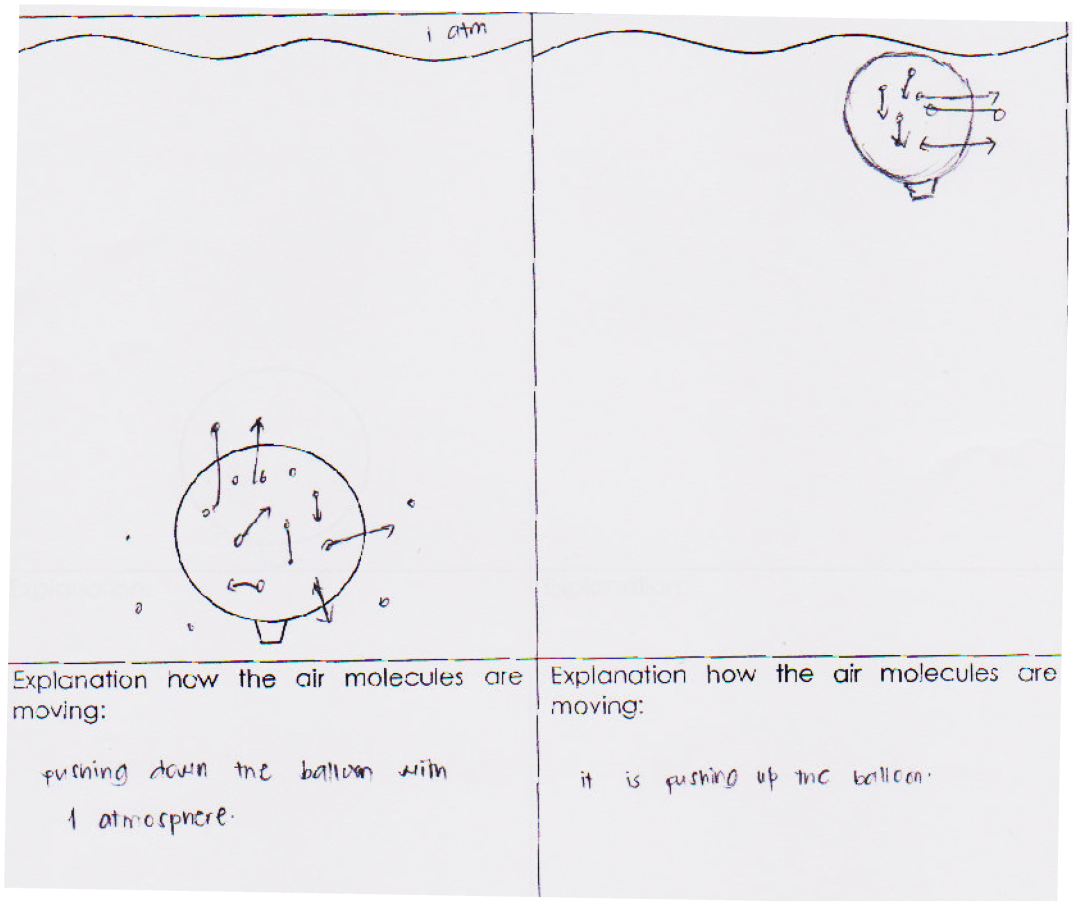


Figure 4.31. Underwater balloon rising to surface, internal pressure orientation, indeterminate model. Diagram by Student 29425.

4.6.1.2 Balloon decreases in volume, pressure system explanation. Student 84816 provided scientific explanations for the previous balloon in a vacuum demonstration, however, he could not apply the previous model to this context (Figure 4.32). The alternative model bore some resemblance to this student's initial alternate conceptions of changes in the volume of a balloon when brought up a mountain (Figure 4.5).

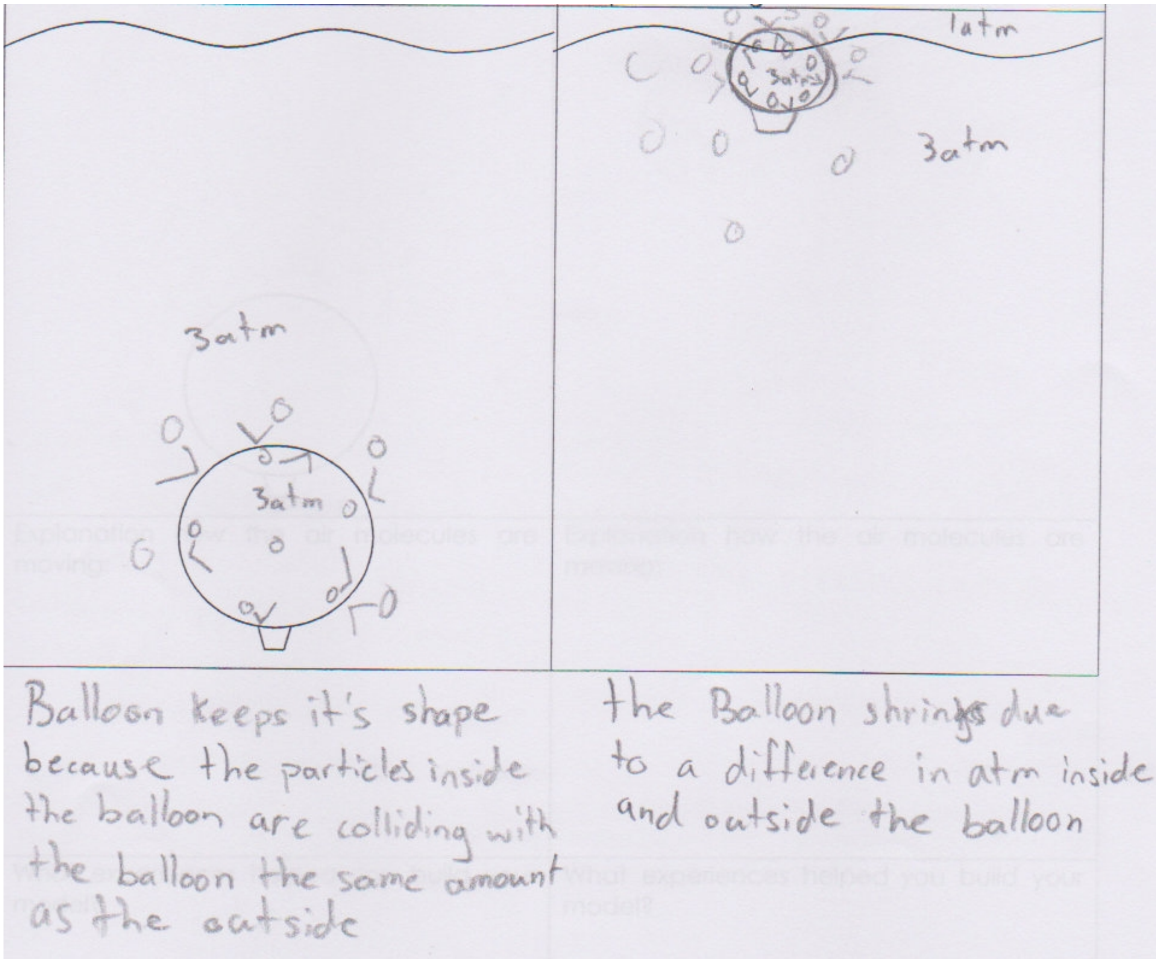


Figure 4.32. Balloon decreases in volume based on the alternate conception of pressure increasing with elevation.

Upon clarification, this student explained that in the first instance (the balloon at 3 atm), "The balloon keeps its shape because the preasure (sic) inside [the] balloon is equal to preasure (sic) outside." When brought to the surface, "The balloon shrinks because the pressure inside is greater [than] the pressure outside." There is clearly an attempt to discuss pressure systematically, however, there appears to be remnants of an extermal pressure orientation.

4.6.2 Volume remains constant. Three students (34988, 62357 and 97608) predicted that the balloon would retain the same volume. Though the ambient pressure decreased by one-third, this was not taken into consideration in these models.

Student 34988 attempted to discuss pressure and internal and external collisions, however, there was no application of pressure differences and the effect of these differences (Figure 4.33).

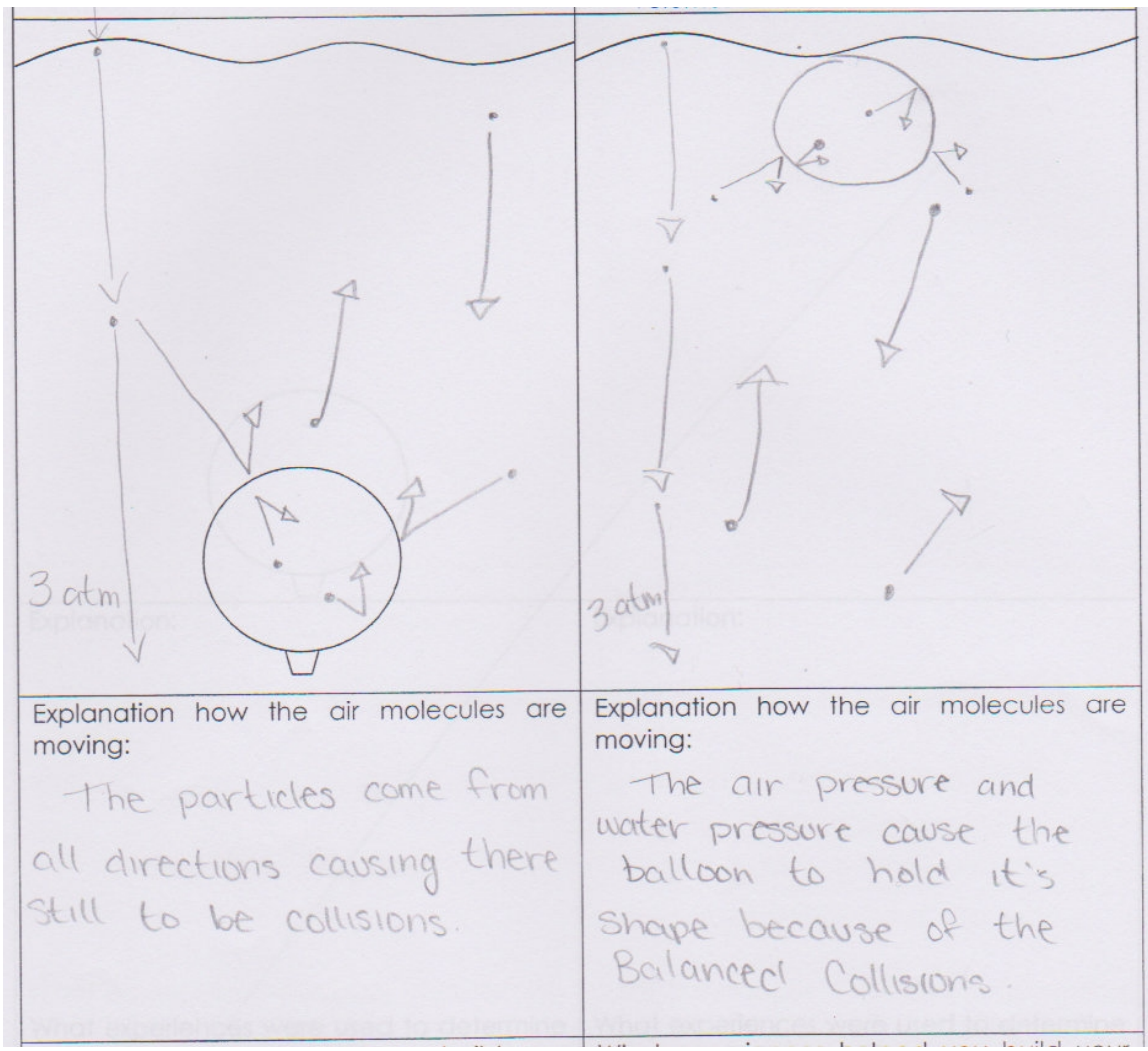


Figure 4.33. Underwater balloon rising to surface, constant volume model, ambient pressure not considered.

Students 62357 and 97608 thought that there was directionality to the movement of the water particles, and both predicted that the balloon would remain the same volume (Figure 4.34). This directionality of ambient particles is reminiscent of the alternate conception student 62357 provided when discussing the movement of liquid particles that are being compressed in a syringe (Figure 4.2).

Previously, these two students provided scientific models for the balloon in a vacuum demonstration, and were able to discuss the change in volume in terms of internal and external pressures. As noted by Coll, France and Taylor (2005) learners may have difficulties applying models to different contexts. It appears that the alternate conception of the directional movement of liquid particles was tenacious, and applied in this context.

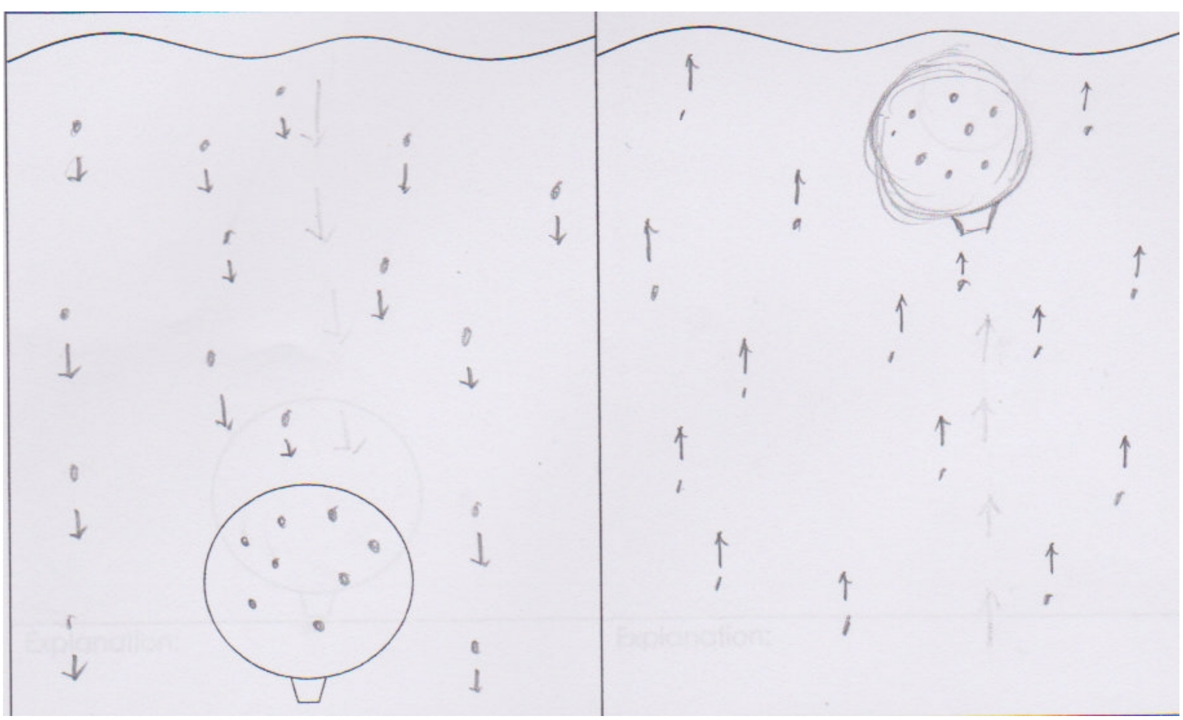


Figure 4.34. Underwater balloon rising to surface, student conception of ambient particles moving in uniform directions.

4.6.3 Volume increases. Nine students predicted that the balloon would expand. Models used for this prediction included internal pressure orientations, one indeterminate model, partial target models and target models.

4.6.3.1 Balloon increases in volume, internal pressure orientation. Two students (59562 and 30913) used and internal pressure orientation to explain the change in volume.

In the case of Student 59562, despite the previous lessons, the student still did not think of pressure in terms of pressure systems (considering both ambient and internal pressures).

Student 30913 discussed the movement and spacing of the internal air particles, but did not draw ambient particles (Figure 4.35). This student was noted previously as having an internal pressure orientation. However, this student also cited the previous demonstration as helping in the formation of his model. As he explained, "If the balloon got larger in the vacuum demo when the atm got smaller, then it should happen here too because the atm starts high and gets smaller." At this point in the intervention, he may have begun to consider ambient versus internal pressures.

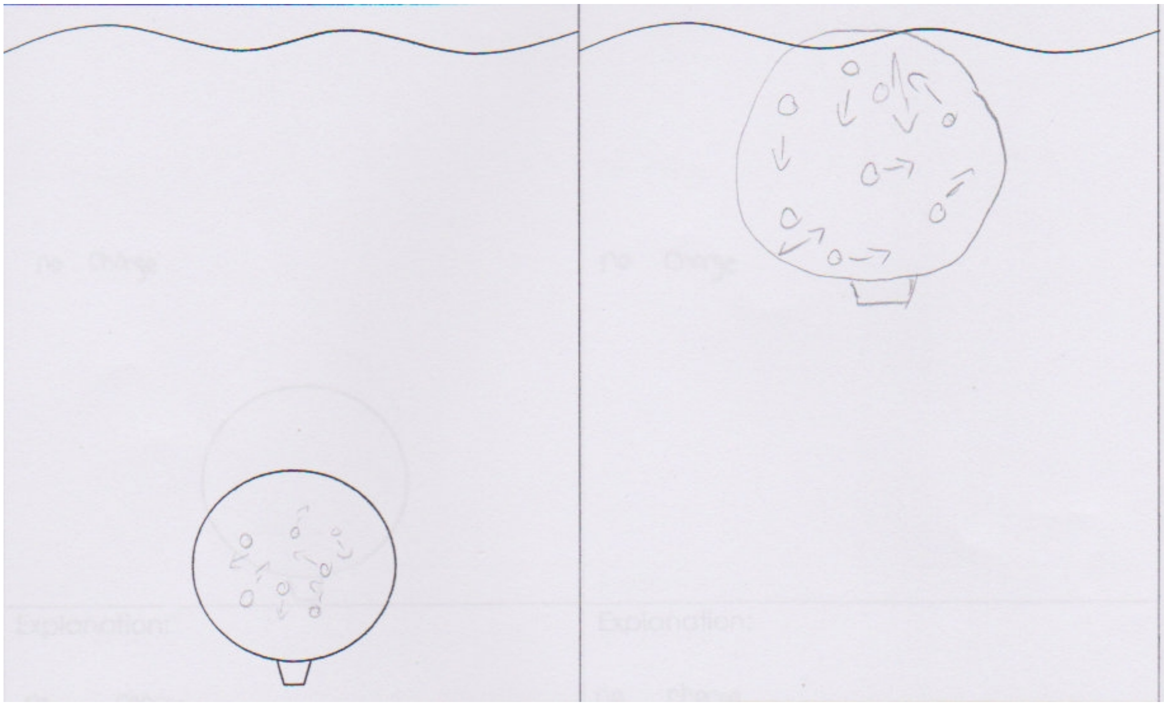


Figure 4.35. Underwater balloon rising to surface, drawing representing volume increase with internal orientation. Drawn by Student 30913.

4.6.3.2 Balloon increases in volume, indeterminate model. Student 36494 did not explain his/her model. Spacing of the water molecules were similar to those of gases. As such, the spacing of the water molecules was either not understood or merely drawn but not thoughtfully considered. No responses were given to questions asking for clarification.

4.6.3.3 Balloon increases, partial target model with reversion back to anchoring alternate conceptions. Student 66774 predicted that the balloon would increase in volume due to a decrease in ambient pressure (Figure 4.36). Though internal and external pressure systems were not addressed directly, the pressure arrows from part 1 suggest that she was thinking in terms of systems. This student, however, thought that the air particles inside the balloon were moving in a circular fashion around the balloon. This tenaciously held alternate conception was first identified when the student explained the movement of air particles inside a balloon (Figure 4.10).

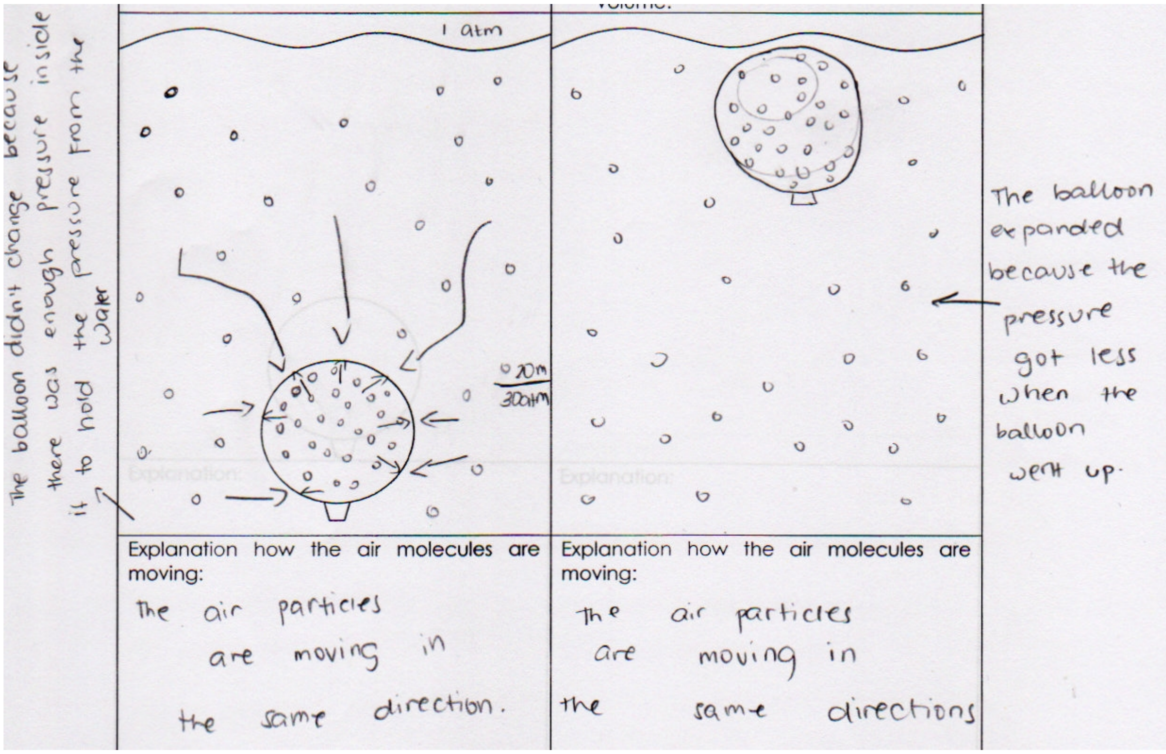


Figure 4.36. Student 66774 partial target model with anchoring alternate conception.

4.6.3.4 Balloon increases, partial target model. Student 59932 drew diagrams in keeping with target models, however, when discussing the role of internal and ambient pressures, she used the word "force" rather than pressure. This student may have had the alternate conception that force and pressure are one and the same (Basca and Grotzer, 2001).

4.6.3.5 Balloon increases in volume, target model. Four students (22724, 26951, 46627, 81886) predicted the balloon would expand using target models. These four students also used scientific models to explain the previous demonstration (Figure 4.37).

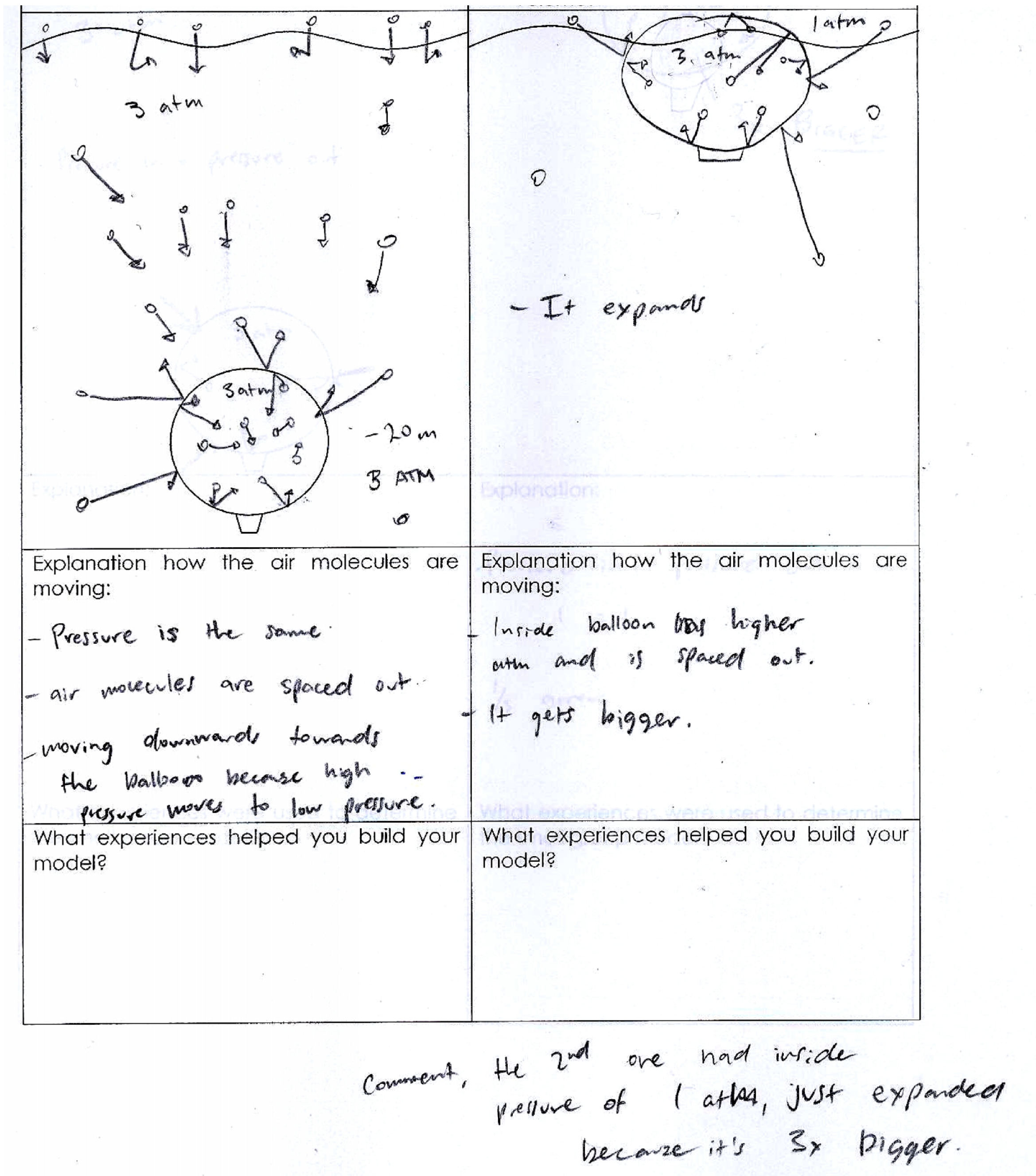


Figure 4.37. Underwater balloon rising to surface, representative example of predicted expansion with target model explanations. Drawn by student 26951.

4.6.3.6 Experiences cited to form target models. Student 22724 cited the previous bell jar-vacuum demonstration as the experience used to form this model.

4.7 Student Conceptions of Pulmonary Barotrauma

Students were asked to determine what would happen to the lungs of a scuba diver who holds his/her breath while ascending from 4 atm to 1 atm pressure (Appendix K). Previously, students predicted what would happen to the volume of an underwater balloon brought up to the surface under the same conditions (Appendix J). The balloon from the previous lesson was meant to serve as a model for the lungs of a scuba diver that holds his or her breath.

Twenty student responses were analyzed. Students predicted that the lungs would either expand or contract. None of the students predicted that lung volume would remain the same. One student's conceptions were difficult to analyze as the written explanation contradicted the accompanying diagrams.

Student responses were categorized based on their predictions of volume change (increased or decreased volume); use of macroscopic, microscopic and symbolic representations; and explanations in terms of pressure systems.

4.7.1 Lung volume decreases. Three students (34988, 62357 and 66774) predicted that the lungs would contract. In the previous lesson, two of these students (34988 and 62357) had predicted that a balloon under the same conditions would remain the same volume (Figures 4.31 and 4.32). Student 66774 had thought the balloon would increase in volume, with the alternate conception that air particles in the balloon are moving in the same direction

4.7.1.1 Macroscopic visualization only, indeterminate model. Student 62357 provided only macroscopic visualizations of her model (Figure 4.38) with what appears to be pressure arrows showing internal and ambient pressures at 30m depth. It was difficult to determine the model this student used to make her prediction as the explanation only re-iterated the sizes of lungs in her drawings. No response was given to clarification questions.

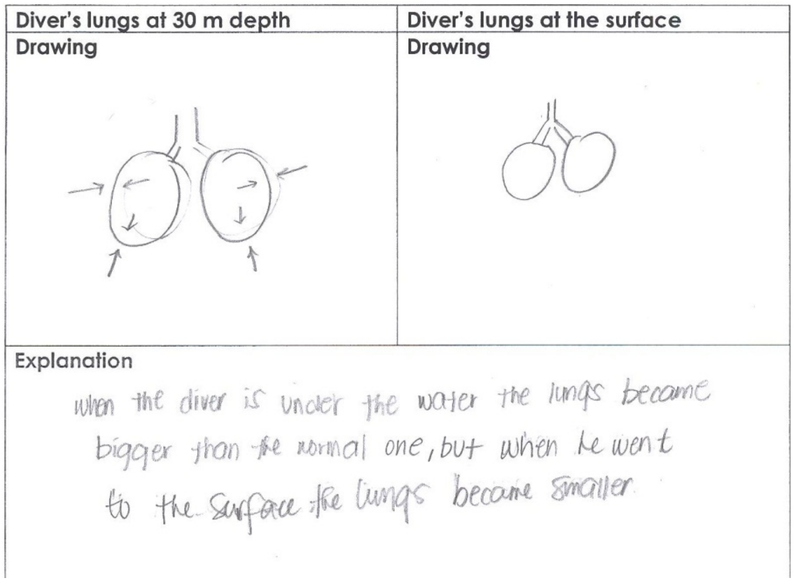


Figure 4.38. Breath holding while surfacing, prediction of lung volume decrease, indeterminate model. Drawn by Student 62357.

4.7.1.2 Macroscopic visualization only, understanding of pressure systems indeterminate. It appears that Student 66774 believed that as the diver ascended, ambient pressure increased, even though the question states that the air pressure is 1 atm, which is smaller than 4 atm at 30m depth (Figure 4.39). It is unknown if the upward arrows in the second picture indicate pressure or movement of air particles in the lungs.

In earlier sessions of the scuba program, a student who created a model similar to this described the pressure felt from the water above you when you swim from the bottom of the pool to the surface quickly. This experience was used to form the model where water pressure increases with elevation. In this case, it is unknown what experiences were used to form this model.

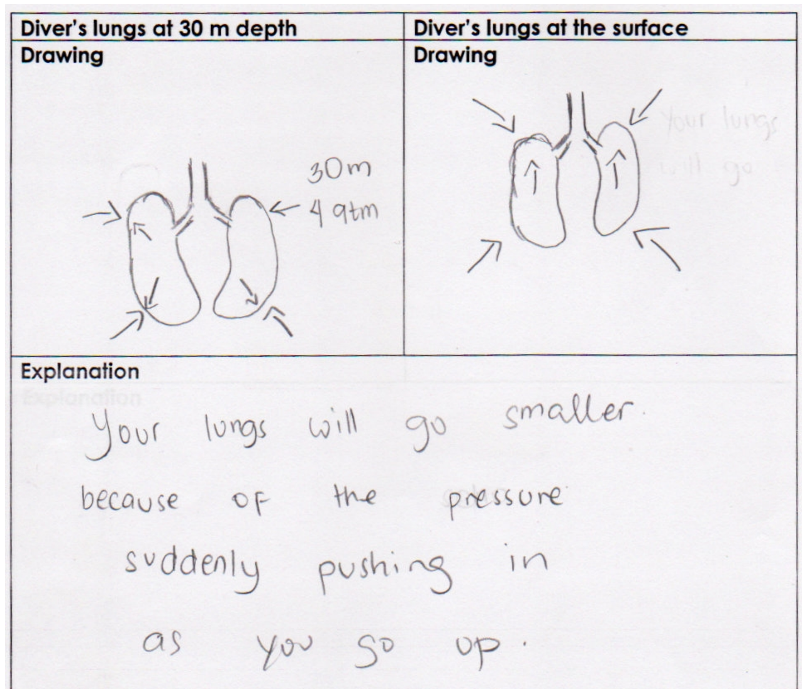


Figure 4.39. Breath holding while surfacing, lung contraction model. Drawn by Student 66774.

Student 97608 provided a confused model with no clarification. Macroscopic drawings suggest that lung volume decreased during ascent, however the statement, "it will expand" was written in the space provided.

4.7.1.3 Macroscopic and microscopic visualization, internal orientation. Student 34988 showed microscopic and macroscopic visualizations of lung volume. Upon clarification, the student indicated that as pressure decreased, lung volume decreased. This suggests an internal pressure orientation. The drawing of ambient particles colliding with external surfaces of the balloon, but not accounting for external pressure was observed in the previous underwater balloon lesson (Figure 4.40).

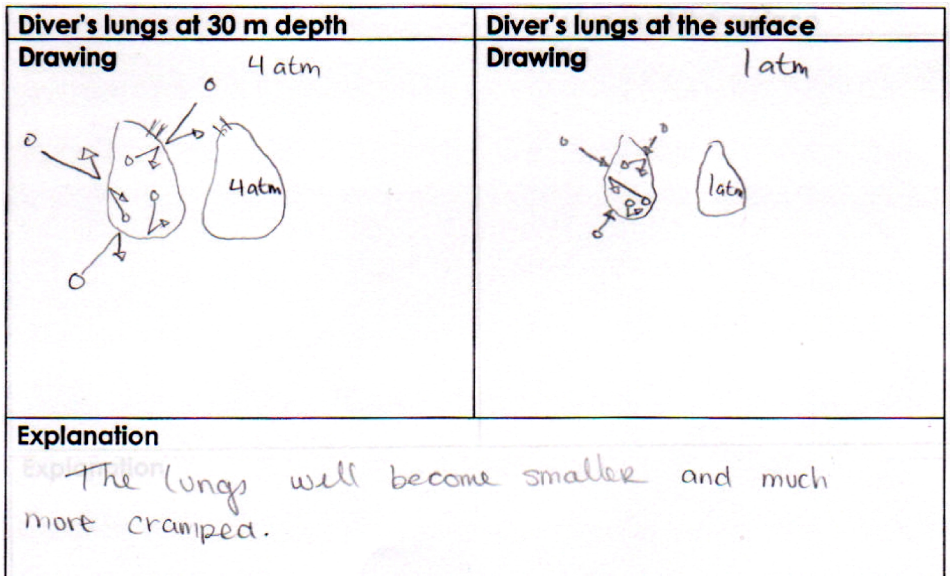


Figure 4.40. Breath holding while surfacing, lung contraction model, internal pressure orientation with drawings of external particles. Drawn by Student 34988.

4.7.2 Lung Volume Increases. Sixteen students predicted that lung volume would increase.

4.7.2.1 Macroscopic visualization only. Two students (30913 and 59562) provided macroscopic visualizations only. Student 59562 only drew increased lung volume with no other explanation than, "it expans (sic)". Student 30913 stated that, "I think they'd enlarge, but I don't know why, I don't know if lungs work the same as balloons." Upon clarification, the student knew that if the lungs were balloons they would enlarge (he remembered this from the previous lesson). However, as lungs are made of living tissue, he was not sure if he could apply the same reasoning. As a consequence, he did not provide microscopic or symbolic representations, nor did he discuss how pressure affected the change in volume (Figure 4.41).

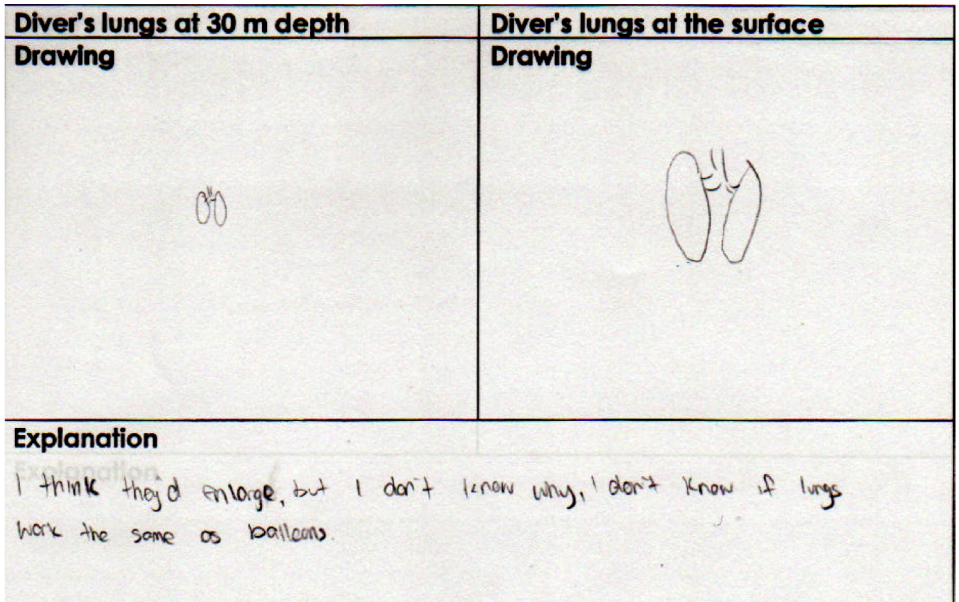


Figure 4.41. Breath holding while surfacing, lung expansion model, macroscopic representation only. Drawn by Student 30913.

The statement provided by Student 30913 may help to explain why some students have difficulties with the transfer of models to different contexts. Either the similarities between the physical models provided may not be apparent, or, (in this case for this student) the student may not be sure if the physical model previously taught is appropriate.

4.7.2.2 Macroscopic and symbolic representations only. Student 36843 predicted the lungs would expand and gave macroscopic and symbolic representations only (Figure 4.42). This student also cited the previous lesson as the basis of her model.

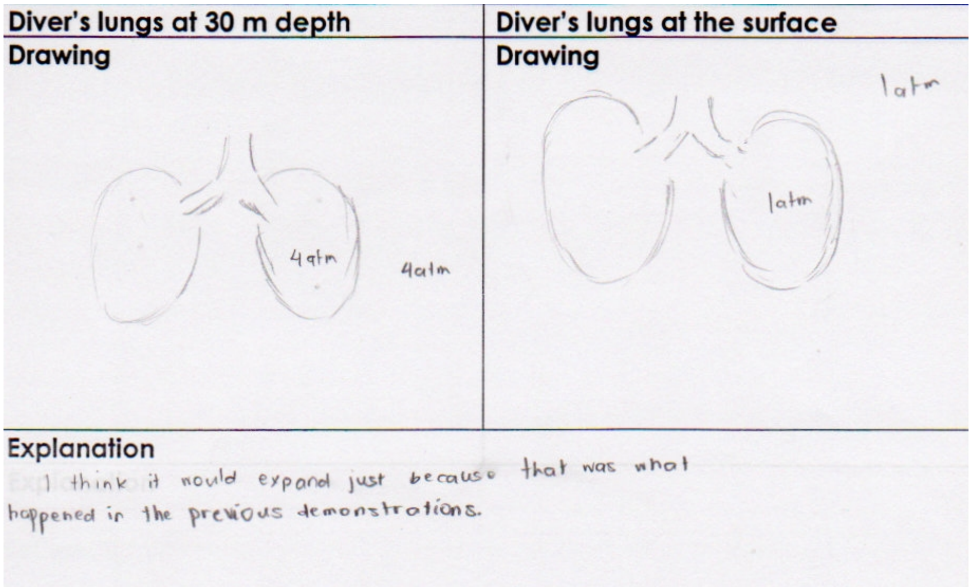


Figure 4.42. Breath holding while surfacing, lung expansion model, macroscopic and symbolic representations only. Drawn by Student 36843.

4.7.2.3 Macroscopic visualization and microscopic visualization of internal particles only. Two students (11252 and 69297) gave microscopic visualizations of internal particles only, with no indication of particle movement (Figure 4.43). Student 69297 stated that there was "less crowding" of internal air particles after the lungs expanded. In the previous lesson, both students predicted that a balloon under the same conditions would decrease in volume using an internal pressure orientation. It may be that the students remembered part of the previous lesson, as they changed the prediction of volume. However, the internal pressure orientation remained.

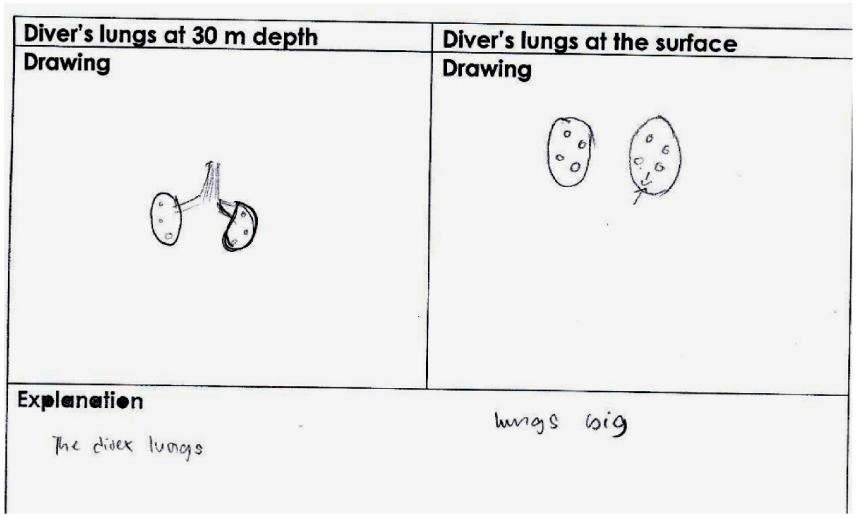


Figure 4.43. Representative drawing of breath holding while surfacing, lung expansion model, internal orientation. Drawn by Student 11252.

4.7.2.4 Macroscopic and microscopic visualization of internal particles, partial microscopic visualization of ambient particles. Students 84816 and 81886 provided macroscopic and microscopic visualizations, but only showed ambient particles in the first part of the question (Figure 4.44). Neither student responded to questions asking for clarification. As a result it is not known if ambient air particles in the second part of the question were visualized.

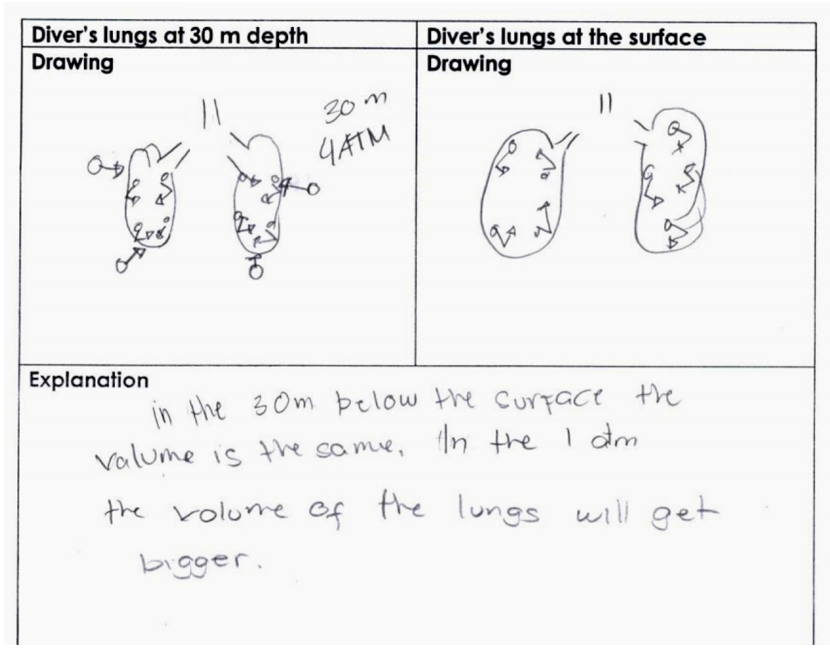


Figure 4.44. Representative drawing of breath holding while surfacing, lung expansion, partial microscopic visualization of external particles. Drawn by Student 84816.

4.7.2.5 Macroscopic and symbolic representation, microscopic visualization of internal particles only. Students 29425 and 77079 showed macroscopic and symbolic representations with drawings of internal particles only. Figure 4.45 drawn by student 77079 is a representative drawing.

Student 29425 qualified her symbolic representations with the statements, "1/4 pressure 4x bigger" and "never hold your breath on the way up". This statement about breath holding while ascending was made by the collaborating teacher and appeared to have resonated with the student. Upon clarification, however, the student could not visualize the external particles and their movement, whereas Student 77079 explained that ambient particles were missing because she wanted to save time.

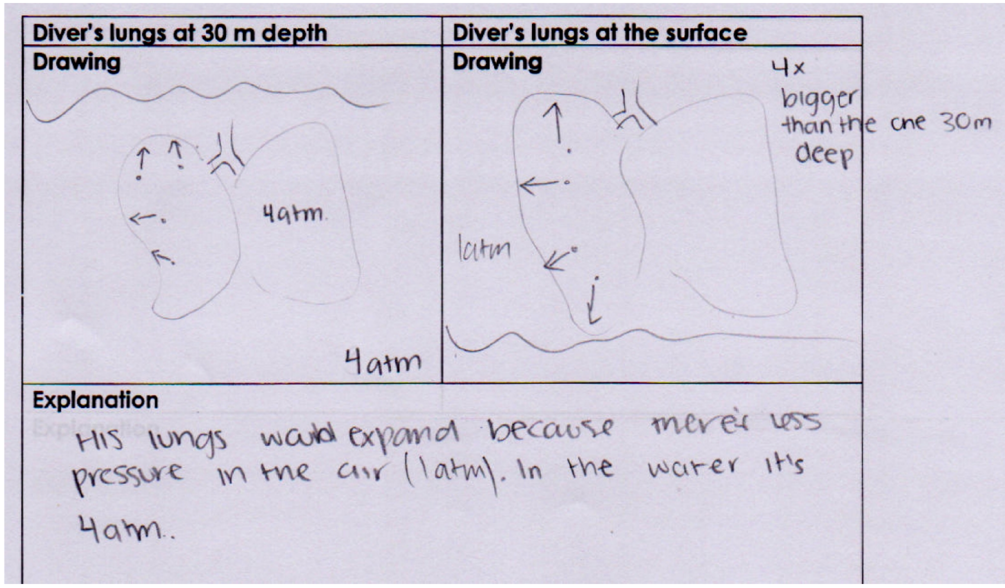


Figure 4.45. Breath holding while surfacing, representative macroscopic and symbolic, microscopic visualization of internal particles only. Drawn by Student 77079.

4.7.2.6 Macroscopic and microscopic representations, no symbolic, no pressure systems explanations. Students 36494 (Figure 4.46), 59932 and 62533 did not provide symbolic representations or discuss pressure in terms of systems.

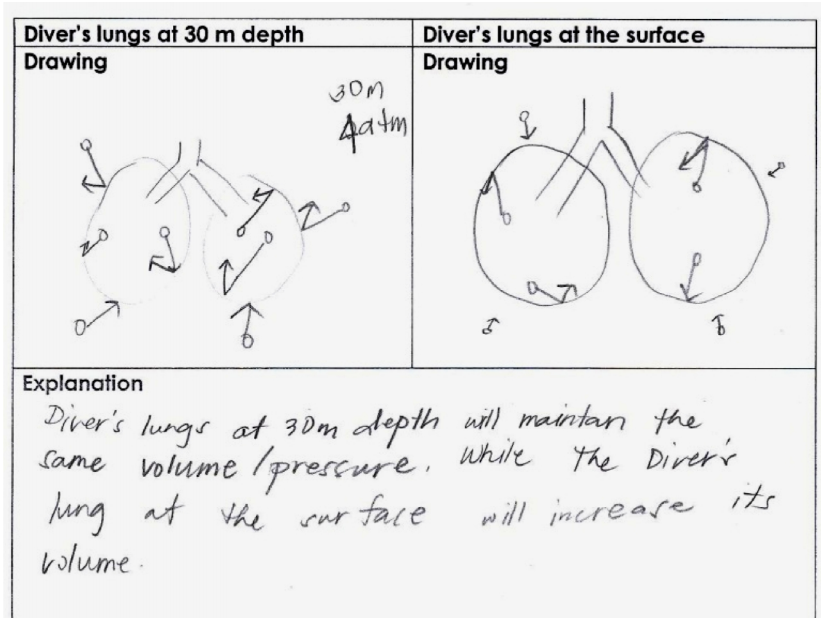


Figure 4.46. Representative drawing of breath holding while surfacing, macro- and micro-representations,, no pressure system explanation. Drawn by Student 36494.

Students 59932 (Figure 4.47) and 62533 discussed pressure but referred to the changes in external pressure only. Student 59932 thought the lungs would shrink at 30m depth and expand during ascent. Upon clarification, the student misunderstood that the scuba diver's lungs were already a certain volume at 30m.

As agreed upon by the researcher and external examiners, there wasn't enough evidence to suggest an external pressure orientation. In fact, evidence from previous written conceptions suggest that these students often describe pressure in terms of systems, and only referred to external pressure in this case because it was pertinent (as they already understand internal and external pressures, they only needed to refer to the change in external pressure) given time constraints.

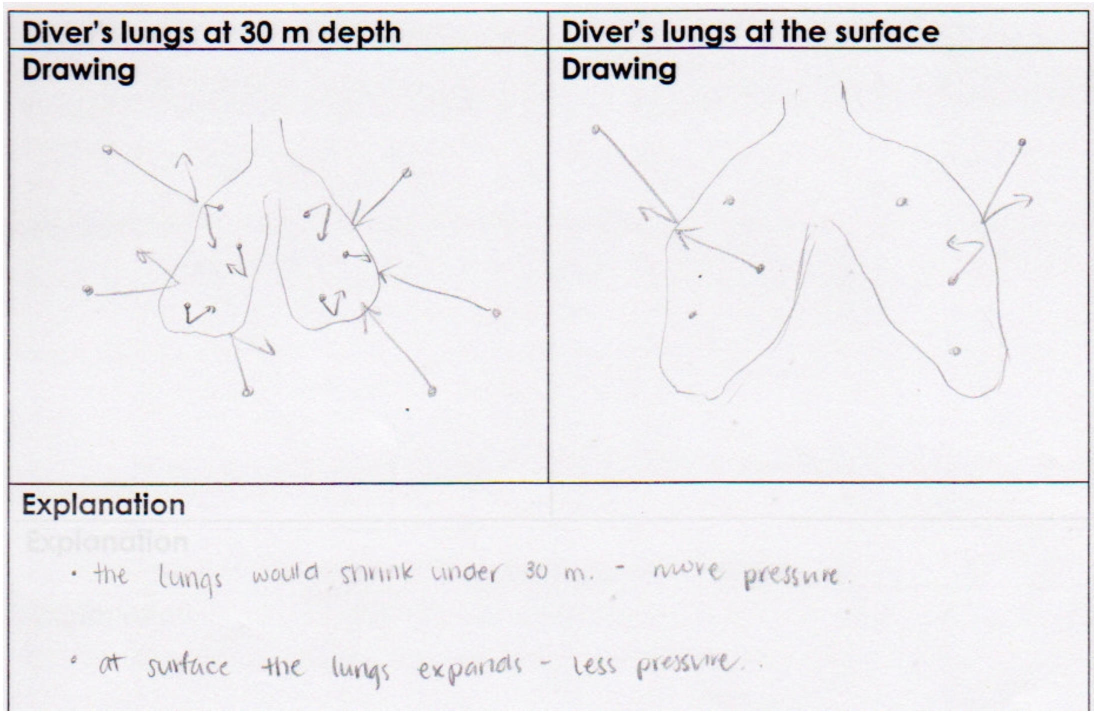


Figure 4.47. Representative drawing of breath holding while surfacing, description of external pressure change only. Drawing by Student 59932.

4.7.2.7 Three representations, systematic reasoning, reinforced alternate conceptions. Students 26951 and 46628 gave explanations close to scientific models, each with a different reinforced alternate conception.

Student 26951 thought that the same number of internal and external particles collided with internal and external surfaces resulting in the same internal and ambient pressures (Figure 4.48). This limitation was described by the collaborating teacher when presenting the problem, but was taken literally by the student.

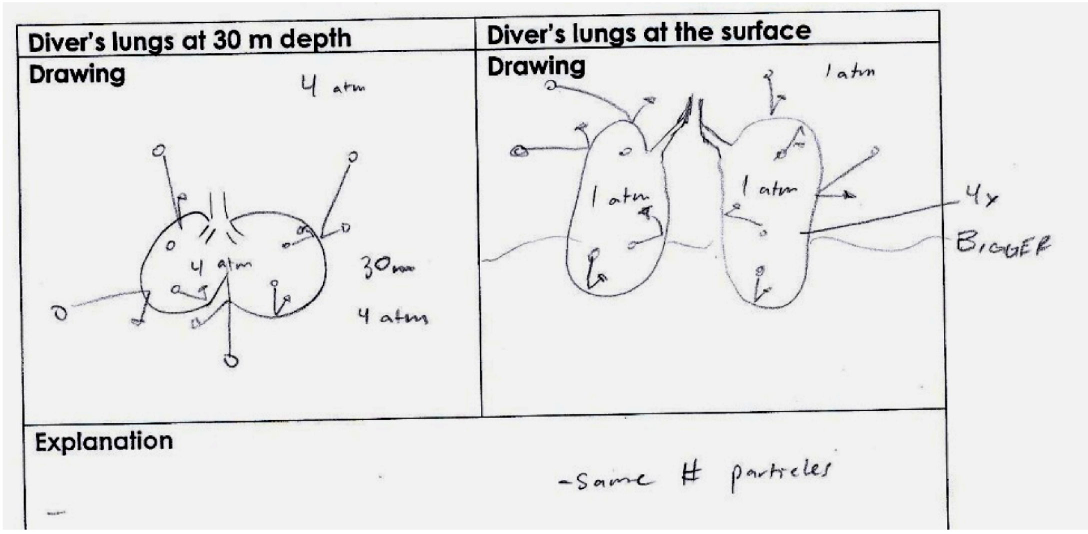


Figure 4.48. Breath holding while surfacing with reinforced alternate conception. Drawn by Student 26951.

Student 46628 also demonstrated a reinforced outcome. That is, there is a lag time between pressure and volume changes rather than both changes occurring at the same time. As Student 46628 explained, "The lungs will expand 4x because more pressure in lungs than outside, however, lungs will match pressure outside soon after".

This is also considered a reinforced outcome as the collaborating teacher was asked to explain changes in pressure and volumes by drawing balloons with the original internal pressure labelled so the students could compare the internal pressure to the change in external pressure to determine whether the balloon would expand or contract. Though this limitation was explained, and discussed during the balloon in a vacuum chamber demonstration (i.e., the change in volume was instantaneous and the internal and external pressure were equal immediately), students were allowed to continue writing original internal pressures for comparison. This likely contributed to the reinforced outcome that volume changed after pressure, or that the internal pressure remained the same when volume increased or decreased.

4.7.2.8 Target model. Two students (22724 and 27536) provided models aligned with target models (Figure 4.49). Both students cited "past discussion and demonstrations" and "balloon examples" as helping them with their models. It is not known to which examples or demonstrations they were referring to. Student 22724 cited, "past discussions and demonstrations" as the experiences used to build her model.

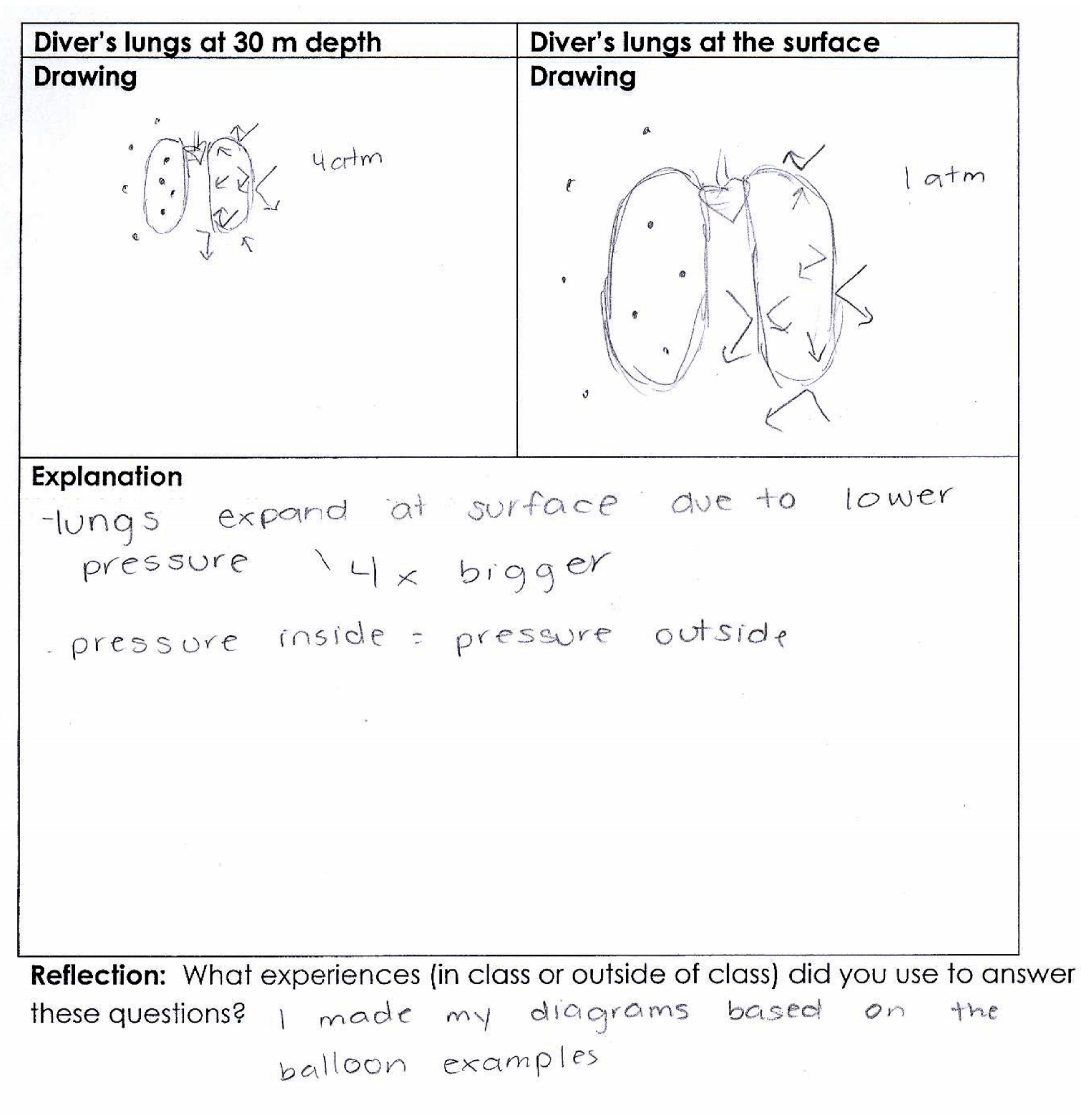


Figure 4.49. Representative example of breath holding while surfacing, explanations in keeping with target models. Drawn by student 27536.

4.8 Student Conceptions of Ear Squeeze

Eighteen responses were analyzed to determine student conceptions of ear squeeze and equalization (Appendix R). None of the students provided target models for ear equalization, which is not surprising as it is a specialized area of knowledge. Resonance was found between the student alternate models, many of which had been observed in earlier sessions the scuba program.

4.8.1 No Eustachian Tube. Despite the diagram the collaborating teacher drew on the board to help students with the anatomy of the ear, three students (29425, 38667 and 97608) drew models without the Eustachian tube. These models support the findings of Mak, Yip and Chung (1999) who found that the placement of the Eustachian tube was commonly forgotten by science teachers.

4.8.2 Pinna pop. Student 66774 described a model observed in previous sessions of the scuba program known as the "pinna pop" (Figure 4.50). In this case, pressure is experienced only by the external auditory pinna (herein called the pinna). Upon clarification, this student thought that no pressure (including air pressure) was experienced at the surface, and the Eustachian tube remained open.

The inside surface of the pinna was identified as internal pressure, and the outside surface of the pinna (edges and the back of the ear) was identified as external pressure. During ear squeeze, the internal and external parts of the pinna experienced pressure, and the Eustachian tube was closed. When the Eustachian tube opened, the internal and external pressure was released. In previous sessions of the scuba program, students with this model thought that that air moved from the Eustachian tube through the tympanum to "push away" the pressure from the pinna. However, no clarification was given in this case.

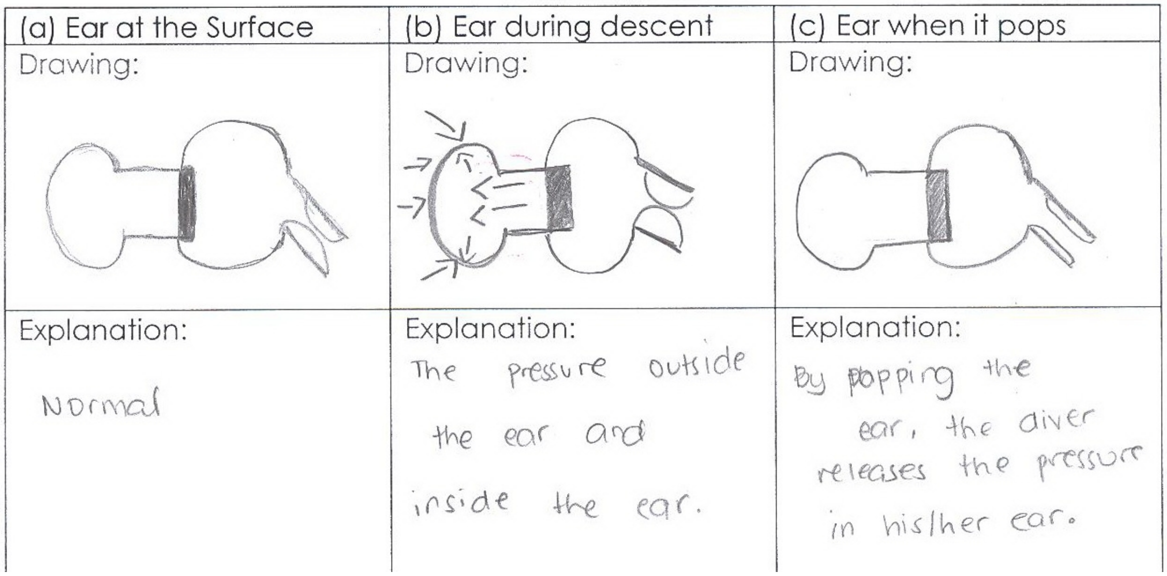


Figure 4.50. Ear squeeze and equalization, pinna pop model. Drawn by Student 66774.

4.8.3 Rigid/straight position tympanum model. Six students (26951, 34998, 36494, 36843, 59562 and 84816) thought that the tympanum would remain in the vertical (or normal) position at all times. These students thought that the tympanum was rigid, with no flexibility, and that if did not open or close.

Students 36494 and 26951 provided drawings showing a straight tympanum with the correct relative internal and ambient pressures. No microscopic visualizations were included. Figure 4.51 drawn by Student 26951 is used a representative drawing for this model.

Student 36494 indicated that no drawings of particles were included because he "…didn't think of it and we were rushing…". In response to clarification questions, the student thought the tympanum was solid and impervious to pressure differences, "…like the glass of the bell jar". This student thought the Eustachian tube would remain open the entire time, and gave no indication of the movement of air or water particles.

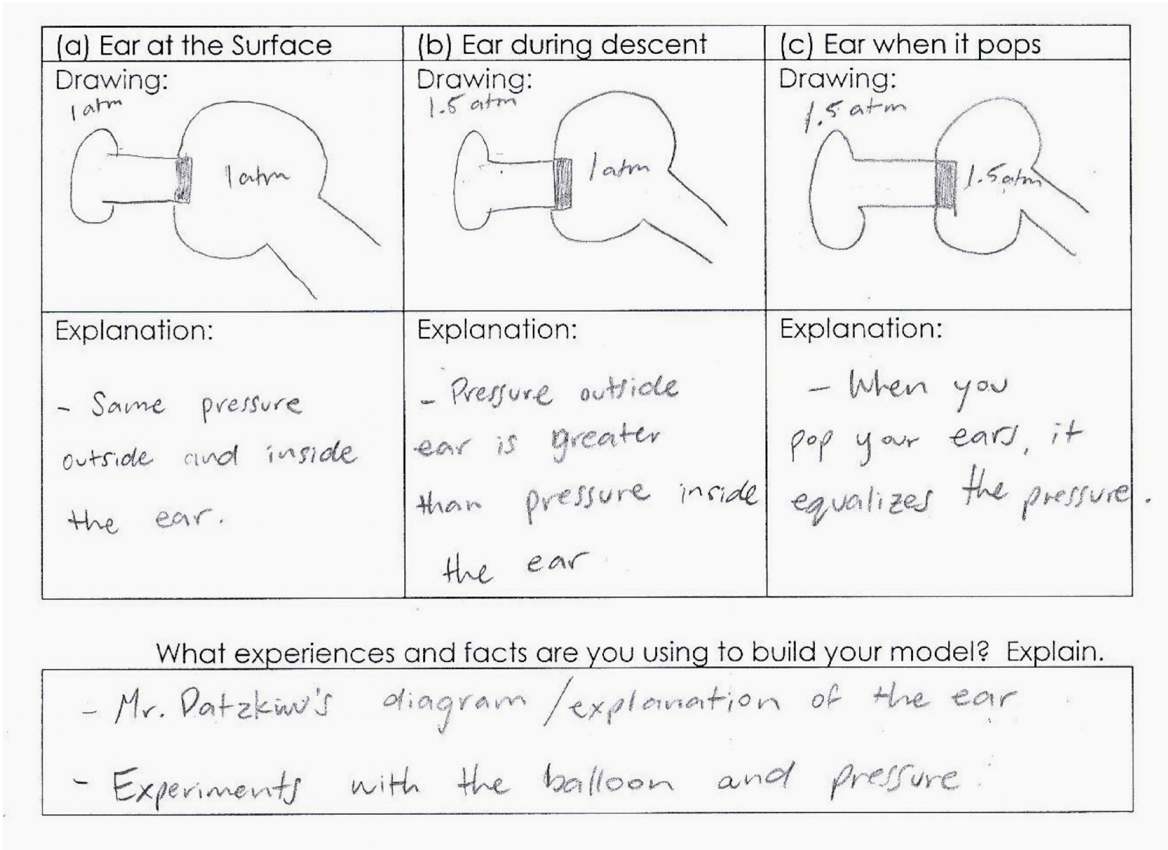


Figure 4.51. Ear squeeze and equalization, straight tympanum model. Drawn by Student 26951.

4.8.3.1 Rigid ear drum, internal pressure orientation. Student 84816 proposed a model with a partial internal pressure orientation (Figure 4.52). Though there was an attempt to show internal and external pressures with arrows, in this case, the student thought that middle ear pressure increased (that is internal pressure increased) rather than external pressure. This would imply remnants of an internal pressure orientation where internal pressure is changed whether the change is internal or external. For this student, the internal pressure orientation was tenacious, and demonstrated previously (Figure 4.32). No mention was made about the role of the Eustachian tube.

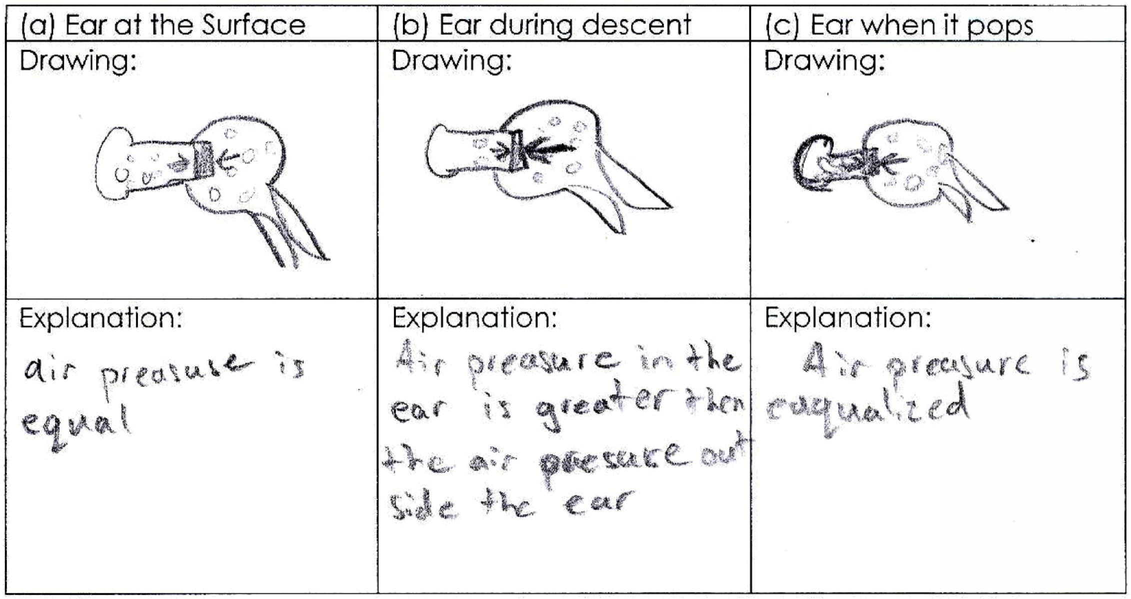


Figure 4.52. Ear squeeze and equalization, rigid ear drum model, an internal pressure reasoning. Drawn by Student 84816.

4.8.3.2 Rigid ear drum, indeterminate model. Student 36843 drew the same ear model without symbolic or microscopic drawings. No response was given to clarification questions.

4.8.4 Swininging door/permeable eardrum model. Two students (22724 and 38667) thought that the eardrum behaved like a door, or that the eardrum would tear to let particles in and out of the middle ear (Figure 4.53). These alternate models were also observed in each of the previous sessions of the scuba program.

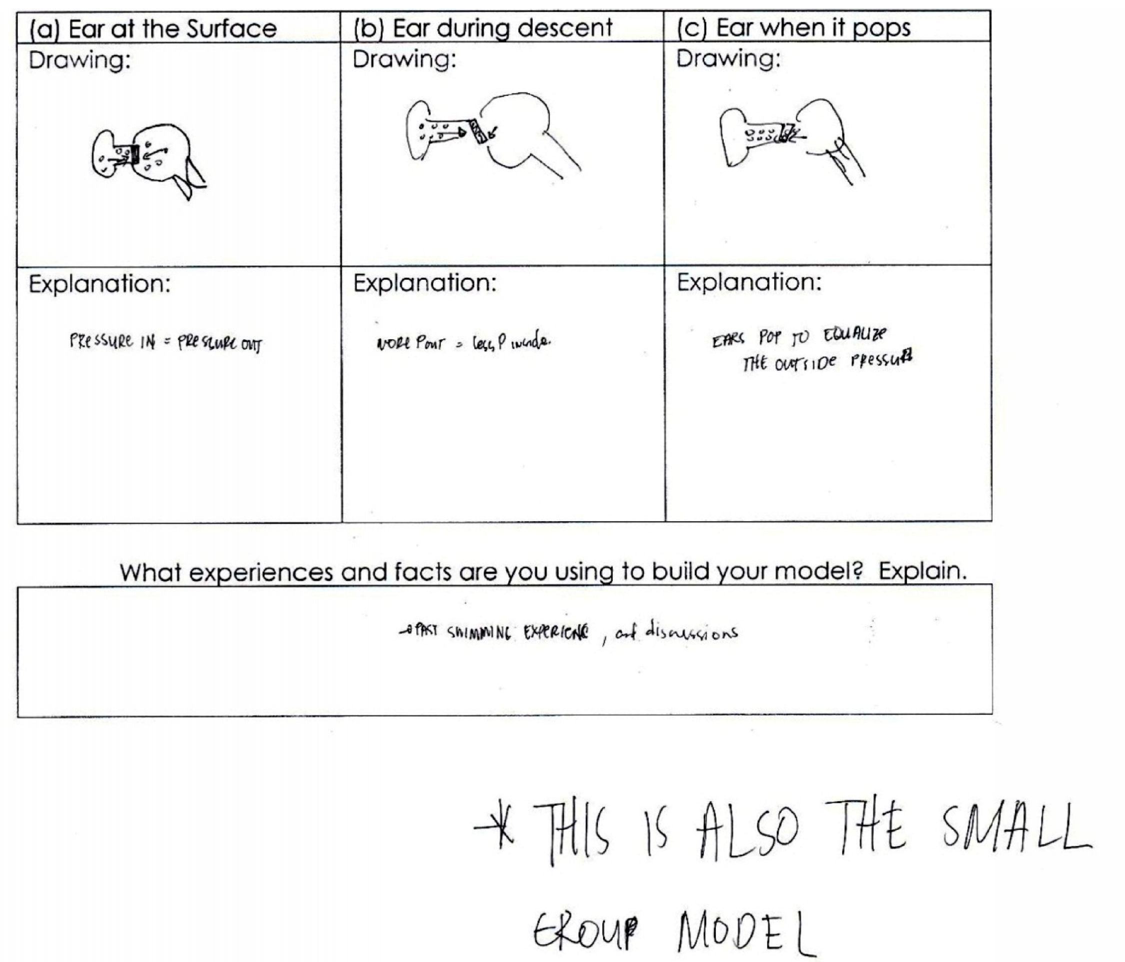


Figure 4.53. Ear squeeze and equalization, swinging door model. Drawn by Student 22724.

Student 38667 did not include the Eustachian tube in his drawings (Figure 4.54). In his model, the pressure felt during ear squeeze was the result of the eardrum vibrating as the ambient pressure was pushing through the eardrum. Upon equalization, the ambient pressure tears through the eardrum, causing the 'pop".

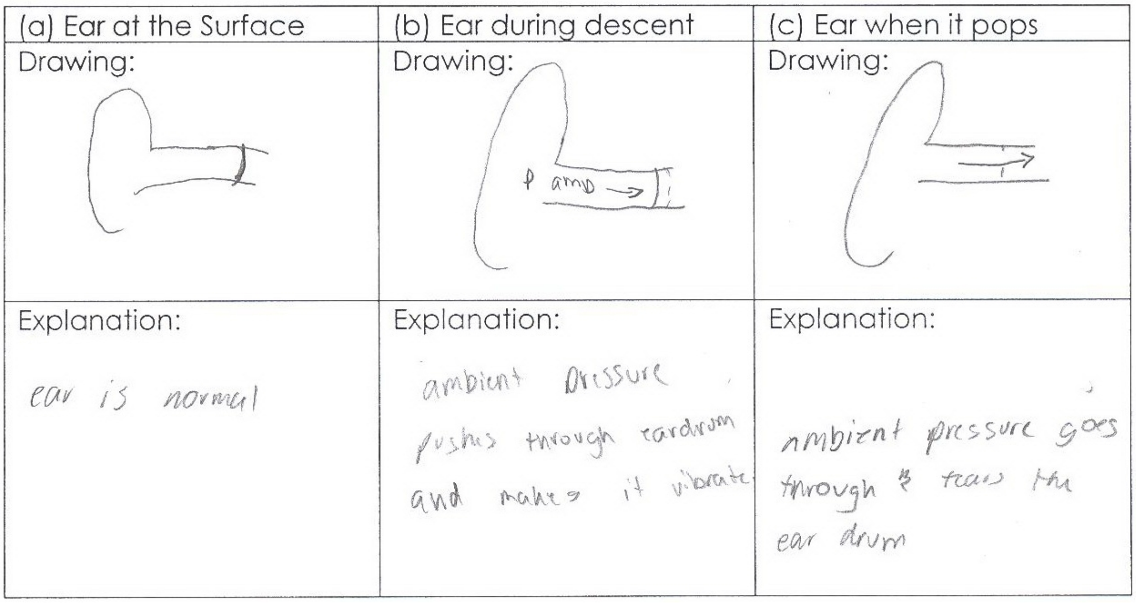


Figure 4.54. Ear squeeze and equalization, tearing ear drum model. Drawn by Student 38667.

4.8.5 Middle ear pop model. Two students (46628 and 59562) thought that the middle ear itself caused the popping sound during equalization.

Student 46628 visualized the eardrum as a rigid structure that would move in its entirety during ear squeeze (Figure 4.55). At the surface, the middle ear is round. The eardrum would compress the middle ear, changing it into a "D" shape. Upon clarification, the student also explained that the whole middle ear would compress as there was, "…more pressure outside than in." When the ear popped, the ear drum moved back into place, and the middle ear would pop back into shape. However, the internal pressure was still less than external pressure. The ear popping appeared to be independent of the pressure system. She did not identify any role of the Eustachian tube.

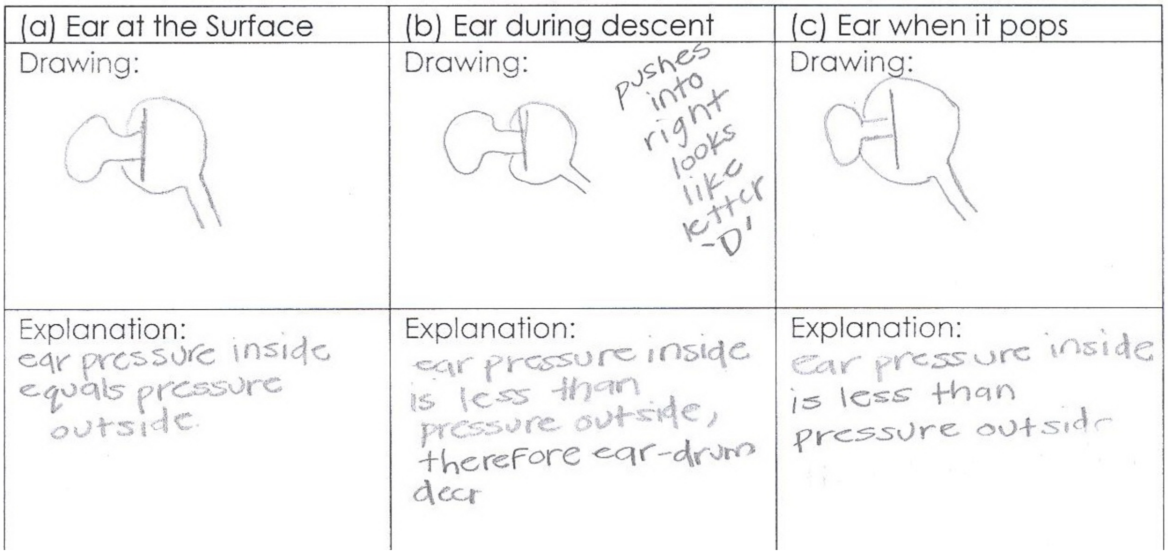


Figure 4.55. Ear squeeze and equalization, middle ear pop model. Drawn by Student 46628.

Student 59562 gave a similar model, with a rigid eardrum compressing the middle ear, then the middle ear and eardrum shifting back into shape upon equalization (Figure 4.56). Particles were drawn on either side of the eardrum, but it is unclear if the student thought water particles had the same spacing as air particles. This student also thought that the Eustachian tube remained open during equalization, and was closed during ear squeeze, which is discussed below.

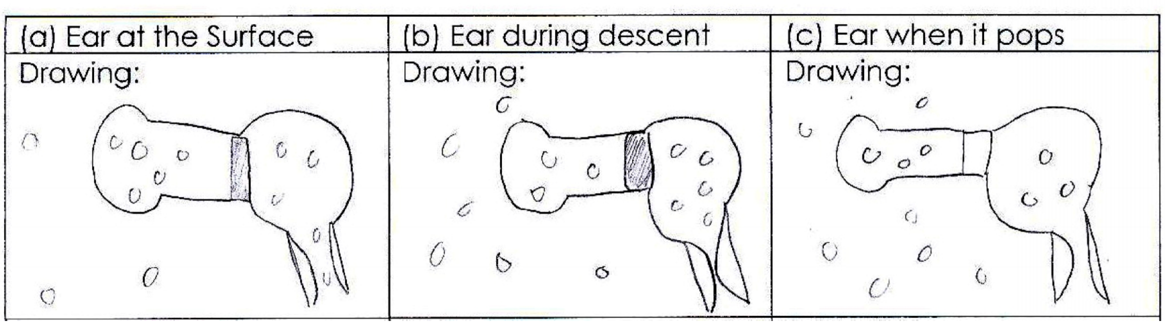


Figure 4.56. Ear squeeze and equalization, combined "middle ear pop" and "open Eustachian tube during equalization" models. Drawn by Student 59562.

4.8.6 Flexible, impermeable tympanum, concave during ear squeeze. Eight students (29425, 27536, 30913, 59932, 62533, 69297, 77079, and 97608) predicted that the tympanum would be in the concave position during ear squeeze. Six (29425, 27536, 30913, 59932, 62533, and 77079) of these students predicted that at equalization, the eardrum would move back to the vertical position. Two of the students (69297 and 97608) predicted that the eardrum would move into a convex position after equalization.

4.8.6.1 Concave tympanum, open Eustachian tube at equalization model. Three students (30913, 59932, and 62533) predicted that the tympanum would move to the concave position during descent (Figures 4.57 and 4.58), then back to the vertical position during equalization. When the eardrum was equalized (that is, at the surface and after the ear pops), the Eustachian tube was open during that time. This "open Eustachian tube at equalization" model had not been noted in any other previous sessions of the scuba program. These students came close to target models of ear equalization.

Upon clarification, these students explained that at the surface, the Eustachian tube remained open so the air could flow to the middle ear so that internal and external pressures were equal. During descent, the outside pressure increased, so the ear drum would "push in". (Student 30913 also thought that the Eustachian tube closed in case water came in through the tympanum.) Student 30913 thought that when the ear popped, the Eustachian tube opened to let air into the middle ear so that internal and ambient pressures were equal (Figure 4.56). Student 59932 thought that pressure was relieved by pushing water molecules away from the eardrum (Figure 4.57).

At this point, it appears that Student 30913 had adopted the systematic model of pressure rather than the internal pressure orientation noted throughout the teaching intervention. This student was also able to make logical (albeit inexperienced) applications of pressure systems to a physiological context. However, it is unclear if the student had clear microscopic visualizations and understood the movement of the particles.

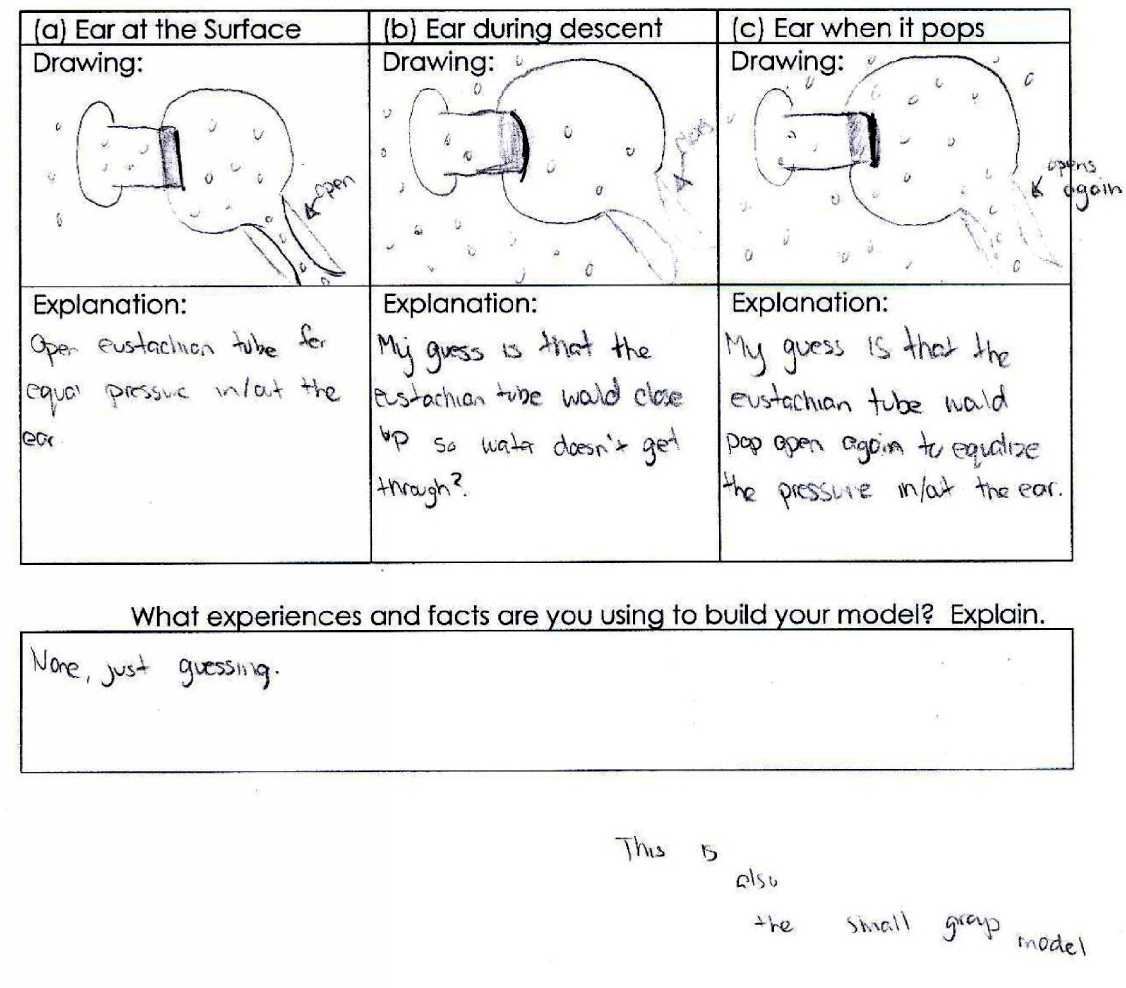


Figure 4.57. Ear squeeze and equalization, flexible, impermeable tympanum, open Eustachian tube model. Drawn by Student 30913.

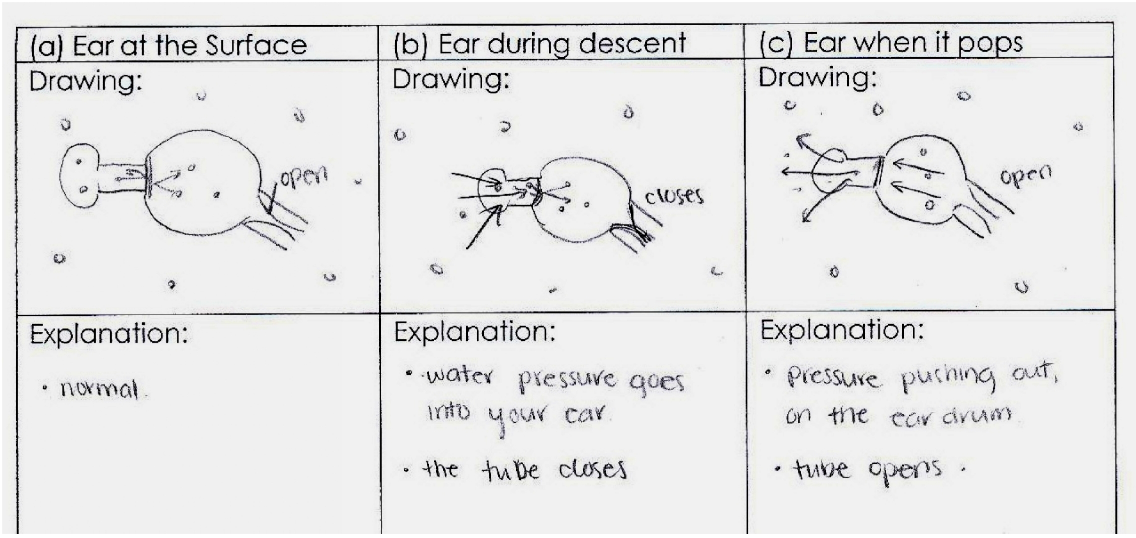


Figure 4.58. Ear squeeze and equalization, flexible, impermeable tympanum, open Eustachian tube model, pressure system explanation. Drawn by Student 59932.

The explanation provided by Student 62533 was almost identical to the explanation of Student 59932, however, Student 62533 showed an external pressure orientation rather than explaining the movement of the eardrum in terms of pressure systems (Figure 4.59). No mention of internal (or middle ear pressure) was given during the initial explanation or with responses to clarification questions.

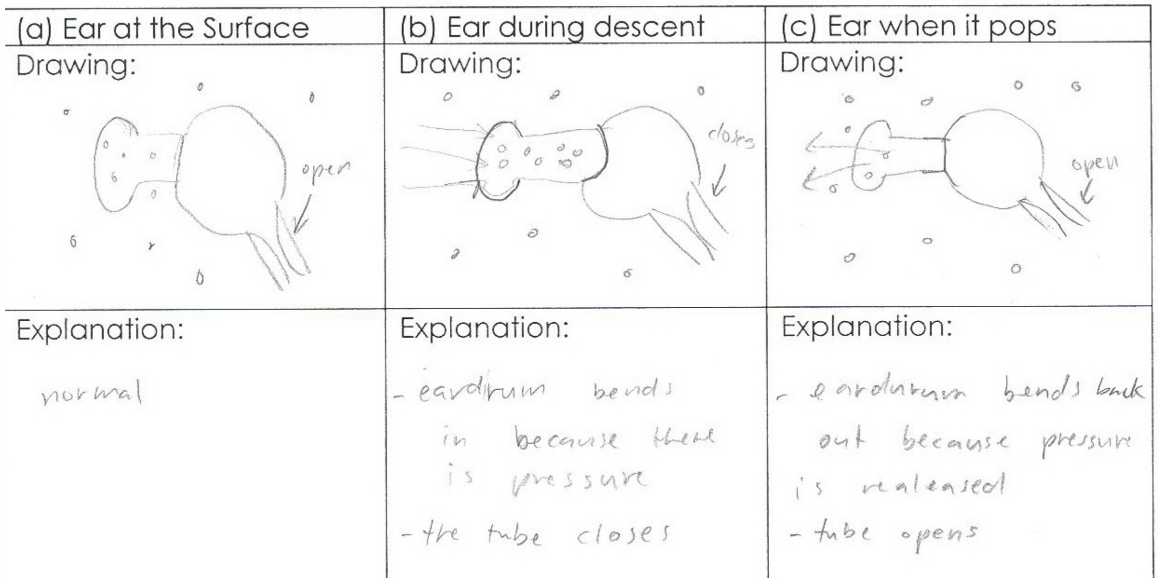


Figure 4.59. Ear squeeze and equalization, flexible, impermeable tympanum, open Eustachian tube model, external pressure orientation. Drawn by Student 62533.

4.8.6.2 Concave tympanum during ear squeeze, macroscopic representations only. Three students provided models where the tympanum was concave during ear squeeze and vertical during equalization, with no drawings of internal or ambient particles.

Student 29425 drew ear models without a Eustachian tube, which was a model observed before the teaching intervention (Figure 4.60). In both cases, no macroscopic or symbolic representations were given.

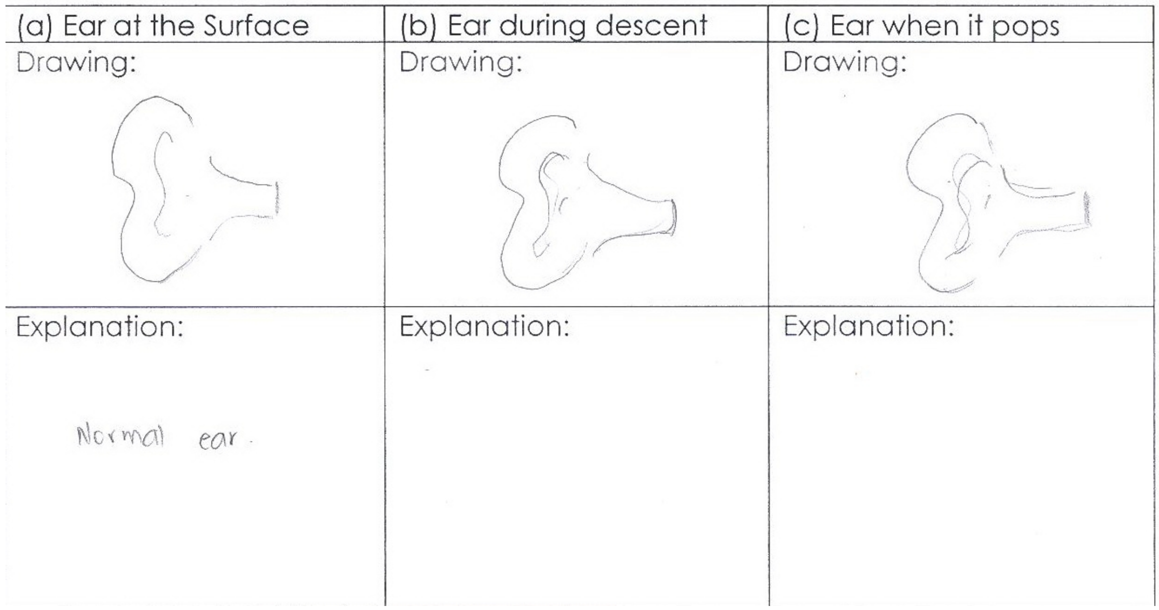


Figure 4.60. Ear squeeze and equalization, tenacious alternate conceptions consistent with original, pre-instructional models. Drawn by Student 29425.

Students 27536 and 77079 drew diagrams that included the Eustachian tube, but there was no discussion of the role of the Eustachian tube during equalization (Figure 4.61). Student 27536 cited a change in pressure (presumable external pressure) causing the tympanum to assume the concave position.

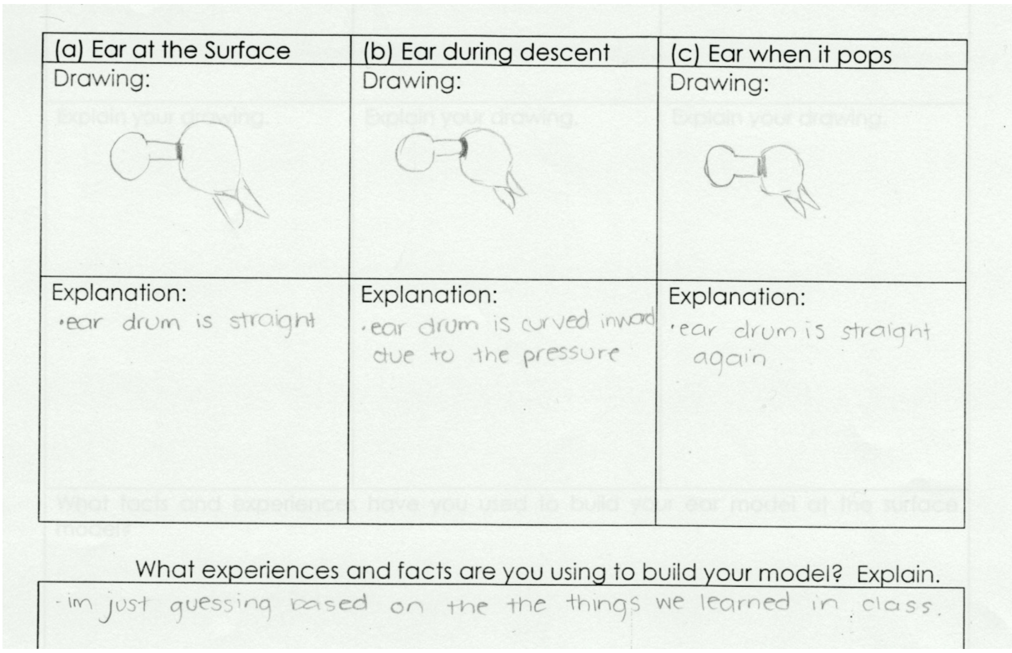


Figure 4.61. Ear squeeze and equalization, representative drawing of flexible, impermeable tympanum without microscopic visualization. Drawn by Student 27536.

Student 77079 predicted that the tympanum would assume the concave position during ear squeeze based essentially on a guess. As she explained, "The eardrum changes. I'm not sure if it goes inwards or outwards though so I assumed inwards." She also predicted that during ear equalization, "The eardrum goes back to normal, like it is at the surface."

4.8.6.3 Concave tympanum during ear squeeze, convex tympanum at equalization. Two students (69297 and 97608) described models where the eardrum "pops back out" after equalization.

Student 69297 drew models where the eardrum is concave during ear squeeze (Figure 4.62). Upon clarification, the "1 atm" in part b represents the internal pressure of the entire ear (including the ear canal and middle ear). As external pressure is greater than internal pressure, the eardrum will become concave. Upon equalization, the eardrum becomes convex when air enters the middle ear and ear canal.

For Student 69297, this alternate model was tenaciously held and used to answer ear equalization questions in post-test 3.

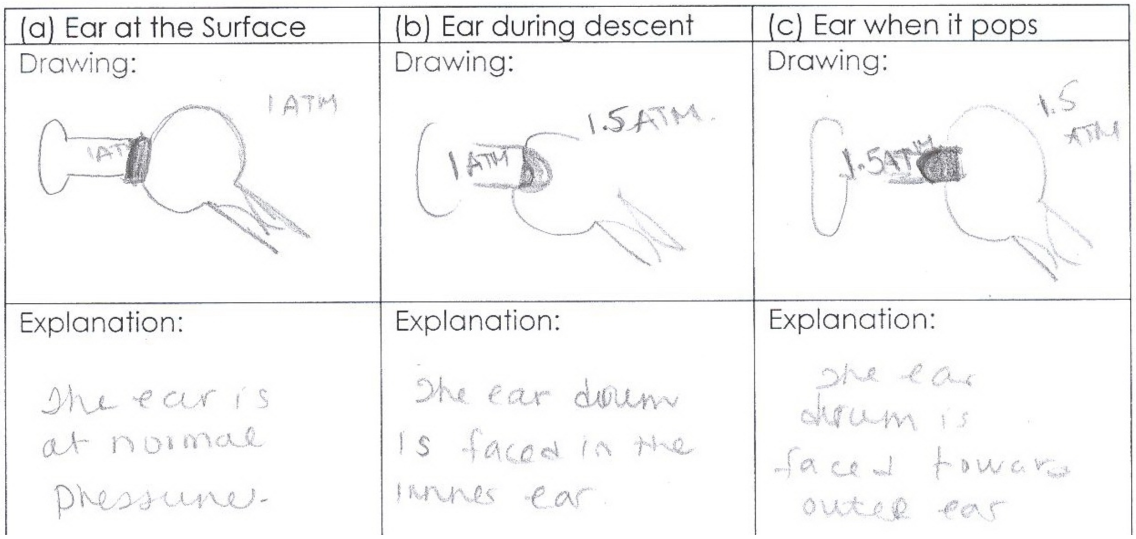


Figure 4.62. Ear squeeze and equalization, convex tympanum model of equalization. Drawn by Student 69297.

Student 97608 drew the diagrams of the ear without a Eustachian tube (Figure 4.63). The convex position after equalization was similar to the model shown by Student 696297.

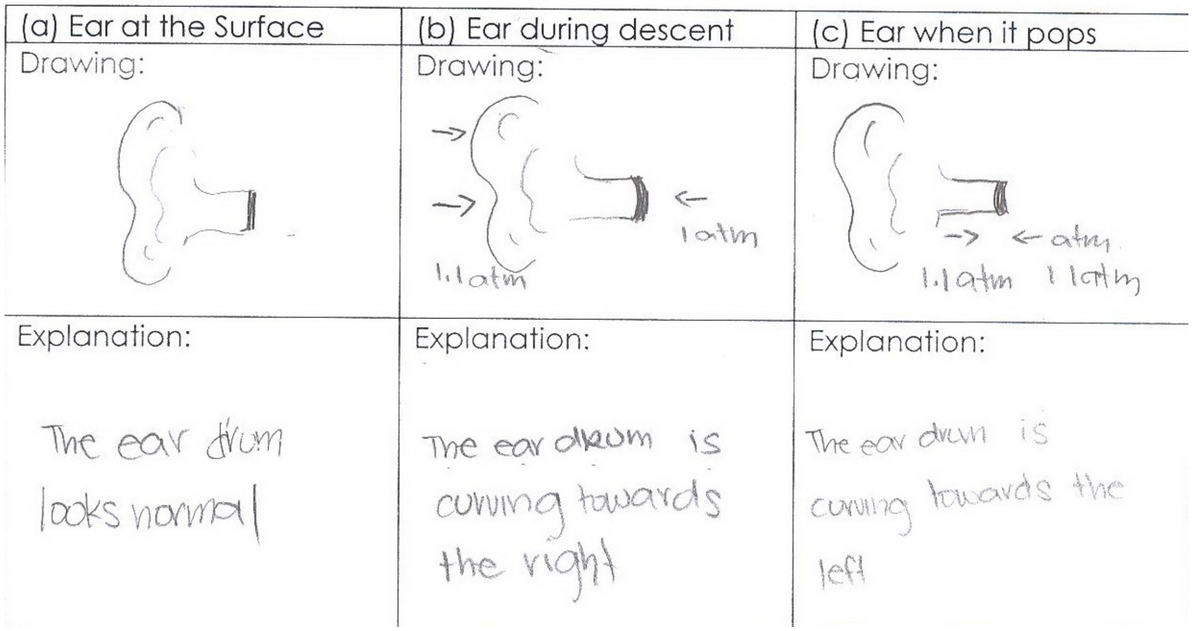


Figure 4.63. Ear squeeze and equalization, convex tympanum model of equalization, no Eustachian tube. Drawn by Student 97608.

4.9 Student Conceptions of Ear Squeeze During Flight Demonstration

Eighteen student responses were analyzed to determine student conceptions of the ear squeeze during flight demonstration (Appendix V). In this case, as ambient pressure decreased, the tympanum would assume a convex position.

One student predicted that the tympanum would remain vertical, three students predicted that the tympanum would assume a concave position, and fourteen students predicted that the tympanum would assume a convex position.

4.9.1 Vertical tympanum model. Student 11252 predicted that the tympanum would remain vertical, with no explanation of her model (Figure 4.64). No ambient particles indicate an internal pressure orientation.

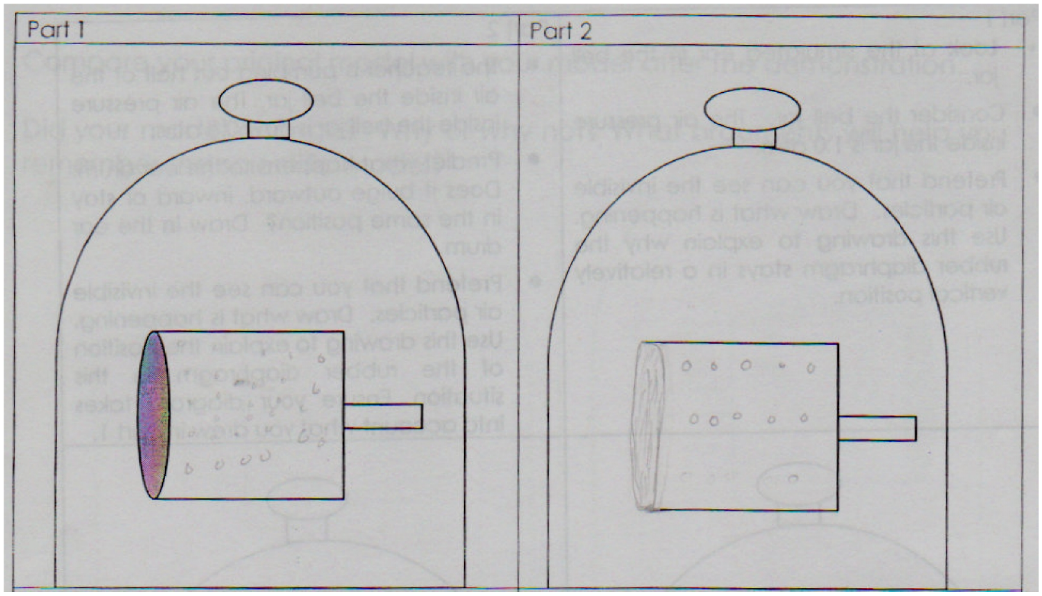


Figure 4.64. Ear squeeze during flight demonstration, straight tympanum model, internal pressure orientation. Drawn by Student 11252.

4.9.2 Concave tympanum. Students 34988, 36843 and 29425 predicted that the tympanum would curve inward. These students had difficulties in determining which particles would be removed (internal or ambient or both) or thought that air was added to the vacuum chamber. In essence, the difficulty did not appear to lie in their understanding of pressure systems, rather, the difficulty occurred in the change of context to which the vacuum was applied, similar to that of the original "visualization of a vacuum" (Appendix H) and "balloon in a vacuum" (Appendix I) teaching sequence.

4.9.2.1 Evacuation of internal air particles. Student 34988 predicted that the tympanum would assume a concave position after evacuation, and provided an explanation where microscopic and macroscopic drawings were in agreement, but directly contradicted her symbolic representations. Though Student 34988 wrote that external pressure was 0.5 atm and internal pressure was 1.0 atm, she wrote the statement, "the pressure is greater outside" and "$P_{out}>P_{in}$". The symbolic representation contradicts her first written statement (Figure 4.63).

The microscopic drawing shows that upon evacuation, internal air particles would be removed rather than external air particles (Figure 4.65). As there were more ambient than internal particles present, the tympanum would move inwards. Thus, the position of the tympanum would be correct given her statement that ambient pressure was greater than internal pressure. However, this is in direct disagreement of the symbolic representations of pressure drawn in the diagram.

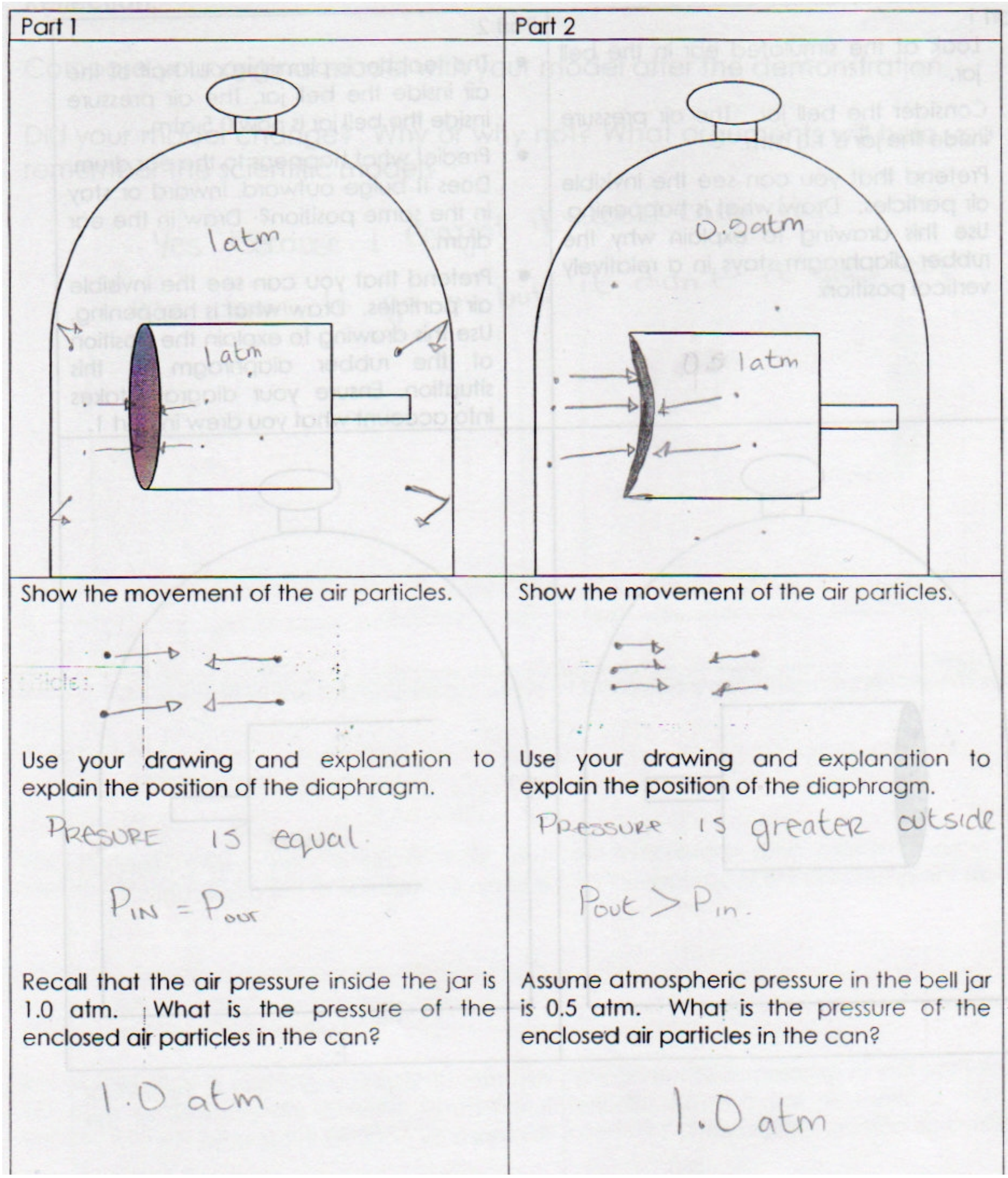


Figure 4.65. Ear squeeze during flight demonstration, concave tympanum, evacuation of internal particles. Drawn by Student 34988.

4.9.2.2 Addition of ambient particles. Student 36843 thought that upon evacuation, ambient air particles would be added rather than removed (Figure 4.66). As there were more ambient than internal particles present, the tympanum would move inwards.

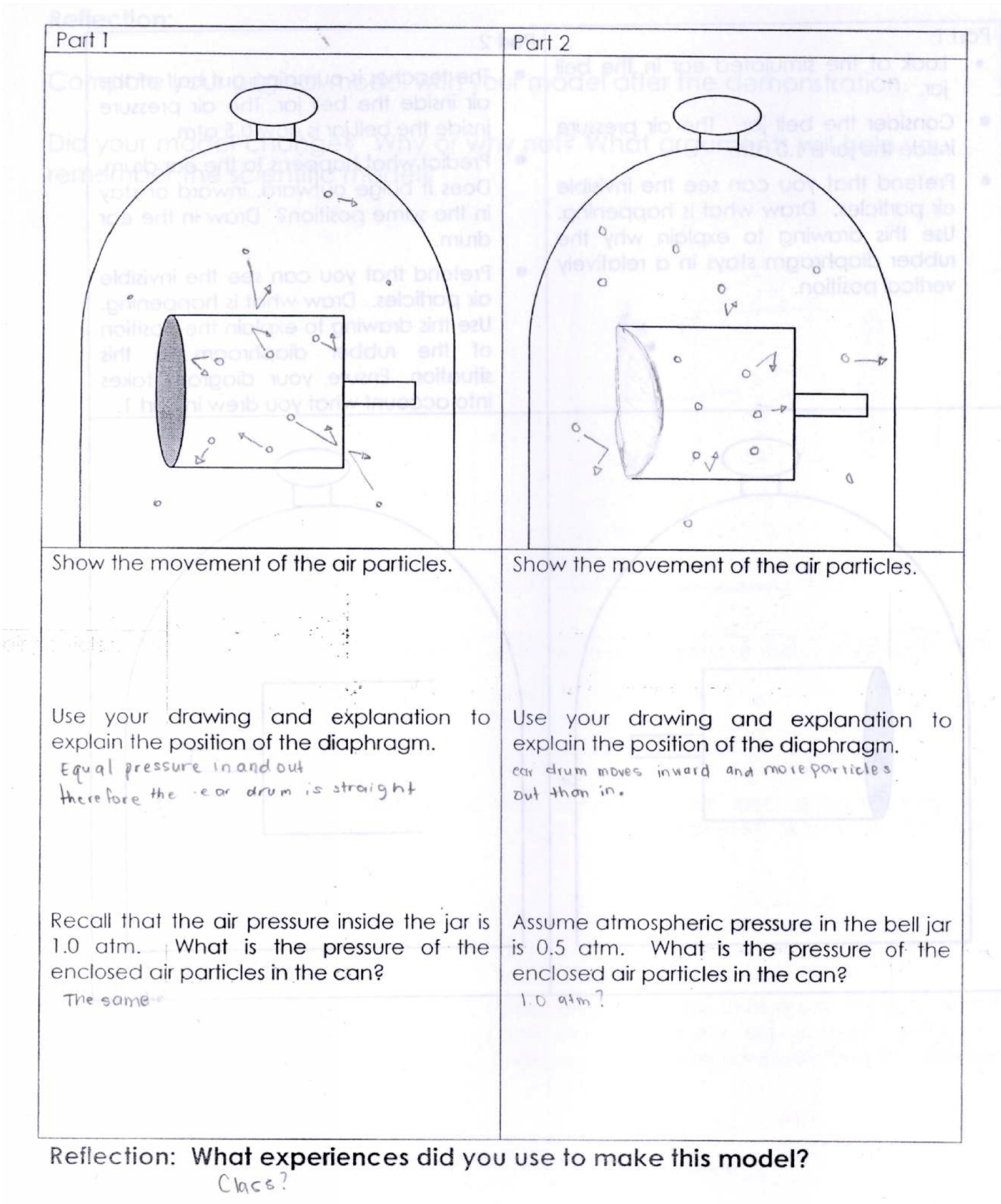


Figure 4.66. Ear squeeze during flight demonstration, concave tympanum, addition of ambient particles. Drawn by Student 36843.

4.9.2.3 Evacuation of internal and ambient particles. Student 29425 thought that both internal and ambient air particles were removed (Figure 4.67), resulting in a decrease in volume. In the previous balloon in a vacuum demonstration (Appendix I), this student had given explanations that the balloon would increase in volume. The transfer of this model did not occur in this context. However, the alternate conception that when a balloon is placed in a vacuum chamber, removal of both ambient and internal air particles occurs during evacuation was observed in other students (Figure 4.24).

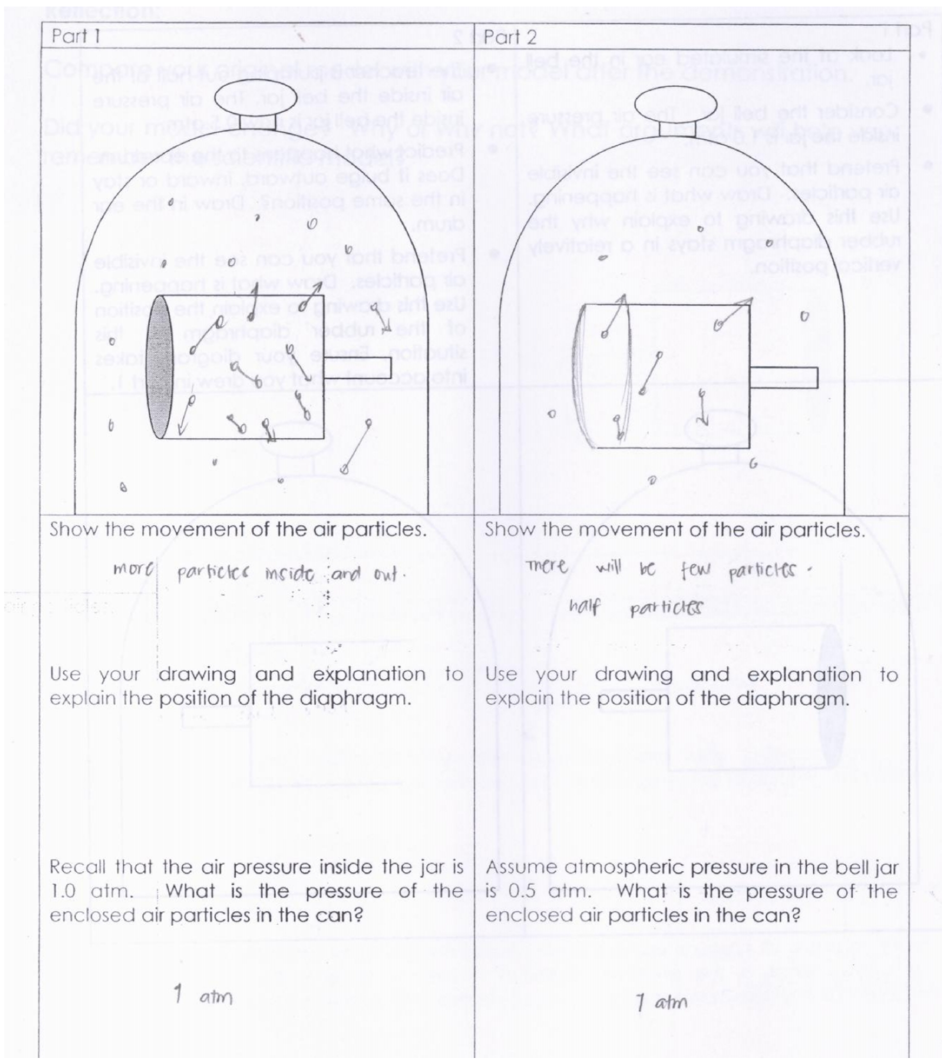


Figure 4.67. Ear squeeze during flight demonstration, ambient and internal air particles removed. Drawn by Student 29425.

4.9.3 Convex tympanum. Fourteen students predicted that the tympanum would assume a convex position. Most of these students discussed pressure in terms of systems, but demonstrated other alternate conceptions as described below.

4.9.3.1 Partial scientific model, alternate conception of slower particle movement. Students 62375, 66774 and 67297 showed partial scientific models, with the exception of describing the movement of internal particles (Figure 4.68). Student 62375 thought that internal particles would move more slowly because the distances between them were greater. Student 67297 thought that the particles would move more slowly because of decreased ambient pressure, and Student 66774 gave both reasons.

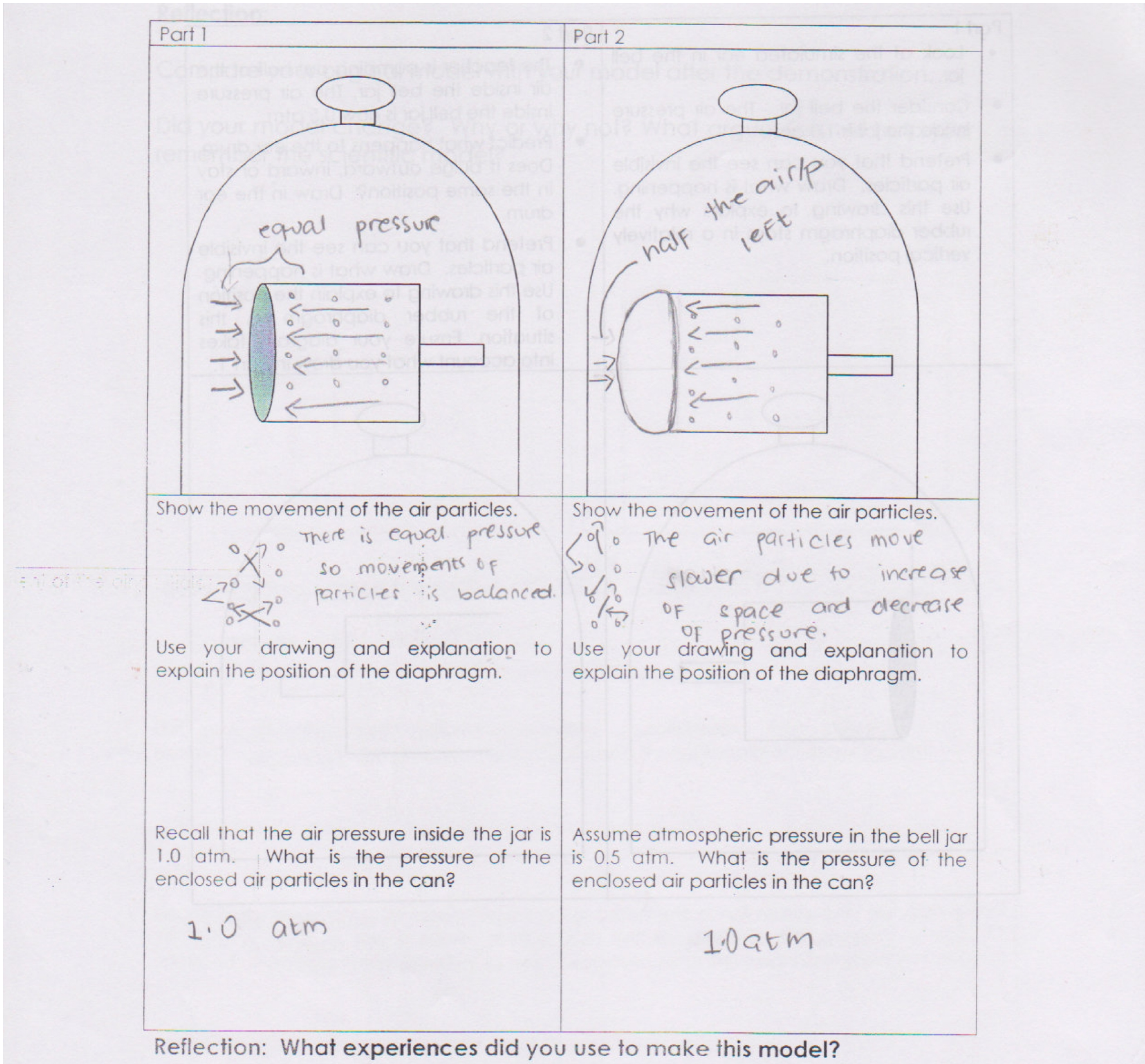


Figure 4.68. Ear squeeze during flight demonstration, representative example of a partial scientific model with slower particle movment. (Drawn by Student 66774.)

4.9.3.2 Partial scientific model, reinforced alternate conception. Nine students (27356, 30913, 36494, 46628, 59932, 62533, 77097, 84816 and 97608) provided explanations in keeping with target models, however, these students also thought that the air pressure inside the can (physical model of the ear) was 1 atm rather than 0.5 atm after evacuation of the bell jar (Figure 4.69).

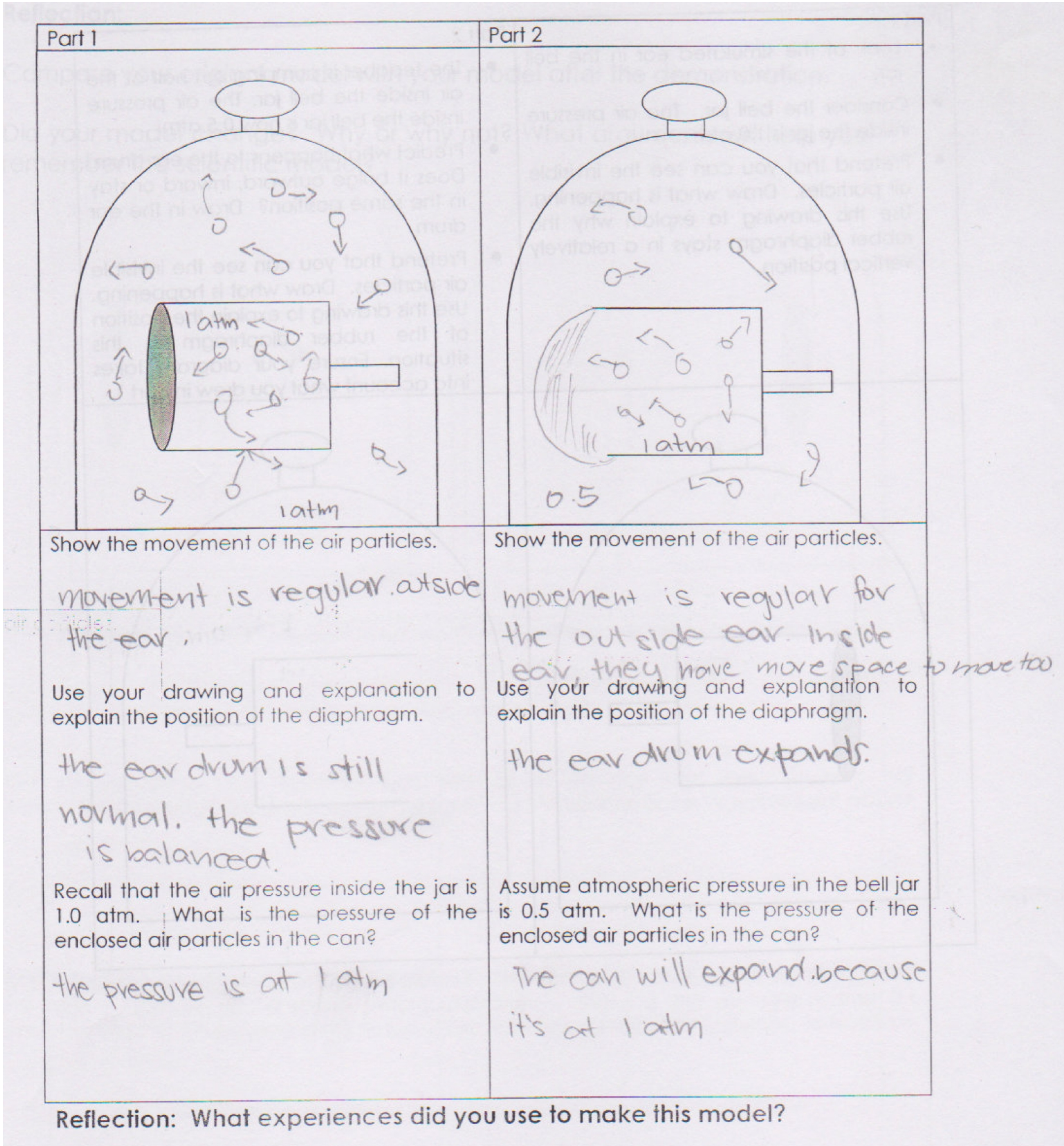


Figure 4.69. Ear squeeze during flight demonstration, representative example of the reinforced conception of constant internal pressure. Drawn by Student 97608.

4.9.3.3 Partial scientific model, no symbolic representation. Student 81886 drew a scientific model without indicating relative internal and ambient pressures.

4.9.3.4 Scientific model. Student 26951 gave explanations in keeping with scientific models, and stated that the internal pressure of the can would be 0.5 atm (Figure 4.70).

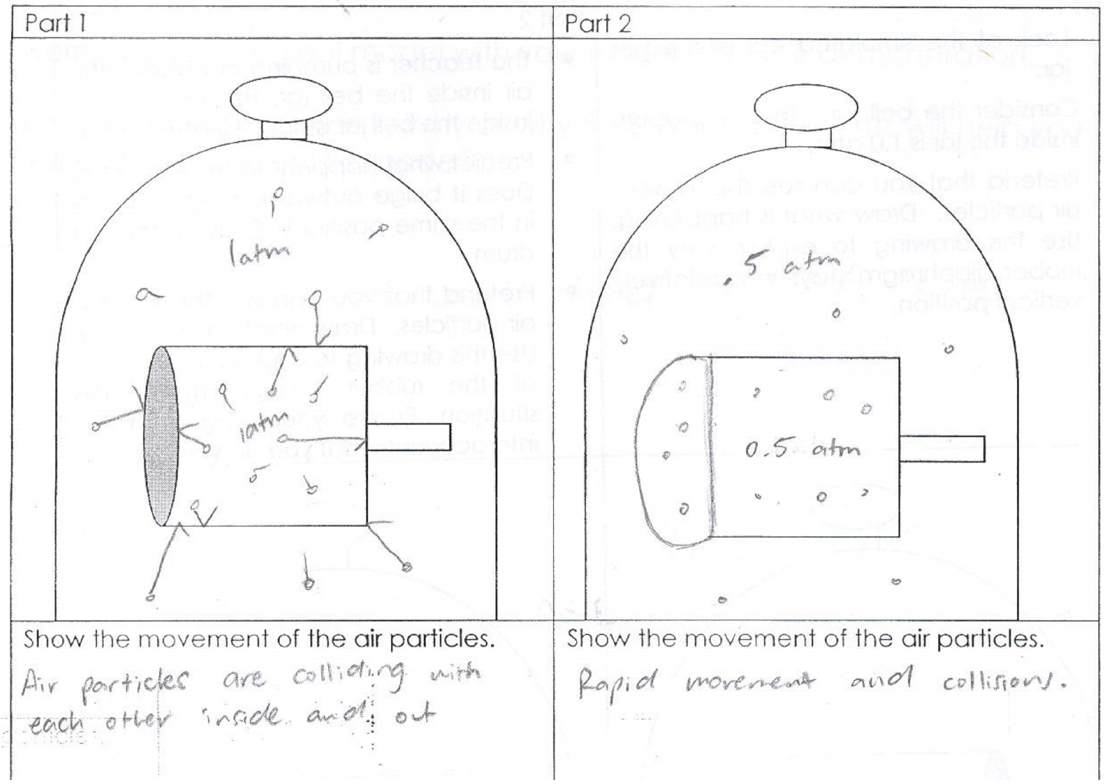


Figure 4.70. Ear squeeze during flight demonstration, scientific model. Drawn by student 26951.

4.9.4 Reinforced alternate conception. A total of twelve students thought that when the tympanum of the can stretched, the internal pressure of the can was still 1 atm rather than 0.5 atm, not realizing that if there is a pressure difference, volume will continue to increase or decrease.

This alternate conception was a direct result of, and reinforced by, the teaching strategy designed by the researcher. Students were allowed to leave the original internal pressure of a balloon or middle ear model in diagrams to help them compare the internal and external pressures to decide if volume would increase or decrease. However, despite the collaborating teacher discussing the limitations of this model, students may have developed the belief and conception that there are actual pressure differences during ear squeeze.

4.10 Tenacious Alternate Conceptions

The most tenacious alternate conceptions regarding pressure and Boyle's Law identified in this part of the study were as follows:

1. The reinforced alternate conception that the internal pressure remains the same once ambient pressure changes.
2. Linear reasoning of pressure, internal orientation (Basca and Grotzer, 2001)
3. Linear reasoning of pressure, external orientation (Basca and Grotzer, 2001)
4. Atmospheric pressure increases with elevation (Dove, 1998).

In some students (for example, students 11252 and 29425), these conceptions can be traced almost all the way through the teaching sequence.

These tenacious conceptions were especially evident when there was a change in context. For example, Student 34988 initially thought that a balloon brought to the top of a mountain would have no change in volume; and made an attempt to discuss her model in terms of pressure systems. In the vacuum and balloon vacuum demonstrations, she was able to successfully predict the expansion of the balloon and discuss the expansion in terms of pressure systems. At this point, it appeared that she started thinking in terms of pressure systems and Boyle's Law in keeping with target models. However, when responding to the question about the scuba balloon, she again predicted that the balloon would maintain its volume; and tried to explain her alternate model in terms of pressure systems as she did in the originally.

Tracking of these conceptions will be discussed in chapter 8.

Chapter 5: Results and Analysis of Assignments 1 and 2

As previously discussed, two assignments (Appendices O and P) were given where students were asked to provide explanations using macroscopic, sub-microscopic and symbolic representations (herein described as the “three representations” or the “chemistry triplet”) in their answers.

Of the 21 participants, 16 sets of assignments were analyzed, and the data from five students were eliminated. Four students plagiarized assignment 2 in its entirety. After an investigation conducted by the collaborating teacher, the student that originally answered the questions was autonomously identified and her data kept for analysis. The students who plagiarized were the identified as EAL. One student did not submit assignments 1 or 2.

As these assignments were used for marks toward student report cards, the marks allocated for these questions (Figures 5.1 to 5.8) were erased as they were not used as part of the analysis for this study.

5.1 Response Expectations for Each Assignment

In assignment 1, students were asked to calculate changes in volume (V_2) of a balloon under different changes of pressure. With these calculations, students were asked to provide microscopic and macroscopic diagrams, with a written explanation explaining why the change occurred, using rationales based on a systematic reasoning of pressure, or by explaining Boyle’s Law. The students were asked to ensure that their microscopic, macroscopic, symbolic and pressure systems reasonings were congruent.

Macroscopic drawings were expected to show a change in volume of the balloon. The drawings of the balloons before and after the pressure changes should be noticeably larger or smaller depending of the context. Microscopic drawings were expected to include internal and ambient particles with some indication that these particles were colliding with internal and external surfaces of the balloon. In addition, the relative spacing of particles should have been indicated; specifically, air particles should have had larger spaces between them, and water particles should have been drawn close together in a disorganized fashion. Symbolic representations were expected in the form of the calculation, with appropriate units. Symbolic representation may also have been shown on the drawings as the number of atmospheres of internal and external pressures.

The written explanation was expected to include a discussion in terms of pressure systems or Boyle's law. All three representations and the written explanation should have been congruent.

In assignment 2, students were asked to calculate changes in both pressure and volume, and justify their answers using the same criteria discussed for assignment 1.

5.2 Consistency in the Use of the Three Orientations, Agreement and Mental models

In the first step of the analysis, the two assignments for each participant were compared to identify if consistencies existed in the use of the three representations, and to identify consistencies in each participant's mental models of pressure and Boyle's Law. If notable differences between the first and second assignments were identified, students were asked to explain why they thought the change occurred (Table 3).

5.2.1 Large differences in the quality of responses between the first and second assignment. Four students were identified with having large differences in the types of explanations provided for each assignment. All four students gave more thorough answers in the second assignment when compared to the first, based on the criteria described above.

Table 5.1

Summary of inconsistent student responses to assignments numbers 1 and 2 (Appendices O and P).

ID Number	Criteria for responses	Assignment 1 Observations	Assignment 2 Observations	Student Response (if any)	Investigator Analysis
26951	Macroscopic representation: • drawings show change in volume (larger or smaller) Microscopic representation: • drawings show internal and ambient particles • indication of internal and ambient particles colliding with surfaces of the balloon • relative spacing between particles (i.e. air particles have larger spacing than water particles. Symbolic representation: • calculations with units • may include numbers representing internal and external pressures. Explanation of pressure systems: • pressure systems or Boyle's Law Congruency between representations: • all three	• No ambient particles drawn	• Ambient particles present • Water particles drawn the same as air particles	• First assignment: Didn't realize students were expected to draw ambient particles • Second assignment: didn't realize were expected to show differences in water and air • Allowed to draw a few particles to save time	• May have had internal orientation of pressure, only considering internal particles • Evaluators: the student demonstrated conceptual understanding in the second assignment
27536		• No drawings of ambient particles in diagrams, nor was there a written description indicating the existence of ambient particles •	• Ambient particles present	• First assignment: Didn't realize had to draw ambient particles	• In the first assignment, this student may have actually forgotten to draw ambient particles, or did not draw ambient particles due to an internal orientation of pressure, only considering internal particles • Evaluators: conceptual understanding in second assignment
36494		• Symbolic description only provided	• Little indication of microscopic understanding • Pressure model: little understanding of internal and ambient pressure systems	• Did not have time to complete drawings • Thought calculations were the most important to complete for the assignment 1.	• Uses knowledge of Boyle's Law to confirm calculations • Can visualize internal particles • Internal pressure orientation
69297		• Though written explanations of the macroscopic expansion or contraction of the balloon are correct, the balloons in some of the questions are drawn the same size.	• Conceptual understanding	• Did not realize that it was important to show the balloon changes size in drawings.	• Most likely had conceptual understanding during assignment 1 • May have not visualized the balloon shrinking or expanding even though the explanation was written

	representations and written explanation in agreement				

The three students (26951, 27536, 69297) that showed large differences in their answers between assignment 1 and 2 appeared to have improved the quality of their responses by ensuring all three representations were present and demonstrating congruency between the representations. Though Student 36494 generally showed some improvement in answering questions (that is, by remembering to give indications of microscopic understanding), it was unclear if Student 36494 had incomplete microscopic understanding, or simply ran out of time to provide higher quality responses.

The assignments of the twelve remaining participants were consistent in the use of the three representations, the agreement between the macroscopic, sub-microscopic and symbolic descriptions and drawings, and agreement between the pressure and Boyle's Law mental models observed as written.

5.3 Use of the Three Representations and Understanding of the Interrelations Between the Three Representations Demonstrated by the Participants

5.3.1 Hypothetical categories of understanding. Hypothetical themes based on combinations of the three forms of representation were initially generated by the researcher. These included:

- Conceptual understanding. (All three representations were present and congruent)
- Macroscopic understanding only. (No symbolic and macroscopic visualizations.)

- Microscopic understanding. (No symbolic and macroscopic visualizations.)
- Symbolic understanding. (No macroscopic and microscopic visualizations.)
- Macroscopic and microscopic understanding (No symbolic understanding.)
- Macroscopic and symbolic understanding (No microscopic visualization.)
- Microscopic and symbolic understanding (No macroscopic visualization.)
- No conceptual understanding (none of the representations were either present or in agreement).

5.3.2 Categories of understanding generated from student responses. To generate themes from the data, the available assignment 2 data were coded in consideration of observations and inferences drawn from analysis of assignment 1, student responses to post-assessment clarification questions, and discussions with external examiners analyzing the data. If assignment 2 data for particular students were unavailable, assignment 1 was used for analysis. The codes were then grouped into themes by the investigator. The following themes were generated from this data:

- Conceptual understanding. Students were marked as having conceptual understanding if the three representations were in agreement, and consistent with the target model. This category is based on the "Theoretical Definition (Verbal)" or TDV as described by Chu, Treagust and Chandrasegaran, (2008). For some participants, minor difficulties were shown. These included, among others, forgetting to add air pressure to specific scuba related questions during calculations or incorrectly calculating pressure at different depths and elevations. However, in such cases, it was clear that students understood that at increased elevation, pressure decreased.

- Symbolic description (no macroscopic and microscopic understanding). Students that provided only formula-based calculations to derive the answer with (a) no macroscopic and microscopic representations present or (b) with macroscopic and microscopic representations that were inconsistent with the numerical answer were classified as giving a symbolic description. This category is based on the Theoretical Definition Formula (TDF) category as described by Chu, Treagust and Chandrasegaran, (2008). The participants who demonstrated symbolic understanding only supported the statements of de Berg (1995; 1991) who discussed the concerns of having students who were mathematically adept at substituting and transposing formulas, yet had no conceptual understanding (i.e., macroscopic and sub-microscopic understanding) of physics concepts, in particular, pressure and Boyle’s Law.
- Macroscopic and Symbolic description (no microscopic understanding or partial microscopic understanding). Participating students utilized macroscopic and symbolic representations in keeping with the target model and were able to discuss pressure, but did not show microscopic understanding by (a) not providing microscopic drawings or explanations or (b) providing partial microscopic visualizations not in keeping with the target model or not in agreement with a student’s macroscopic and symbolic representations.
- Macroscopic and Symbolic description (partial microscopic understanding). Students provided macroscopic and symbolic representations that were in keeping with the target model. However, there were inconsistencies in microscopic visualization that prevented full conceptual understanding.

- Macroscopic description. Participants demonstrating macroscopic understanding could predict changes is balloon volume and draw the changes in volume correctly, but did not provide microscopic visualizations and many times calculations were performed incorrectly or contradicted macroscopic drawings.
- No conceptual understanding. Participating students attempted to incorporate macroscopic, microscopic and/or symbolic representations, but these representations were not in keeping with the target model as there was no agreement between the three orientations as presented.
- Other: No clear classification could be made given a student's written responses.

With the exception of students who demonstrated conceptual understanding, participants were asked clarification questions. The written answers to the assignments, student responses to clarification questions (if responses were given), and discussions between three external examiners and the researcher were used to assign students to the above mentioned categories. If no responses were given to clarification questions, then evidence from the assignments, lab write-ups, post-tests, and the discussions of the educators were used to determine the categories. The number of students identified as being in each of the six themes/categories is presented below.

5.3.3 Conceptual understanding. Eight of the 16 participants (922724, 26951, 27536, 46628, 62533, 69297, 77079, 97608) showed conceptual understanding, where the three representations were in agreement and consistent with target models. An example of a response demonstrating conceptual understanding is shown in Figure 5.1 below.

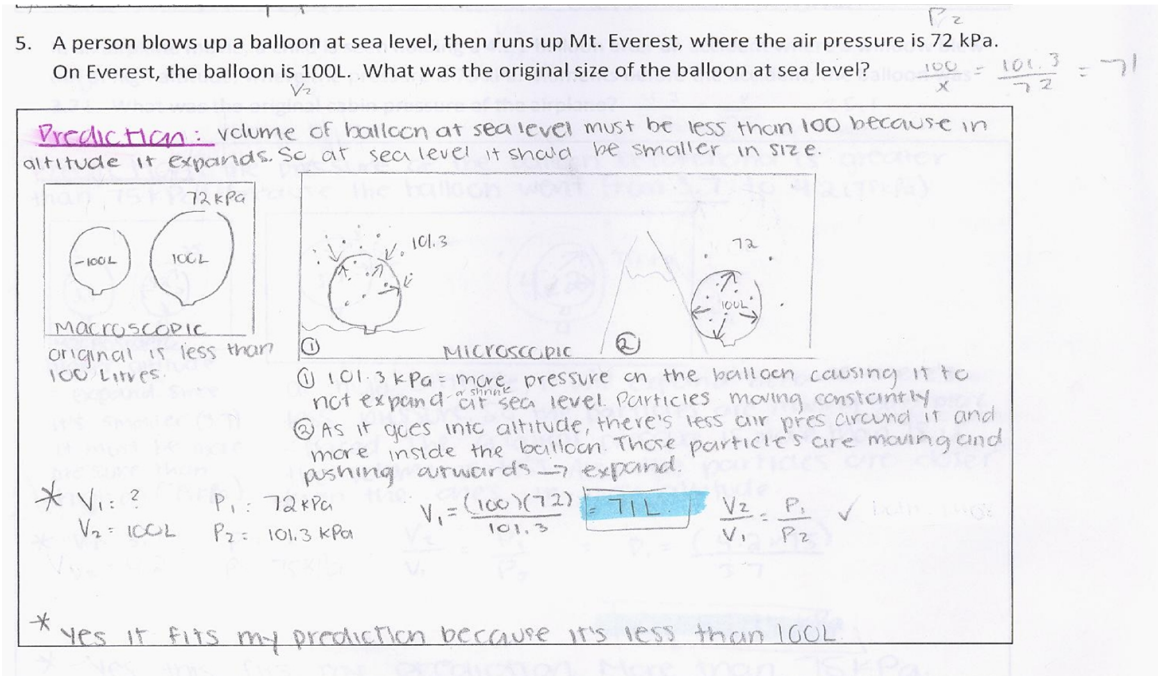
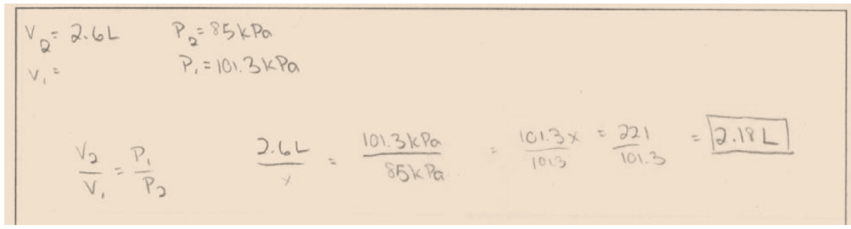
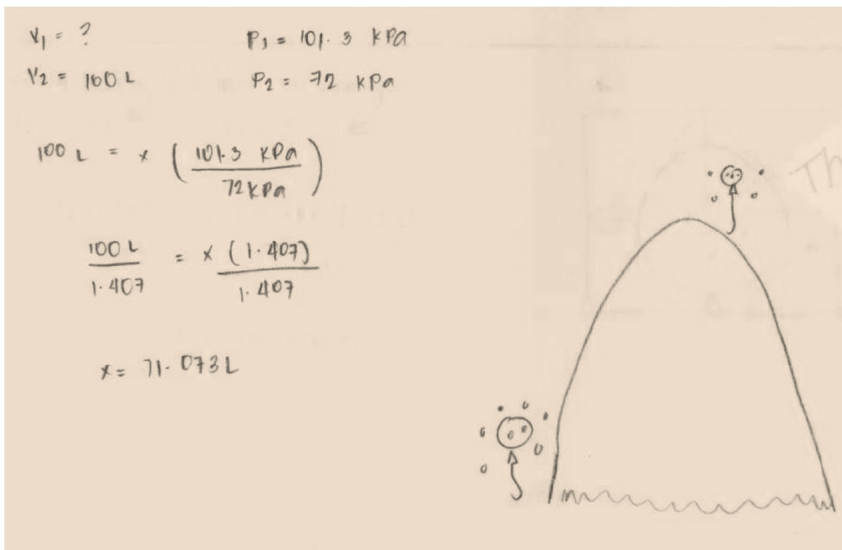


Figure 5.1. Student response to assignment 2, representative example of conceptual understanding. Drawn by Student 77079.

5.3.4 Symbolic description only. Two of 16 students (29425 and 30913) demonstrated a symbolic orientation (Figure 5.2) with no macroscopic or microscopic representations drawn (Figure 5.2a) or inaccurate microscopic and macroscopic representations that conflicted with calculations (Figure 5.2b)



a) Representative example of no microscopic and macroscopic drawings or explanations. Response by Student 30913.



b) Microscopic and macroscopic drawings conflicting with symbolic description. Response by Student 29425.

Figure 5.2. Student response to assignment 2, representative examples of symbolic description.

5.3.4.1 No macroscopic and microscopic representations. Student 30913 didn't draw macroscopic and microscopic diagrams (Figure 5.2a). When asked about this consistent omission, he replied that he didn't understand the macroscopic and microscopic representations. In fact, only when he realized that in order to "pass the course" he would have to show microscopic and macroscopic understanding did he actually attempt to understand these representations. Interestingly, this participant showed improvement in using the three representations in subsequent assignments and showed great improvement in the two-tiered multiple-choice tests.

5.3.4.2 Inaccurate or incomplete macroscopic and microscopic representations. Student 29425 consistently calculated pressure and volumes, but the macroscopic and microscopic diagrams completely conflicted with her calculations (Figure 5.2b). If pressure increased, her calculations showed volume decreased. However, her drawings would show the balloon increasing in size. This is most likely due to an alternate model where pressure is directly proportional to volume. There was no attempt to reconcile the macroscopic and microscopic drawings with the calculations. No comments were made about the conflict, indicating that there were probably two models held simultaneously as described by Osborne and Freyberg (1985).

5.3.5 Symbolic and macroscopic description. Three students demonstrated symbolic and macroscopic understanding, with no microscopic representation or with inaccurate microscopic representations.

5.3.5.1 No microscopic representation. One participant (34988) consistently didn’t show the particles in any of the questions answered (Figure 5.3).

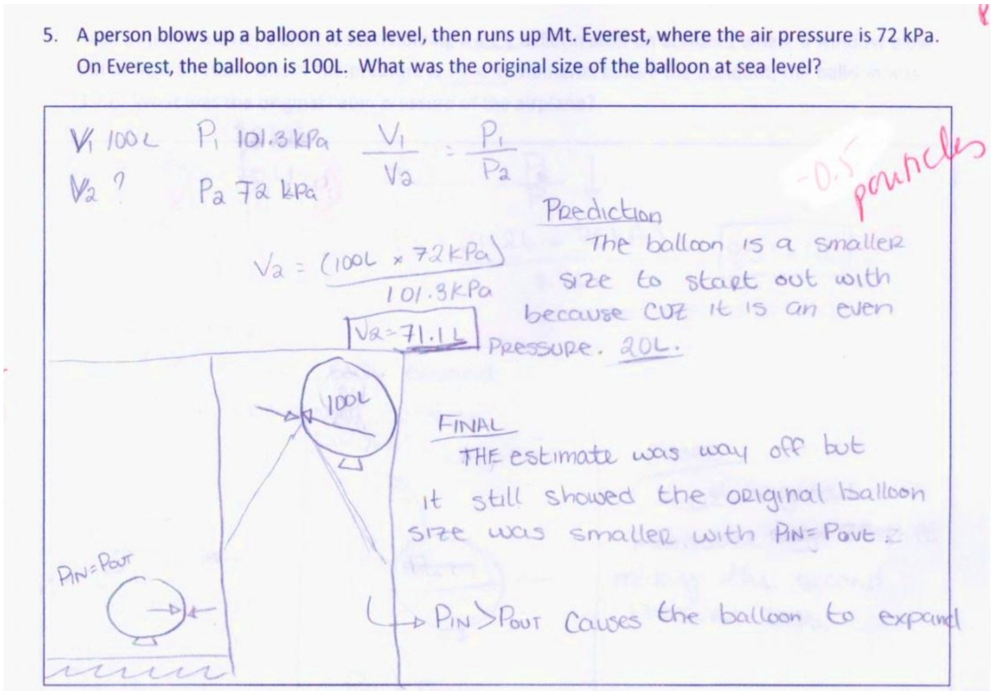


Figure 5.3. Student response to assignment 2, macroscopic and symbolic description, no microscopic. Drawn by Student 34988.

Upon discussions with the student, the collaborating teacher reported that there appeared to be no microscopic understanding. Essentially, the student understood the concept that there is an inverse relationship between ambient pressure and volume, as she could determine if the pressure or volume increased or decreased and could draw the macroscopic representation. She would include pressure arrows in her diagrams; however, she did not draw the ambient or internal particles.

It was noticed by two external examiners that in the second assignment Student 34988 consistently performed calculations first, and then based her predictions on her calculations. This is supported by the analysis of the two-tiered multiple choice post-tests, where many times, she could not answer microscopic questions. However, there was agreement between her symbolic and macroscopic drawings.

5.3.5.2 Incomplete microscopic representation. Two students (36494 and 59932) were proficient with symbolic and macroscopic representations, but employed alternative conceptions that partially affected microscopic understanding.

Student 36493 demonstrated symbolic and macroscopic understanding, where most calculations were complete and changes in pressure and volume were shown macroscopically. However, she consistently didn't draw ambient particles, and she didn't discuss ambient versus internal collisions (Figure 5.4). She was described as having an internal pressure orientation. Despite this alternate conception, she was able to complete all but one question successfully. For the most part, there was agreement between the representations in all but one question, where the drawings contradicted the correct calculations. There was no attempt to reconcile the representations in this case.

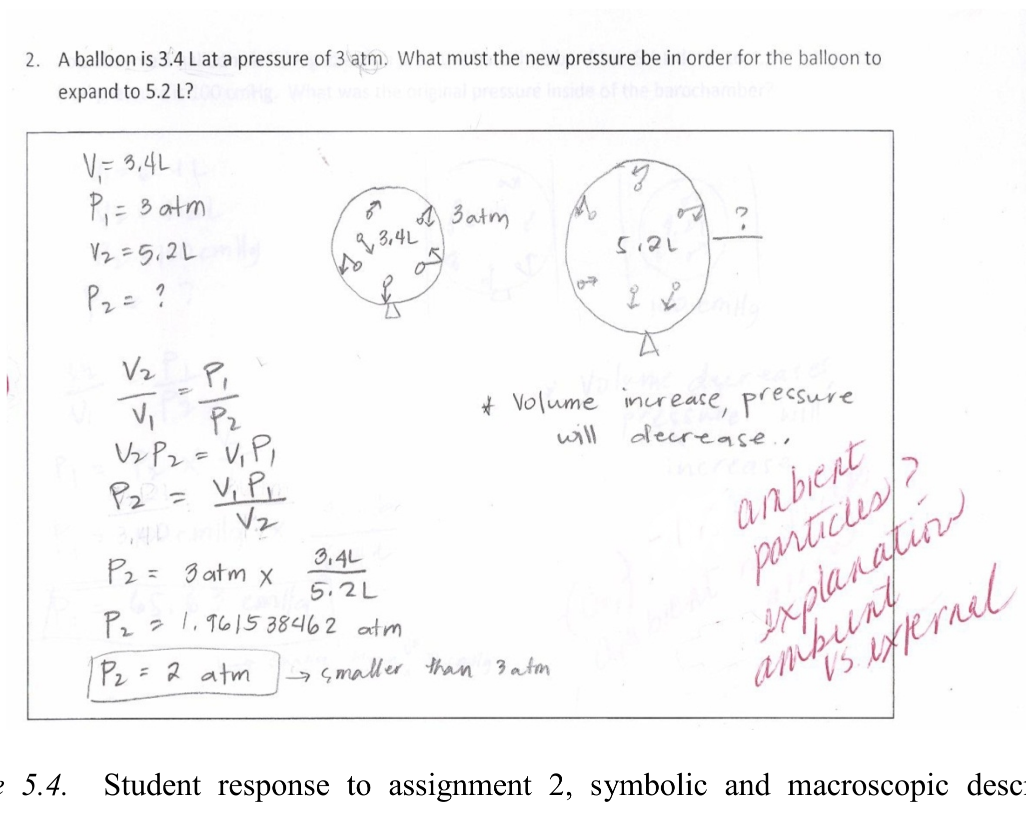
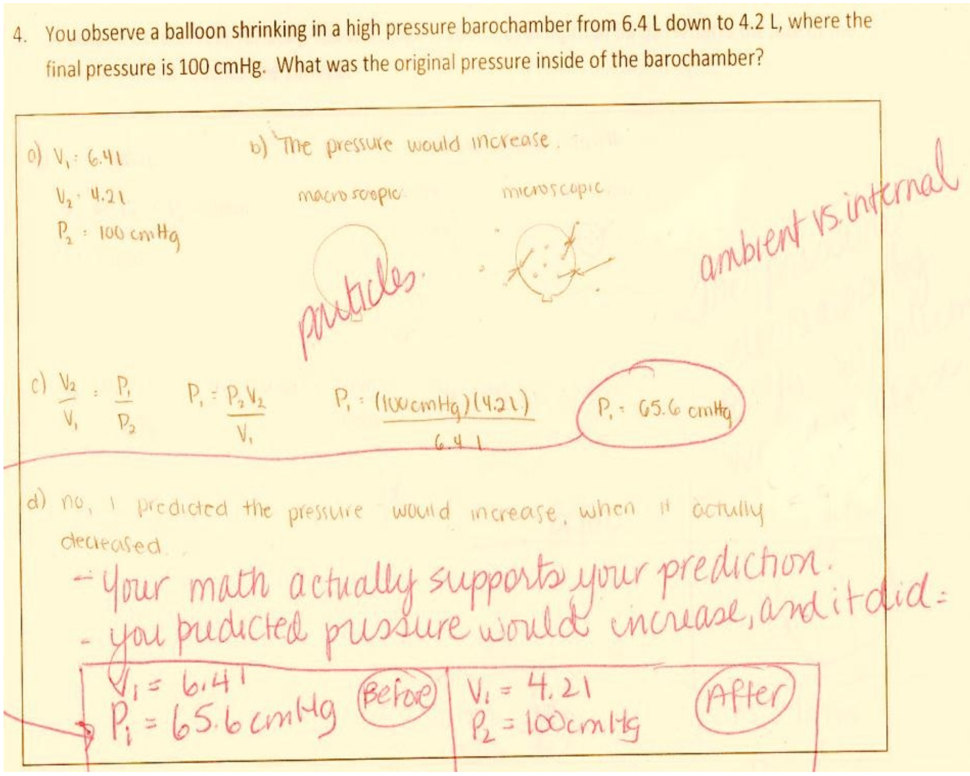


Figure 5.4. Student response to assignment 2, symbolic and macroscopic description, incomplete microscopic. Student 36493.

Student 59932 calculated each question successfully, but consistently stated that there were the same number of ambient and internal particles. In the first assignment, he wrote"…the number of particles equal so (it) balances out." This alternate conception was supported by microscopic drawings showing the same number of particles colliding with the inside and with the outside of the balloon, rather than explaining that the average numbers of internal and ambient collisions were approximately the same. No drawings of particles were included, nor did he provide initial and final drawings.

In the second assignment, microscopic drawings were only provided for either the initial or final volumes (whichever was asked for) rather than both (Figure 5.5). However, when calculating V_1, he consistently stated there was no agreement between the macroscopic and microscopic drawings and his calculations, when in fact, there was. It appears that although he calculated initial volume, he would think that the answer gave him the final volume (Figure 5.5).


4. You observe a balloon shrinking in a high pressure barochamber from 6.4 L down to 4.2 L, where the final pressure is 100 cmHg. What was the original pressure inside of the barochamber?

a) V_1 = 6.4 L
V_2 = 4.2 L
P_2 = 100 cmHg

b) The pressure would increase.
macroscopic microscopic

particles.

ambient vs. internal

c) $\frac{V_2}{V_1} = \frac{P_1}{P_2}$ $P_1 = \frac{P_2 V_2}{V_1}$ $P_1 = \frac{(100\text{cmHg})(4.2\text{L})}{6.4\text{L}}$ P_1 = 65.6 cmHg

d) no, I predicted the pressure would increase, when it actully decreased.

- Your math actually supports your prediction.
- you predicted pressure would increase, and it did:

V_1 = 6.4 L, P_1 = 65.6 cmHg (Before) | V_1 = 4.2 L, P_2 = 100 cmHg (After)

Figure 5.5. Student response to assignment 2, incomplete microscopic representation showing difficulties with the interpretation of initial pressure (P_1). Student 59932.

5.3.6 Macroscopic description. Participant 38667 could predict if volumes or pressures increased or decreased by stating Boyle's Law. However, he had obvious difficulties translating and substituting formulas in more than half of the questions. Moreover, no internal or ambient particles were drawn, and there was no attempt to reconcile the representations (Figure 5.6). The two interpretations of this student's responses were macroscopic understanding only, or no conceptual understanding when the external examiners looked at the assignment as a whole.

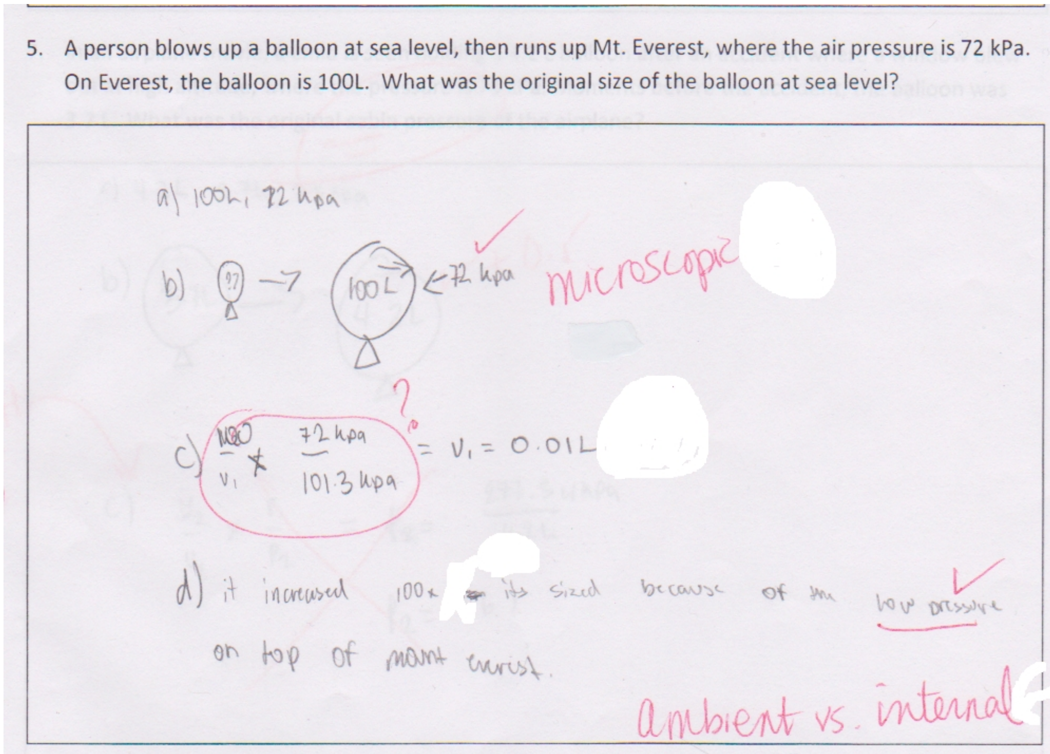


Figure 5.6. Student response to assignment 2, macroscopic understanding, no microscopic representation and calculation difficulties. Student 38667.

5.3.7 No conceptual understanding. One student was determined to have little–to-no conceptual understanding.

In the first assignment, Student 59562 completed only the calculations, and only those calculations with straight substitutions were correct. In the second assignment, the student wrote P↑ V ↓ for each question. Vague diagrams were drawn. There were no ambient particles drawn in any of the illustrative diagrams, which indicated an internal orientation of pressure rather than a systematic understanding. Also, the student rarely clarified which of his drawings represented the "before" and "after" macroscopic and microscopic drawings. In question 6 of the second assignment, pressure decreased thus volume should increase. The calculation showed that volume decreased (though it should have increased), yet next to the calculation P↑ V ↓ was written. The microscopic and macroscopic drawing showed internal particles only, with the balloon increasing in size. In many responses calculations were contrary to Boyle's Law and the drawings did or did not support the calculations. There was no attempt to reconcile the representations (Figure 5.7).

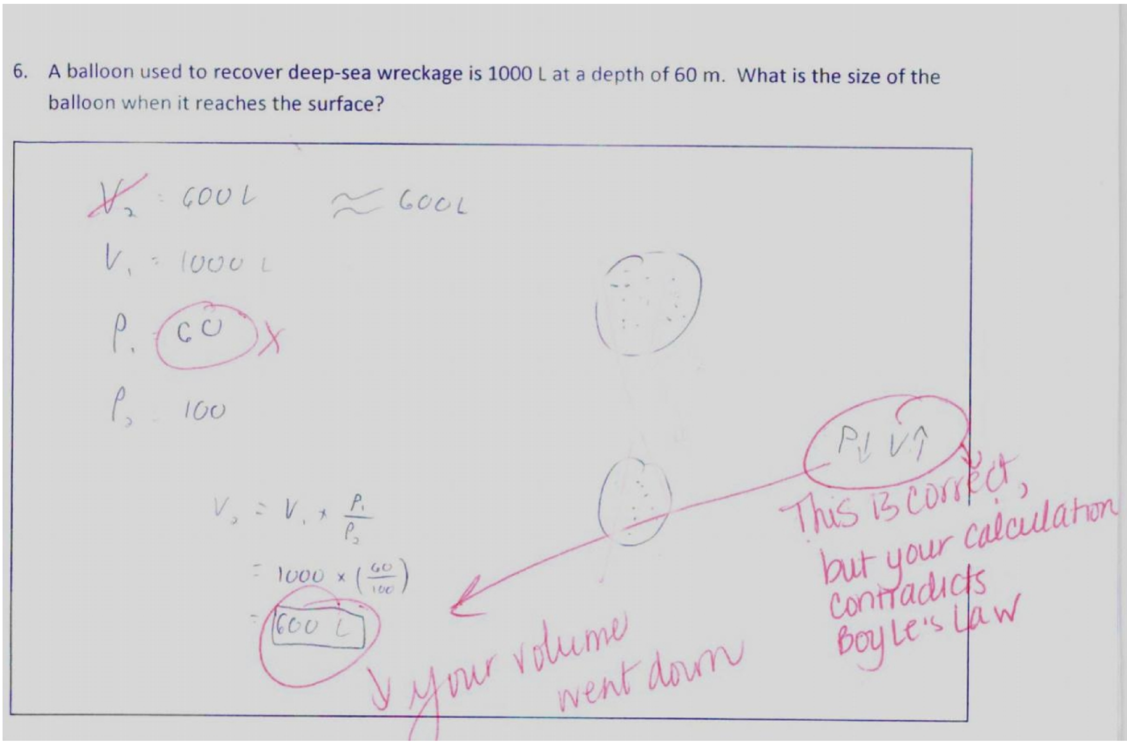
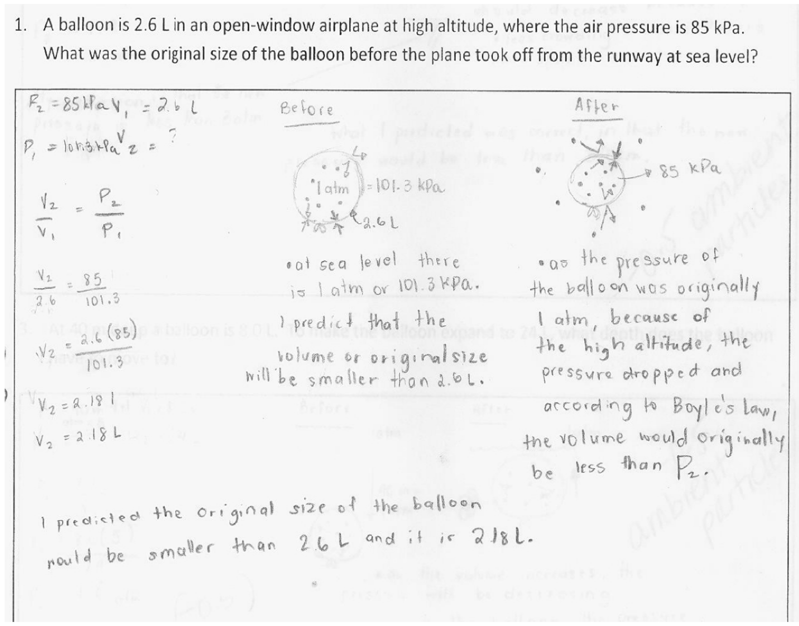
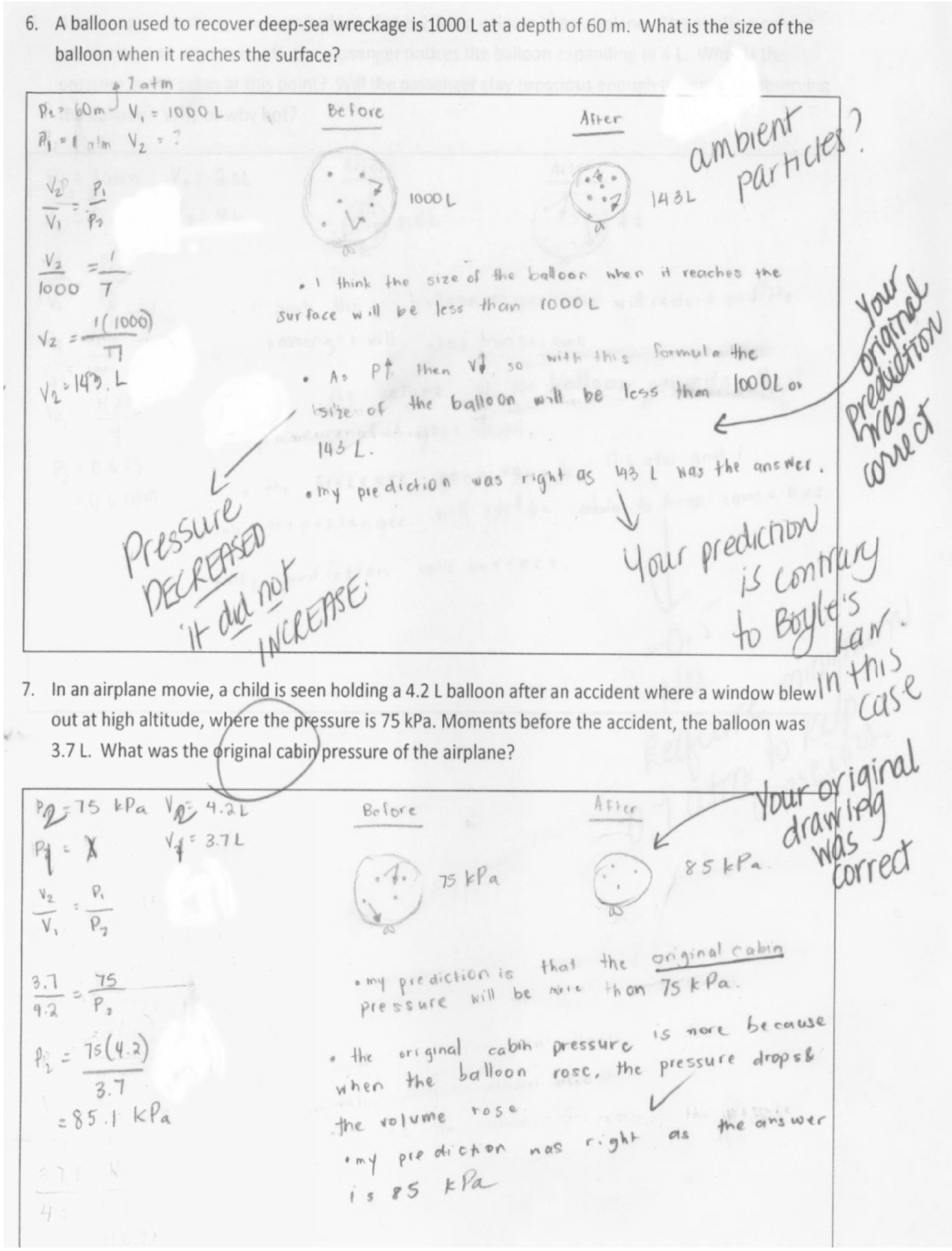


Figure 5.7. Student response to assignment 2, representative example of no conceptual understanding. Student 59562.

5.3.8 Indeterminate classification. One student (36843) was difficult to classify. She demonstrated conceptual understanding with agreement between representations (Figure 5.8a) in all but two questions (Figure 5.8b). When responding to question number 7 of the second assignment, she wrote the correct macroscopic and microscopic explanations and predicted the balloon would expand (Figure 5.8b), but this explanation contradicted her macroscopic, microscopic and symbolic drawings. When she calculated the answer to question 6, she reversed P_1 and P_2, thus calculating the balloon would shrink. As her macroscopic and microscopic explanations were in conflict with her calculations, she erased her macro/micro explanation, and changed it to fit her calculations (Figure 5.8b).



a) Example of conceptual understanding demonstrated by Student 36843.



b) Changing macroscopic and microscopic drawings to match incorrect calculations.

Figure 5.8. Student response to assignment 2, indeterminate classification. Student 36843.

It appears that she understood there should be agreement between the three representations. She has conceptual macroscopic and microscopic understanding as all of her macroscopic and microscopic explanations were in keeping with target models if she hadn't changed them. The decision she made to change her macro- and micro- explanations to fit her calculations indicated that she placed greater value on the symbolic representation. This will be discussed later in the chapter.

5.4 Student understanding of the interconnectedness between the three representations

5.4.1 Assignment 1. In assignment 1, except in the case of students with conceptual understanding, there was little evidence to suggest students understood that in order to meaningfully understand the scientific concept at hand, the interconnectedness of the three representations should be demonstrated. This was explained in class as looking for "agreement" between the three orientations.

A single student (77097), one of the top students in the class, demonstrated understanding of the interconnectedness of the three representations in assignment 1 (Figure 5.9). In question 5, she had provided a written explanation with diagrams to describe the macroscopic and microscopic representations. Her calculations, however, showed that the balloon would have shrunk. In her explanation, she pointed to her calculations and wrote, "I don't think this is right because it goes against my prediction." She clearly had conceptual understanding and could recognize there was something wrong with her mathematical manipulation. In this case, she had reversed P_1 and P_2.

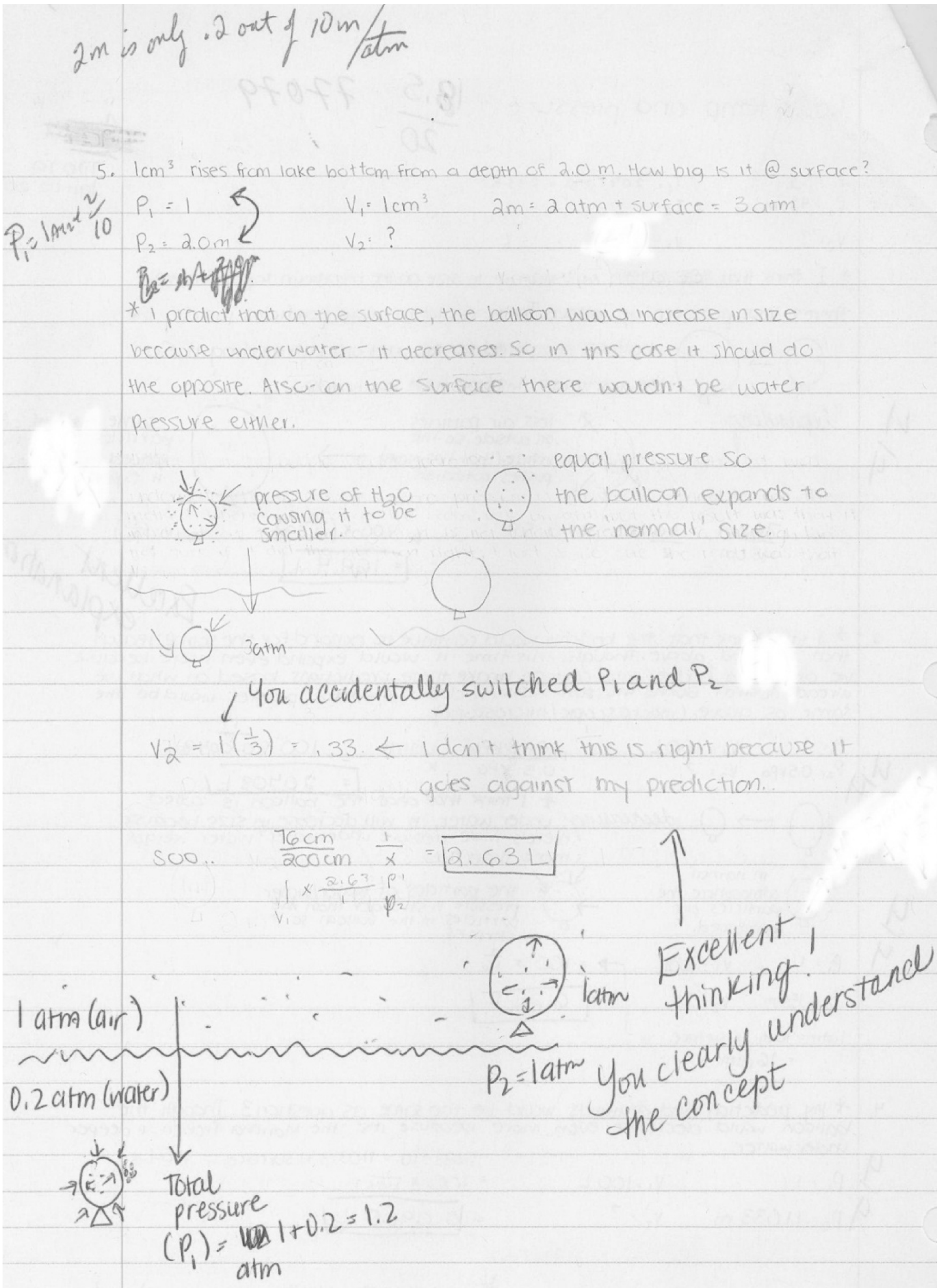


Figure 5.9. Student response to assignment 1, an example of understanding agreement between three representations. Student 77097.

Participants with conflicting representations either did not perceive the discrepancy between the representations, or did not try to reconcile discrepancies.

5.4.2 Assignment 2. In assignment 2 there was an attempt to have students discuss the relationship between the representations by having them write a prediction and look for agreement between their prediction and their answer.

One student (34988) who did not demonstrate microscopic understanding was able to fix her calculation based on pressure systems, Boyle's Law and macroscopic understandings (Figure 5.10). This suggests that she understood there should be agreement between representations.

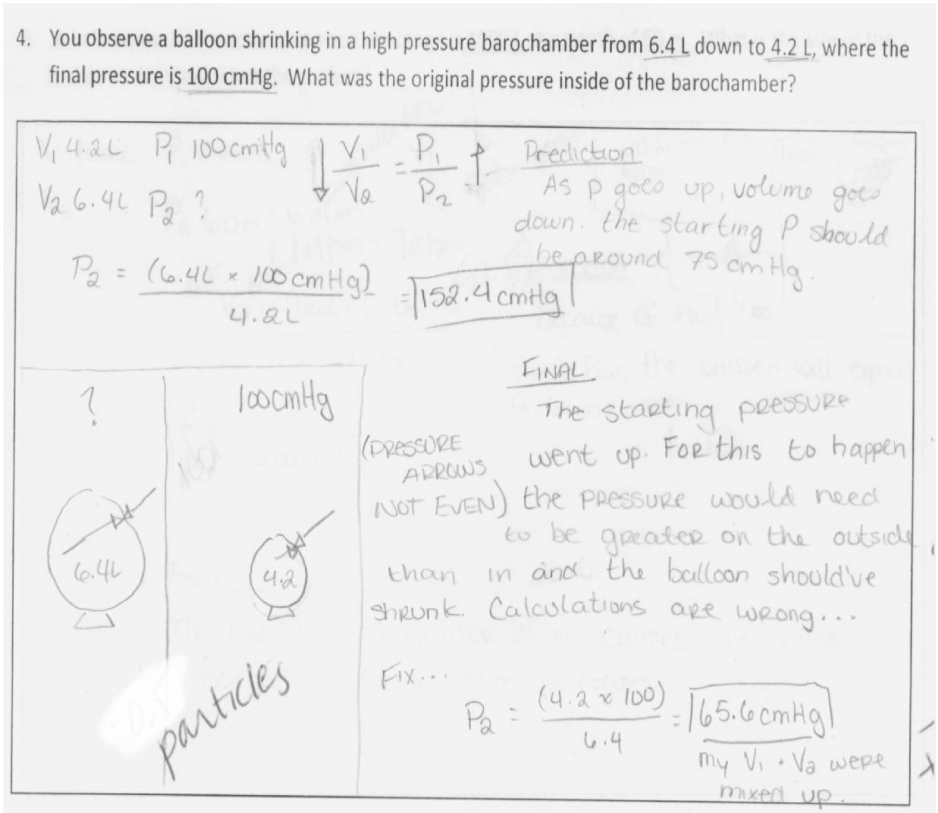


Figure 5.10. Student response to assignment 2, fixed calculations due to macroscopic understanding of Boyle's Law and pressure systems. Student (34988).

Though there was some improvement, as previously discussed, students with conflicting representations would write a simple statement stating that their predictions were not in agreement with their calculations or that their predictions were in agreement with their calculations, even if that wasn't the case, or they would change their macroscopic and microscopic representations to support their calculations.

5.4.3 Student use of the three representations as a gauge for science understanding. Unlike the previous experiences of the researcher described in the introduction, following the analysis of assignments 1 and 2 and discussions with the collaborating teacher, there was little evidence of students autonomously using the three representations to gage their understanding of pressure or Boyle's Law.

These results were not entirely unexpected as:

1. Student integration of the three representations in there models can be difficult for students (Chandrasegaran, Treagust and Mocerino, 2008; Gabel, 1999; Krajcik, 1991).
2. Though discussions were given by the collaborating teacher and researcher informing the students of the agreement required between the orientations, there were no written instructions and examples of work clearly showing integration, and no integration of the representations that would have helped students to understand the importance of the interconnectedness between the orientations.
3. As discussed in the introduction, the personal experience of the researcher showed that it took grade nine students approximately four additional weeks of instruction to establish a routine of using the three representations and analyzing their interconnectedness. Indeed, some of these grade nine students continued to have difficulties with this after two full instructional units.

5.5 Tentative evidence supporting the third level of analysis conducted by Chu, Treagust and Chandrasegaran (2008).

As previously discussed, Chu, Treagust and Chandrasegaran (2008) identified student understanding of physics knowledge as follows:

- Concepts: Physics knowledge is conceptual and often represented by formalism.
- Weak Concepts: Physics knowledge is conceptual, in principal, but conceptual content is not important for a basic understanding.
- Apparent Concepts: Physics knowledge is thought to be made up of a formalism that one can often associate with conceptual content. These conceptual associations are apparent but not essential; one makes connections as is obvious or convenient.

- Formalism: Physics knowledge consists of formulas (Ibid., p. 117).

Though direct evidence for the purpose of supporting Chu and his colleagues' analysis was not part of this study, there may be tentative links and indirect evidence from this study to support their findings.

5.5.1 Concepts. Students who had conceptual understanding, with all representations in agreement, may be identified as having this belief about physics knowledge. Two external examiners noticed that seven of the eight students demonstrating conceptual understanding drew macroscopic and microscopic visualizations first, then gave the calculations as suggested in the assignment instructions. One of these eight students completed calculations first, then provided macroscopic and microscopic explanations.

5.5.2 Weak concepts or apparent concepts. The work of Student 36843 may be an indicator of weak concepts or apparent concepts as she changed her macroscopic and microscopic representations to match her calculations. Though not specifically tested for in this study, it may be that in this case, the student believed that conceptual (macroscopic and microscopic) understanding is less important than formalism (symbolic), given that she changed her original, correct macroscopic and microscopic explanations to support her incorrect symbolic answer. If the predictions of other participating students disagreed with their calculations, there was little attempt to reconcile the representations, and the students simply wrote that their predictions disagreed.

In another example, Student 29425 consistently drew macroscopic drawings of balloons that contradicted her calculations. That is, if the mathematical calculation showed a decrease in volume, the drawing showed an increase in volume. There was no attempt to reconcile the representations in this case.

5.5.3 Formalism. There were indicators of formalism. Some students, for example, commented that they thought that it was “unnecessary” or “not as important” to create macroscopic and microscopic drawings as it was to ensure that the calculations were completed.

In the case discussed above, Student (30913) thought macroscopic and microscopic representations were unnecessary until he lost marks. Then, he learned to use macroscopic and microscopic representations because he was concerned about his marks, but not necessarily concerned about incomplete understanding of a physics concept. This could also indicate formalism.

Interestingly, students that may potentially have had weak concepts, apparent concepts or formalism mind sets towards science understanding appeared to complete the calculations first, then provide macroscopic and microscopic visualizations.

5.6 Mental models of pressure and Boyle’s Law. Identification of alternate conceptions.

As previously discussed, the alternate conceptions identified in these assignments were as follows:

- Direct pressure volume relationship (Basca and Grotzer, 2001; Anders and Guzzetti, 2005);
- Balloons maintain shape when number of internal and ambient particles are equal; and
- Internal pressure orientation (Basca and Grotzer, 2001).

Other difficulties with calculations (symbolic representation) included:

- Forgetting to add air pressure when calculating ambient pressure in scuba contexts.

- Understanding that V_1 and P_1 are the initial volumes and pressures respectively, and confusing them for final volumes and pressures, thus confusing macroscopic and microscopic "before" and "after" interpretations (for example, Student 59932, Figure 5.5 and Student 36843, Figure 5.8b, Question 7).

5.7 Pedagogical Implications

Results from this analysis support suggestions from the authors and writer of the Manitoba Chemistry Curriculum (MECY, 2006) that students show macroscopic and microscopic representations in their assignments.

Assessments based on the three representations can provide more detailed information about student understanding of pressure and Boyle's Law as opposed to traditional calculation questions. Specifically, it may help identify those students with good mathematical ability but poor macroscopic and microscopic understanding (a concern identified by de Berg, 1995). These types of assignments may also provide insights into consistent alternate conceptions that can be re-addressed by the teacher.

As suggested by Chandrasegaran, Treagust and Mocerino (2008), it is also important for students to understand the interconnectedness of the three representations, which requires consistent teacher modeling. In this case, there could be more discussion of the inter-relation of the three representations, and examples of completed questions that, in some cases, show good agreement within the representations and, in other cases, show conflict within the representations.

Three students showed large improvements in the quality of answers from assignment 1 to assignment 2. In these cases (and others), the students did not carefully consider how to draw diagrams using the three orientations and how to explain their answers. This evidence suggests that when designing assignments, the criteria for responses need to be clear and responses need to mention that all three representations are required and there must be agreement between the representations and written explanations. Also, students need practice responding to questions using the three representations even if the previous lessons had continually addressed concepts using the chemistry triplet.

5.8 Limitations

Various limitations to these assignments were identified through researcher observations of the collaborating teacher and observations of student discussions with the collaborating teacher.

5.8.1 Limitations of the assignment design. The design of the assignment in terms of instruction and types of questions were as follows.

5.8.1.1 Limitations in pre-assignment instructions. As previously discussed, in assignment 1 students were given verbal instructions to include the three representations. The teacher also reminded them that if the three representations were not in agreement, that there was a problem in understanding the concept. Many students did not write down these instructions, and may have ignored them for the first assignment. However, clarification questions, when answered, indicated that many students did understand that they were to show all three representations. Some students simply didn't believe that microscopic or macroscopic orientations were actually required to show understanding, while other students actually had difficulties understanding the content.

Furthermore, in assignment 1, there were no written directions expressly stating that students were required to show the interconnectedness of the representations. In assignment 2, there was an attempt to have students discuss the relationship between the representations by having them write a prediction, then compare their prediction with their answer and to look for agreement.

5.8.1.2 Limitations in question design – the humanistic representation. All the questions were abstract in nature, dealing with balloons rather than more applicable, real-world scenarios. Also, there were no questions asking students how they remembered the concept or what experiences they used to answer the assignment questions.

5.8.1.3 Limitations due to written responses. Some students, and EAL students in particular, have difficulty writing responses rather than verbalizing them, or using some other method of showing their understanding.

5.8.2 Limitations in analysis. Many times it was difficult to determine what a student was attempting to explain. Though the researcher and external examiners were able to come to consensus, these interpretations may not reflect the intent or cognition of the student.

5.8.3 Other considerations. Students were becoming exhausted as winter break was drawing near, and there were multiple tests and assignments not only in this class, but in others. In order to save time, the teacher suggested just showing a few "representative particles" which was interpreted by some students as showing water particles in the same way as air particles. These short-cuts made analysis and interpretation of microscopic drawings difficult.

Chapter 6: Analysis of Alternate Conceptions Pressure and Boyle's Law at the End of the Teaching Intervention

Seventeen tests were analyzed to determine stable alternate conceptions of pressure. To determine alternate conceptions, each question from post-test 1 was compared with analogous test questions. The analysis of student responses to post-test 1 by the external examiners was used to look for resonance.

There were two general types of stable alternate conceptions identified by external examiners. The first type of alternate conception appeared to be stable, and there was evidence to suggest that the conception was consistent across analogous questions and may have been used to solve other questions.

The second type of alternate conception appeared to be stable, but used in a specific context only (Adadan and Savasci, 2012) For example, one student demonstrated understanding of the target model for the syringe experiment. In the Boyle's Law syringe (in-class) experiment, she correctly predicted that as ambient pressure increased, internal pressure increased, thus increasing the number of internal collisions. Conversely, in the Boyle's Law cylinder (scuba) experiment, she predicted that as ambient pressure increased, internal pressure decreased, thus decreasing the number of internal collisions. These context-dependent alternate conceptions provide evidence of the two-perspective outcome (Freyberg and Osborne, 1985). Many of these types of alternate conceptions were identified. If more than one student demonstrated the alternate conception, the number of students doing so is shown in parentheses.

6.1 Alternate Conceptions of the Definition of Pressure

Fifteen of the seventeen students who wrote post-test 1 were able to identify the correct explanation of pressure. Two students demonstrated alternate conceptions of the definition of pressure as described by Basca and Grotzer (2001). These were, pressure is a force with a direction (1) and air pressure pushes down due to gravity (1).

6.2 Alternate Conceptions of Pressure Systems

6.2.1 Stable alternate conceptions. Students demonstrated alternate conceptions of pressure systems as discussed in Basca and Grotzer (2001). These included

- The internal pressure orientation. (2)
- Constancy in internal pressure regardless of increasing or decreasing changes in ambient pressure. (1)
- Identifying positive and negative pressure. (1)

6.2.2 Context-dependent alternate conceptions. The following alternate conceptions were demonstrated when answering questions about internal and ambient pressure in the scuba cylinder experiment. These students could correctly identify analogous questions in the in-class syringe experiment but showed consistent alternate conceptions in the scuba context. These conceptions are listed below:

- Total ambient pressure is equal to water pressure, rather than water pressure and atmospheric pressure combined. (The student correctly identified that total ambient pressure in the syringe experiment is equal to the pressure exerted by the student plus atmospheric pressure.) (3)
- Internal pressure remains the same with increased ambient pressure. (2)

- When ambient pressure increases, internal pressure (pressure of the air bubble) decreases, and there is a decrease in the average number of air particle collisions with inside surfaces. (1)
- Internal pressure (pressure of the air bubble) is equal to atmospheric pressure rather than water and atmospheric pressure. (1)
- External pressure orientation. (1)

6.3 Alternate Conceptions of Air Pressure

Two alternate conceptions of air pressure were identified. The first conception was that there is no air pressure (0atm) at cruising altitude. Though not directly addressed in the context of flight, de Berg (1991) observed the alternative conception that air does not exert pressure in a closed syringe, and Basca and Grotzer (2001) identified the alternate conception that air exerts no pressure. The second alternate conception, identified in two students, was "pressure increases with elevation" (Basca and Grotzer, 2001; Dove, 1998).

6.4 Alternate Conceptions of Changes in Density

6.4.1 Stable alternate conceptions. A stable alternate conception identified in one student was an inverse relationship between ambient pressure and density. This student answered analogous questions consistently in both the in-class syringe experiment and scuba experiments. Thus, when ambient pressure increased, spaces between air particles were identified as becoming larger (rather than smaller, owing to decreased air density rather than increased density); and when ambient pressure decreased, spaces between air particles become smaller (rather than larger, as a result of increased air density rather than decreased density).

6.4.2 Context-dependent alternate conceptions. One stable alternate conception that only applied to the scuba context was identified in two students. These students were able to explain increases and decreases in spaces between air particles during the syringe experiment, but in a scuba context, the air spaces between air particles were thought to remain the same during descent (that is, increased ambient pressure).

6.5 Determining Total Ambient and Internal Pressures

Students had difficulties determining total ambient pressure in both the syringe and scuba experiments. In the syringe (in-class) experiment, total ambient pressure is equal to the pressure exerted by the student plus atmospheric pressure. Thus, internal pressure of the confined gas is the same. In the scuba experiment, total ambient pressure is equal to water pressure plus atmospheric pressure. Thus the internal air pressure is the same.

6.5.1 Syringe experiment. One alternate conception that was consistent throughout the teaching intervention as identified in both assignments, the lab activity and the post-test was that students forgot to include air pressure in both calculations and written descriptions of ambient pressure in the syringe experiment. Three students thought that both internal and external pressure in the syringe experiment were due to the pressure exerted by the student only. Another alternate conception shown by one student was that total ambient pressure is equal to the pressure exerted by the student minus atmospheric pressure.

6.5.2 Cylinder (scuba) experiment. Three students thought that ambient pressure was equal to atmospheric pressure minus water pressure. One student thought that the pressure of the air space in the cylinder (internal pressure) was equal to atmospheric pressure only.

6.5.3 Stable alternate conception across contexts. One student consistently subtracted the external pressure from the other source. Thus, ambient pressure for the syringe experiment was equal to atmospheric pressure minus the pressure exerted by the student. Ambient pressure for the scuba experiment was equal to atmospheric pressure minus water pressure.

6.6 Alternate Conceptions of Pressure Systems of a Balloon

Three students demonstrated the alternate conception that there are the exact same number of internal and external air particles colliding against the internal and external surfaces of a balloon when internal and external pressures are the same (that is, the balloon is equalized, or does not change in volume). One student consistently thought that the internal pressure of balloon that did not change volume was 1 atm, regardless of the current ambient pressure.

6.7 Alternate Conceptions of Boyle's Law

Two stable alternate conceptions were identified with student understanding of pressure-volume relationships.

6.7.1 Direct pressure-volume relationship. Three students thought that pressure and volume were directly related. In other words, as pressure increased, volume increased; as pressure decreased, volume decreased. This evidence supports articles written by Basca and Grotzer (2001) and Anders and Guzzetti (2005).

6.7.2 Arithmetic rather than inverse proportional reasoning. The syringe and scuba experiment questions were adapted from de Berg (1995). In these questions, student understanding of 3:1 proportionality was tested by providing the correct answer and a distracter that was the average (arithmetic mean) between two stated pressure/volume points. Both answers were in the correct "range". Consistent with de Berg (1995) four students demonstrated arithmetic reasoning rather than proportional reasoning for questions with 3:1 ratios. These students could identify the correct answer for 2:1 or multiples of 2:1 proportions.

6.8 Agreement Between Three Representations

6.8.1 Macroscopic and microscopic understanding (incomplete symbolic). Three students were able to correctly identify macroscopic and microscopic visualizations of pressure systems in both the syringe and cylinder experiment but had difficulties estimating or calculating final pressures and volumes. This type of understanding was not identified in assignments 1 and 2. One student also showed this type of understanding of the representations, but in the scuba context only.

The discrepancy may be due to one or any number of the following:

- the assignments were not analyzed.
- the students understanding of the representations changed during the course of the teaching intervention.
- this theme was missed in the analysis by the evaluators.
- the criteria used to assign categories was not sufficient to identify this theme.
- analysis of the two-tiered multiple choice questions may not be the cognitive structures used by the students.

6.8.2 Macroscopic and symbolic understanding (incomplete microscopic understanding). Two students were identified that had difficulties with the microscopic representation. In one case, there was inconsistent microscopic understanding across contexts. In the other case, the student appeared to have difficulties visualizing particles, but if a number was attached to the diagram or explanation, the student could identify the correct answer.

6.8.3 Disconnect between macroscopic and microscopic representations. One student demonstrated a disconnect between macroscopic and microscopic representations in the context of increasing ambient pressure. In these questions, the correct microscopic choice was identified (increased density, increased collisions), but the macroscopic visualizations (through diagrams) were shown to decrease. This reasoning was consistent with the stable alternate conception of a direct relationship between ambient pressure and density as described above.

6.9 Analysis of Alternate Models from an Outcomes Perspective (Freyberg and Osborne, 1985)

Alternate models were analyzed through the lens of teacher-learner outcomes described in Freyberg and Osborne (1985).

6.9.1 Undisturbed children's science outcome. Three stable alternate models were identified in the students participating in this study. Research has also shown that these models are held by elementary and middle school students (Basca and Grotzer, 2001). Given that they were identified as being more-or-less stable for some of the high school students in this study, these models were classified as "undisturbed children's science outcomes" (Freyberg and Osborne, 1985). These alternative models are:

- Direct relationship between elevation and pressure (that is, pressure increases with elevation);

- Direct relationship between volume and pressure (that is, volume increases with increased pressure); and
- Internal pressure orientation (that is, pressure is viewed in terms of internal pressure only, rather than systematically).

6.9.2 Two-perspective outcome. For the purposes of this study, the two-perspective outcome was demonstrated when a student could answer questions in keeping with the target model, but reverted to their original, non-scientific conceptions when the situation could not be identified or when a student used an alternate model for specific contexts. The conceptions listed are stable and context bound and, in this study, they happen to be directly related to the undisturbed children's science outcome.

For example, one student could correctly identify pressure and volume relationships in the syringe experiments, some of the time. In her post-test analysis, the student pointed out questions where she "guessed". In the instances she was unsure as to the answers in this experiment, or when she "guessed", she used the alternate model that pressure and volume are proportional (pressure up, volume up). This model directly conflicted with her other answers that were in keeping with target models. Her intermittent use of the alternate model was also identified in assignment 2 and the Boyle's Law lab activity.

Another student demonstrated a unified scientific outcome in all but one context, the scuba experiment. In this case, internal pressure and air density (spaces between air particles) were thought to remain the same with increased ambient pressure (that is, upon descent). However, in the syringe experiment, the student could identify that internal pressure and density increased with increased ambient pressure. This context-bound alternate model was also observed in a different student who also showed a number of other alternate conceptions.

Another context-bound scuba alternate conception was observed in a proficient student who identified internal pressure and numbers of internal collisions decreasing with increased ambient pressure during descent.

6.9.3 The reinforced outcome. One alternate conception due to the design of the teaching intervention was identified.

Some students thought that when ambient and internal pressures were equal (gas on both sides), equal numbers of particles collided with internal and external surfaces, rather than the average numbers of collisions being equal on both surfaces. During the teaching intervention, models were drawn showing equal numbers of internal and ambient particles colliding with internal and external surfaces. Though the collaborating teacher explained the limitations of the drawings during class, some students still viewed the model as an exact replica of reality. This supports the findings of Thiele and Treagust (1991) and Treagust (1993). Rather than learning what the model represented, students learned the model.

6.9.4 The unified scientific outcome. No student received 100% on the test. However, students that exhibited a proficient understanding of target models, identified mistakes in the post-test analysis as "careless mistakes" or interpreted a question in a manner that was not intended, were identified as possessing a unified scientific outcome. Three students met this criteria.

It is also considered reasonable to suggest that students with one alternate conception that did not greatly affect overall understanding also present with a unified science outcome. For example, one student showed understanding of target models in all questions but one. In this case, the student forgot to add atmospheric pressure to the pressure exerted by the student during the syringe experiment. This would probably be easily clarified, and does not necessarily outweigh the understanding of target models the student possessed. The same could be said for the student who subtracted rather than added the air pressure in this same syringe experiment.

Finally, a case could be made for students who show one stable, context-bound alternate conception. As the alternate conception is context bound (e.g. scuba cylinder experiment), this does not necessarily mean the student does not have a unified scientific outcome in most instances. The degree to which alternate conceptions are acceptable is difficult to determine and would ostensibly be different for different investigators. Also, Hazma and Wickman (2007) suggest that despite the presence of alternate conceptions, further understanding of target models may not be inhibited and these conceptions can, in fact, be considered a temporary bridge to link concepts together until a better model can be used to replace the alternate conceptions.

If these participants are included, the number of students achieving a unified science outcome would rise to eight. Seven of these students are normally recipients of grades in the range of A- to A+, and consistently showed proficiency (to a greater or lesser extent) in model building. The eighth student did not score well on the first two assignments, then realized he was required show microscopic and submicroscopic understanding to receive good marks in the class.

6.9.5 The confused outcome. Students presenting a confused outcome showed both stable models, and incoherent, unstable, fragmented (p-prisms) and context bound models. Stable models were identified as described above. If a student didn't answer sets of analogous questions in a consistent manner, this was taken as evidence of unstable fragmented models. In one case, during post-test analysis, a student indicated that he kept "changing his mind". Another student indicated that he had "no idea what was going on" as he hadn't studied. These indicators were also taken into consideration when making this confused outcome designation.

A third student showed two stable alternate conceptions, one context-bound conception, and what appeared to be many instances of inconsistency between analogous questions. This student indicated, like the first student in this category, that he was uncertain and continuously "changing his mind". He also showed limited understanding of target models when responding to assignments.

6.9.6 Other. In some cases, it was difficult to determine the types of outcomes that a student may hold. For instance, the two EAL students identified as having deficits in conversational English also presented with confused outcomes. One of these students appeared to have been able to successfully answer questions that were phrased similarly to the teacher's everyday speech or notes, but could not answer the re-phrased question. In these cases, it was difficult to determine if there was truly a confused outcome or if there were issues relating to the language barrier. Both students were allowed to bring translators and to ask the collaborating teacher for help with translation, but chose not to do either.

6.10 Summary

6.10.1 Alternate conceptions. Students that participated in this study showed the alternate conceptions identified in the literature (Basca and Grotzer, 2001; de Berg, 1995; Dove, 1998). Furthermore, there is evidence to suggest that alternate models may have various characteristics in terms of stability and use. In this study, there was evidence of stable and theory-like alternate models; stable and theory-like contextual alternate models; and fragmented, inconsistent and contextual alternate models (reviewed in Adadan ans Savasci, 2012). Many of the alternate conceptions were tenacious and remained unchanged despite the teaching intervention.

6.10.2 Use of the two-tiered diagnostic. Evidence from this study supports many of the advantages of two-tiered diagnostic assessments described in articles by other authors (reviewed in Adadan and Savasci, 2012; Akkus, Kadayifci and Atasoy, 2011). In this case, the use of the two-tiered diagnostic provided insights into student alternative conceptions and reasoning, could be administered to large groups and, for school purposes, was easy to mark.

6.10.3 Outcomes perspective for analyzing alternate models. There is evidence to support the outcomes described by Freyberg and Osborne (1985). This also provided a useful framework for analyzing alternate models. As explained by the authors (Freyberg and Osborne, 1985), evidence from this study also suggests that these outcomes are not mutually exclusive, and students may hold conceptions stemming from each of the outcomes simultaneously.

6.11 Limitations

6.11.1 Internal consistency and reliability. Cronbach's alpha coefficient (Cronbach, 1975) was not determined for the two-tiered multiple choice test. Thus, there is no measure of internal consistency and reliability. The minimum sample size suggested by Yurdugul (2008) is n=100. As there was only 21 participants in the study, an unbiased estimation of the alpha coefficient would not be possible (Yurdugul, 2008).

6.11.2 Identification of alternate models. Given the vast amount of data, the chaotic nature of finding trends due to the randomization of questions, and the contributing perceptions via third-party analysis (analysis was done through the collaborating teacher, researcher and external examiners, where the researcher and external examiners had little-to-no contact with the students), identification of alternative conceptions was difficult. Some may have been missed and misinterpretations of student responses may have occurred.

Chapter 7: Alternate Conceptions of Pressure and Boyle's Law in Scuba and Flight Contexts at the End of the Teaching Intervention

In this chapter, alternate conceptions of pressure and Boyle's Law in the context of scuba diving and flying in an airplane that were held by students at the end of the teaching intervention, and the results of the teaching intervention analyzed through Freyberg and Osborne's (1985) outcomes are described.

7.1 Comparison of Post-Test 3 Written Answers and Analogous Multiple Choice Questions from Post-Test 2

7.1.1 General comparison between post-test 3 (written) and post-test 2 (multiple choice). For the most part, there was resonance found between written answers about ear squeeze and equalization during flight ascent and scuba descent when comparing responses in post-test 2 and post-test 3. That is, students who showed understanding of target models in both contexts consistently showed understanding in both written and multiple choice responses. Conversely, if a student showed little understanding of pressure imbalances and equalization in post-test 3, they showed little understanding of the same concepts in the same contexts in post-test 2. Furthermore, alternate anchoring conceptions such as "air pressure increases with elevation" were consistent between post-test 2 and post-test 3, and students identified with a two-model outcome through written responses answered consistently between post-tests 2 and 3.

There was one case, Student 69297, where there was a discrepancy between the written response in post-test 3 and the analogous questions in post-test 2. In post-test 3, the student's drawings indicated little understanding of ear anatomy, and she did not include the middle ear in her diagram. However, she had a clear understanding of the movement of the tympanum given relative internal and ambient pressures. In the analogous questions in post-test 2, all of the correct answers were chosen.

In the case of EAL students who participated in this study, analysis of two-tiered multiple choice tests (post-test 2) provided evidence of student cognition and alternate conceptions above and beyond the long-answer written responses from post-test 3. This is described in the section below.

7.1.2 Anlaysis of EAL student post-tests. Four students identified as EAL, two of whom were identified with major difficulties speaking and understanding conversational English. In these cases, it appeared that analysis of the two-tiered multiple choice questions gave more insight into alternate conceptions than the long-answer questions.

7.1.2.1 Student 11252. As one example, for the written long answer responses in post-test 3 (Appendix C), Student 11252 was able to draw the correct structures (ear canal, tympanum, middle ear and Eustachian tube) for both the flight and diving questions. However, the tympanum was always shown in the vertical or "equalized" position even if ear squeeze was occurring. There were no microscopic or symbolic representations and no written explanations. The conception that the tympanum is always in the vertical position was confirmed by both the drawings in post-test 3 and the distracters chosen in post-test 2. However, using post-test 3 only, details concerning anchoring conceptions and alternate models could be identified.

The multiple choice test revealed that this student fairly consistently chose distracters indicating there were three alternate anchoring conceptions. These three alternate conceptions were pieced together to form a stable, alternate model used to answer ear equalization questions in both the scuba and flight contexts. This student held the following anchoring conceptions:

1. The tympanum acts like a "door", or is permeable and allows air or water through;
2. Internal and ambient pressures are equalized by reducing positive pressure only, regardless if the middle ear is experiencing positive or negative pressure; and
3. The tympanum was always in the vertical position, whether there is an imbalance between ambient and internal pressure or not.

Ear equalization normally occurs by adding air to the middle ear during descent (because the middle ear is negative compared to ambient pressure) and releasing air from the middle ear during descent (because the middle ear pressure is negative).

From the perspective of Student 11252, if ambient pressure (air pressure) increased (or was positive) and internal pressure (middle ear pressure) was negative, air flowed through the ear drum until ambient and middle ear pressure was equal. During ascent, pressure was taken away from the positive space, whether it was internal or ambient, by water or air flowing through the ear drum for equalization.

When answering questions about the causes of reverse block, this student thought that during ascent while scuba diving reverse block was caused by the ear drum swelling and water being unable to leave the middle ear through the ear drum for equalization. In the case of reverse block during flight descent, air could not move through the ear drum because it was swollen, thus preventing equalization. In the scuba context, this student chose options showing that equalization could not occur because positive pressure could not be relieved by water or air flowing though the ear drum.

Ultimately, both tests revealed that the student had very little macroscopic, microscopic and symbolic understanding of ear equalization. However, alternate models were more readily revealed through the analysis of the two-tiered multiple choice test.

7.1.2.2 Student 62357. In post-test 3, Student 62357 provided diagrams with incorrect microscopic drawings for the flight ascent question and provided no macroscopic visualization for the scuba descent question. In the flight ascent question, the macroscopic drawings of the ear drum showed that this student held the alternate conception of air pressure increasing during ascent. Macroscopic drawings of the tympanum at equalization were correct and were described in terms of internal and ambient pressures only. However, there was no indication of how or where air flowed for equalization to occur.

Analysis of post-test 2 confirmed difficulties with microscopic visualization as the student did not answer questions about microscopic representations or chose distracters in an inconsistent manner. In the case of ear squeeze during ascent in both the scuba and flight contexts and reverse block during ascent in the scuba context, the student chose macroscopic, microscopic and symbolic representations that were consistent with the conception that air pressure increased during ascent.

During equalization, diagrams written in post-test 3 showed that the student understood the tympanum is straight when equalized, and that the numerical value of the internal and ambient pressures are equal. However, no explanations or microscopic representations were given in these contexts, indicating the student had little microscopic understanding, which again supported evidence from post-test 3.

Analysis of post-test 2 also revealed that the student believed that the tympanum acted like a "door" or was permeable and allowed air through but only in the context of flight. The student consistently chose distracters indicating that air moved through the tympanum during flight, but not in the scuba context.

Consistencies between the two tests revealed that the student had very little microscopic understanding of ear equalization, and held the anchoring conception that air pressure increases with elevation. As with the previous EAL student, macroscopic conceptions of ear squeeze during ascent in both the scuba and flight contexts were revealed through the analysis of the two-tiered multiple choice post-test (post-test 2) rather than the long-answer post-test (post-test 3).

7.1.2.3 Student 81886. In post-test 3, Student 81886 only provided diagrams of the equalized ear at 1 atm. The student was able to identify that the tympanum was straight when equalized and that internal and external pressures were equal. The only microscopic representation shown was in this first diagram (equalized ear at the surface), with equal numbers of air particles on either side of the ear drum. No other macroscopic or microscopic visualizations were given when explaining ear squeeze and re-equalization.

When explaining ear squeeze during ascent, the only written explanation was that ambient pressure increased with elevation. This was a long-standing alternate conception demonstrated from the beginning of the course for this student.

Comparison of post-test 3 to post-test 2 confirmed the student held the alternate anchoring conception that "pressure increased with elevation" and demonstrated little microscopic understanding. However, analysis of the post-test 2 also revealed that this student consistently chose distracters indicating that air and water moved through the ear drum in order for equalization to occur. The anchoring conception that "the ear drum acts like a door or is permeable" may not have been demonstrated in post-test 3 because the student did not have the English skills to write an explanation of her conceptions.

Many of the questions in post-test 2 were answered inconsistently amongst analogous questions. The collaborating teacher noted that when this student answered multiple choice questions that were worded using the "common language" used in class, the student generally scored better than when answering the analogous questions that may have used more technical wording, or phrasing that was not common in his classroom. Thus, this student may have been inconsistent in answering two-tiered multiple choice questions due to language difficulties. In this case, it was not easy to determine other anchoring conceptions as it was not clear that the student had many unstable or p-prism conceptions or that the choices were a result of difficulties with English, or both.

7.1.3 Potential advantages for using the two-tiered multiple choice method for EAL students. In the cases of the three EAL students with deficits in reading, writing, listening and speaking skills (four core language skills), the two-tiered multiple choice tests appeared to be more informative than having the students write long-answer responses. This may be a result of the students having better reading strategies than vocabulary and writing skills. Thus, these students may have been able to locate the answers they were looking for within the body of the question but, as they have limited vocabulary and writing skills, were not able to express their ideas in long-answer format, or to make a knowledge transfer if different vocabulary is used (D.L. Savage, personal communication, December 2, 2012). Based on the assumption that the EAL participants had significant exposure to the common subject matter language used in the classroom, one could assume that the students, using basic reading strategies, would be able to answer multiple choice questions with greater ease if those questions also used the common language of instruction. Likewise, the students would have greater difficulty making a knowledge transfer from the common, expository language to a technical term of the same meaning. As Ms. Savage explains:

> In regard to mastering English in the four measurable areas (listening, speaking, reading and writing), students will often appear to have a higher mastery in reading than the other skills, especially in areas in which they have prior experience, knowledge or interest. For example, if a Chinese student is proficient in math in their first language, they will have an easier time transferring that knowledge to English when reading a word problem or a math question. However, if they hear the same question and have to respond verbally, they will have more difficulty doing so because they cannot see the question in written form and make the correlation to Chinese. A chemistry question in Chinese and English will use the same formulas but obviously different vocabulary. However, the Chinese student when reading the problem will be able to recognize the equation being asked of them versus a situation where a student has to read a paragraph about the Canadian education system (which they have don't have a contextual reference for) and then answer corresponding comprehension questions.
>
> To expand on this idea, if you gave a student a multiple choice math or science quiz and a long answer math or science test in their second language, they will score higher on the multiple choice test, even if the questions are the same, because they have the ability to read the problem and find the corresponding answer, but they don't have the vocabulary or the written skills to explain their answer in

their second language on the written test. Thus, the two-tier multiple choice questions may provide better indicators of conceptions for EAL students.

7.2 Alternate Conceptions

7.2.1 Ear anatomy and physiology. Students' alternative conceptions about ear anatomy and physiology were consistent with the conceptions found in certified divers and students in the second, third and fourth sessions of the scuba project. The numbers of students identified with these conceptions are identified in parentheses:

- Mucus is found in the middle ear. (2)
- The popping sound during equalization is due to the tympanum popping into place during equalization. (4)
- The popping sound during equalization is due to the middle ear popping into shape. (2)
- The popping sound during equalization is due to the ear canal popping out air or water. (3)
- The tympanum acts as a gateway or is permeable. Air enters and leaves the middle ear through the ear drum. (3)

The alternate conception that the tympanum acts like a gateway or was permeable was found in this study, as well as in previous sessions of the scuba program. In previous sessions of the program, this alternate conception was often found to be coupled with the alternate conception that the tympanum popped (or "swung") back into place during equalization. In this study, only one person held both of these alternate conceptions simultaneously.

7.2.2 Pressure imbalance and equalization. Alternate conceptions of the general (non-context specific) definition of squeeze, equalization (non-context specific) and mask squeeze (scuba specific) were as follows:

7.2.2.1 Definition of squeeze and locations. Most students correctly identified the definition of squeeze, its cause (that is, a pressure imbalance) and the most common areas affected by squeeze while scuba diving. One person identified the definition of squeeze as the bends, and two people identified squeeze as hypoxia. Both students who identified squeeze as hypoxia were EAL students. Language proficiency may have been a factor when answering this question for these students.

A majority of the participating students were able to correctly identify common areas for squeeze to occur. However, three people identified the lungs as being affected by squeeze.

7.2.2.2 Mask squeeze and equalization. Mask squeeze is caused during descent while scuba diving. Ambient pressure is greater than mask pressure, so the mask pushes on the face, which may result in bruising. To equalize mask pressure, air is exhaled through the nose into the mask.

Alternate conceptions of mask squeeze were as follows:

- Squeeze occurs during ascent. (4)
- Mask pressure is greater than ambient pressure. (3)
- Water is added or subtracted from the mask for equalization to occur. (2)

One student (36843) that identified mask pressure as being greater than ambient pressure also thought that mask squeeze occurred during ascent. The student consistently answered that in order for equalization to occur, air needed to be added to the mask. This choice was inconsistent with the alternate conception that mask pressure was greater than ambient pressure. It was also inconsistent with squeeze occurring during ascent. There appeared to be no microscopic understanding in this context.

Two other students (77079, 46682) who also thought that mask squeeze occurred during ascent identified the mask as having negative pressure compared to ambient pressure. These students identified that air needed to be added to the mask. It may be that the students viewed ascent with decreasing mask pressure (that is, while ascending, pressure decreases, thus, the mask pressure decreases). In this case, both the identification of negative mask pressure and equalization by adding air to the mask would be consistent with this alternate conception.

The three students who identified that mask pressure was greater than ambient pressure also identified that air needed to be inhaled out of the mask to equalize pressure. This was consistent with the tenets of their alternate conceptions. That is, mask pressure was positive and ambient pressure was negative, thus, to decrease positive pressure, air is inhaled out of the mask through the nose.

Student 62357 was able to identify that mask squeeze occurred during descent, and that mask pressure was negative and air need to be added to the mask. However, in question number 34, the student identified that the mask had positive pressure, and air needed to be inhaled out of the mask. In question number 34, students look at a diver with extreme mask squeeze. This student appeared to associate this with greater internal (mask) pressure, and consequently chose inhaling air out of the mask was required for equalization. This phenomenon was observed with one other student (22724).

Two students (26951 and 81886) thought that mask equalization occurred by adding or subtracting water molecules from the mask. One student thought that mask squeeze occurred due to equal but increased ambient and internal pressures.

7.2.2.3 Equalization procedures. Students were tested for their knowledge of equalization procedures. Normally, ear equalizations should occur continually, before pain starts, and gently. If a diver has difficulty equalizing during descent, the diver should ascend to *decrease* ambient pressure on the ear drum, equalize, and then try the descending again. If a diver has difficulty equalizing during ascent, the diver should descend, to *increase* ambient pressure on the ear drum, equalize, and then try ascending again.

When to equalize. Two participants thought that equalization should occur when a diver starts to feel pain.

Procedures when having difficulty equalizing during ascent and descent. Two participating students (26951 and 11252) had similar alternate conceptions of equalization, where it was assumed that in the case of difficulty when equalization, forceful equalizations were required. Though they were able to determine that a short ascent was required when descending, or a short descent was required when ascending, both participants also thought that, in either case, this action was required to *decrease* water pressure against the ear drum.

Another student appeared to have two models for ascent and descent procedures. The student was able to pick the correct action and rationale in the case of descent. When encountering difficulties during ascent, the student was also able to identify that a diver should descend; however, the rationale chosen was that this decreases water pressure against the ear drum, and short forceful equalizations were required.

7.2.3 Pulmonary barotrauma, and physiological effects of unequal pressure. Alternate conceptions regarding the physiological effects of unequal pressure systems were analyzed in two contexts:

1. Lung over-expansion sicknesses due to breath holding during ascent while scuba diving, and
2. Hypoxia due to rapid cabin pressurization at cruising altitude during flight.

7.2.3.1 Lung over-expansion (scuba context). Lung-overexpansion sicknesses such as pulmonary embolism and pneumothorax are caused by scuba divers holding their breath during ascent. As ambient pressure decreases, lung volume increases, which over expands the lungs, and may cause tears. Three students (11252, 81886 and 34988) held the alternate conception that the lungs would compress rather than expand.

7.2.3.2 Hypoxia (flight context). In rapid cabin depressurization, cabin pressure suddenly decreases to below optimal pressures for comfortable breathing. Once air leaves the lungs upon exhale, the cabin pressure is not enough to ensure adequate oxygen supply, causing shortness of breath and eventual unconsciousness. This condition is called hypoxia.

Two students (30913 and 81886) held the alternate conception that during rapid cabin depressurization, cabin pressure is positive and lung pressure is negative resulting in lung collapse. One student (62533) thought that original lung pressure was maintained, and air flowed from negative to positive pressure.

7.2.4 Mechanisms to ensure proper lung pressure during scuba and flight.

7.2.4.1 Function of the second stage regulator. To ensure proper air pressure to the lungs during scuba diving, high-pressure gas from the scuba tank is reduced by the second stage regulator to maintain lung pressure close to the surrounding pressure.

The following alternate conceptions about the second stage regulator were observed, with the number of students with the alternate conception in parentheses:

- Maintain the same air pressure as the tank. (4)
- Increases pressure from tank to lungs. (3)
- Maintain the lungs at surface atmospheric pressure. (1)
- Increase lung pressure to greater than the surrounding pressure. (1)

7.2.4.2 Function of cabin pressurization. The function of cabin pressurization is to maintain cabin pressure as close to1 atm without going over internal-to-ambient pressure tolerances. At various cruising altitudes, ambient air pressure is low, and can cause various physiological ailments such as hypoxia, altitude sickness, decompression sickness, and ear and tooth barotrauma. Compressed air is pumped into the fuselage so that normal breathing is maintained. Six participants held the alternate conception that the function of pressurization was to maintain the cabin pressure at cruising altitude rather than closer to sea level (or 1 atm).

7.2.5 Alternate models of reverse block. Reverse block occurs when the Eustachian tube is swollen and cannot open, thus, equalization of the middle ear cannot occur. If a scuba diver has a cold and takes medicine to reduce swelling in the sinuses, there is a danger that the medicine will wear out during a dive. Thus, when ascending at the end of the dive, the Eustachian tube becomes swollen again and cannot open to release air out of the middle ear.

During an airline flight, reverse block usually occurs during descent and landing. If a passenger takes a flight and uses cold medicine that wears off during the flight, when the plane descends, the Eustachian tubes cannot open to let air into the middle ear.

Reverse block in these two contexts (scuba and flight) were tested. Alternate conceptions of the physiology of reverse block were as follows, with the number of students with the alternate conception in parentheses:

- The middle ear cannot pop back into shape. (3)
- Ear drum is swollen preventing equalization. (2)
- Air cannot leave the sinuses. (2)

7.2.6 Alternate Models of Ear Squeeze.

7.2.6.1 Alternate models of ear squeeze during descent (increased ambient pressure). Generally the ear squeeze questions during descent in both the scuba and flight contexts were answered in keeping with target models.

7.2.6.2 Alternate models of ear squeeze during ascent (decreased ambient pressure).

Ear squeeze at decreased ambient pressure – scuba and flight contexts. One student (59932) consistently chose distracters indicating that air is added to the middle ear during ascent in both the flight and scuba contexts. In this case, the alternate model that air is added to the positive space (middle ear) during decreased ambient pressure was applied to both the scuba and flight contexts.

Furthermore, when answering questions about equalization during rapid cabin depressurization, the student was correctly able to identify that at altitude cabin pressure decreases (or is negative) and lung pressure is positive. However, the student also predicted that when cabin and lung pressure were equalized, air would be added to the lungs rather than released from the lungs.

This alternate conception may have stemmed from the alternate conception that ambient pressure increases with elevation. In question #29, the student selected the response that a balloon would become three times larger during ascent. However, the student also selected the microscopic option stating that that ambient pressure became greater during ascent rather than less. For this student, in the context of equalization during ascent, there appeared to be a tenacious alternate conception that ambient pressure increases. The conflict between macroscopic and microscopic visualizations was not resolved.

Ear squeeze at decreased ambient pressure - flight context only. Four students (26951, 81886, 62357, 36843) held the alternate anchoring conception that pressure increased with elevation in the context of flight only.

Alternate conceptions of ear squeeze, flight context, both increasing and decreasing ambient pressure. For both ascent and descent during flight, Student 36494 reversed internal and ambient air particle densities.

7.2.7 Alternate Models of Ear Equalization. Alternate models of ear equalization during descent in both the scuba and flight contexts were also answered by most students in keeping with target models. Alternate models of ear equalization during ascent were observed in both scuba and flight contests.

7.2.7.1 Equalization during ascent (decreased ambient pressure).

Scuba context. In post-test 2, Student 59962 chose macroscopic, microscopic and symbolic distractors indicating that pressure increased during ascent in a scuba context, but was able to correctly answer questions about ascent during flight.

Student 29425 also chose distractors and gave a written explanation demonstrating the anchoring conception that "pressure increases during with elevation" in the scuba context only. When compared to post-test 3, this anchoring conception was also demonstrated in the ear squeeze and equalization question about ascent during flight. However, this student was able to answer similar questions on post-test 2 correctly.

Flight context. As previously discussed, four students (26951, 81886, 62357 and 36843) were identified with having alternate conceptions for ascent in the flight context only. These students held the anchoring conception that pressure increased with increased elevation, and they selected microscopic and macroscopic representations consistent with this alternate conception.

Alternate models of ascent for both scuba and flight contexts. Student 59562 appeared to have two models for equalization. In questions about equalization during descent, the student could accurately predict how ears are equalized in both the scuba and flight contexts. However, in questions involving ear equalization during ascent, an alternate model was used in both the scuba and flight contexts,

For ear equalization during flight ascent, the student accurately showed ambient and middle ear pressure differences using all three representations in both post-test 3 and 2. That is, ambient pressure was negative (or less) and middle ear pressure was positive (or more). The ear drum was also in the convex (correct) position. Yet both written and multiple choice answers show that the student believed that air is added to the middle ear rather than taken away for equalization to occur. In this case, the alternate anchoring conception is that in order for equalization to occur air is added to positive pressure when ambient pressure decreases. This alternate conception of equalization during ascent was also shown in the scuba context in both the ear equalization question and the action to take if there are difficulties in ear equalization during ascent. Furthermore, when answering questions about equalization during rapid cabin depressurization, the student was correctly able to identify that at altitude cabin pressure decreases (or is negative) and lung pressure is positive. However, the student also predicted that when cabin and lung pressure were equalized, air would be added to the lungs rather than released from the lungs. This alternate conception may have stemmed from the alternate conception that ambient pressure increases with elevation, as described by Freyberg and Osborne (1985). In question #29, the student selected that during ascent a balloon would become three times larger, however, the student also picked the microscopic option stating that that ambient pressure became greater during ascent rather than less. For this student, in the context of equalization during ascent, there appeared to be a tenacious alternate conception that ambient pressure increases with elevation. The conflict between macroscopic and microscopic visualizations was not resolved.

Student 36494 had difficulties with microscopic visualization in the reversed particle densities for the ear squeeze problems during flight. Evidence from assignments 1 and 2, and from written explanations in the process-folio suggests that this student had some difficulties with microscopic visualization throughout the course.

Student 29425 was identified as having with a two-model outcome (in this case, one model for flight ascent and a different model for scuba ascent) which was confirmed through written responses in post-test 3 distracters chosen from post-test 2.

Student 29425was able to explain and answer questions about ear equalization during descent in both the scuba and flight contexts according to target models. For ear equalization during flight ascent, the student accurately showed ambient and middle ear pressure differences using all three representations in both post-test 3 and 2. That is, ambient pressure was negative (or less) and middle ear pressure was positive (or more). The ear drum was also in the convex (correct) position. Yet both written and multiple choice answers show that the student believed that air is added to the middle ear rather than taken away for equalization to occur. This alternate conception of equalization during ascent was also shown in the scuba context in both the ear equalization question and the action to take if there are difficulties in ear equalization during ascent.

Student 62533 maintained an alternate model where air passes in and out of the ear drum in the context of flight only. Target models involving the opening and closing of the Eustachian tube were chosen in the context of scuba diving for both ascent and descent. The alternate model where air passes in and out of the ear drum during pressure differences on land had also been observed in informal interviews with a certified diver in the first session of the scuba program.

7.3 Analysis of Alternate Models from Freyberg and Osborne's (1985) Outcomes Perspective

7.3.1 Undisturbed children's science outcome. The most common undisturbed children's science outcome identified in post-tests 2and 3 was pressure increases with elevation (Dove, 1998), and an internal reasoning of pressure or internal pressure orientation as described by Basca and Grotzer (2003).

Two undisturbed outcomes, or tenacious anchoring conceptions identified in three students were that the eardrum was permeable or acted like a "door", letting air in and out of the middle ear. For these students, the role of the Eustachian tube was not understood.

7.3.2 The two-perspective outcome.

There were many two-perspective outcomes described in previous sections of this chapter, where different models were used in different contexts. It appears that if the context was unclear to the students, initial alternate models would be reverted to.

7.3.3 The reinforced outcome.

One alternate conception that was a direct result of the methods used to teach pressure concepts was identified. It is an extension of the reinforced alternate conception of pressure systems discussed in Chapter 4.

During ear squeeze, the concave or convex position of the tympanum occurs because of the differences in internal and ambient pressures, however, the pressures on either side of the tympanum are actually equal (refer to question 8 as an example, Appendix D). Thus, although the "correct" answer is "f", the actual ambient and internal pressures are 1.5 atm. The reason why the difference was noted was to help students understand why the change occurred. However, despite the collaborating teacher discussing the limitations of this model, students may have an alternate conception that actual pressure differences during ear squeeze exist.

7.3.4 The unified scientific outcome. Four students (26951, 27536, 30913, 368433) were categorized as having a unified scientific outcome. In the case of Students 26951, 27536 and 30913, errors were few, with only one or two context-dependent stable conceptions that did not appear to impede overall understanding of pressure systems.

For example, Student 36483 developed an alternate conception used in the case of mask squeeze only. He correctly identified positive and negative pressures, but consistently thought that air needed to be added from the mask rather than taken away.

7.3.5 The confused outcome. Three students (11252, 62357 and 29425) were characterized as having a confused outcome (Freyberg and Osborne, 1985).

Student 29425 was described by the collaborating teacher as a, "…very weak student" having, "…great difficulties understanding science" (Datzkiw, personal communications, date unknown). This student received 21% on pre-test 1 and and 30% on post-test 1, indicating little in terms of gains in conceptual understanding. However, this student received 58% on post-test 2 (no pre-test 2 was submitted), indicating some gains in understanding when applied to scuba and flight contexts.

Evidence from this student's process-folio suggests that the student was able to think about pressure systematically predicting the volume of a balloon in a vacuum (Chapter 4), but reverted to his initial linear reasoning of pressure (internal pressure orientation) when applied to different contexts. This alternate anchoring conception was demonstrated throughout the teaching intervention. However, there was also evidence of macroscopic understanding when applied to physiological contexts.

Analysis of assignments 1 and 2 for this student indicated that there was no agreement between macro- and microscopic visualizations compared to symbolic calculations (refer to Chapter 5). This student could calculate changes in pressure and volume, but macroscopic and microscopic explanations would directly contradict his calculations. Moreover, there was not an attempt to reconcile the three representations. Observations noted by the collaborating teacher suggest that this student was not even aware that the macroscopic and microscopic representations were contradictory to the calculations. As such, the discrepancy was not addressed.

Analysis of the post-test 2 from Student 29425 showed that most answers were inconsistent and conflicted in terms of microscopic understanding. There was some ability to predict macroscopically what would occur in scuba and flight contexts, however, inconsistencies in amalgamating microscopic, macroscopic and symbolic representations were observed throughout the program and throughout the process-folio produced by the student.

As EAL was reportedly not an issue, it may be that the student memorized bits of information that came into play (p-prisms) and held alternate anchoring conceptions (Clement, 2000) in conflict with target models (Adadan and Savasci, 2012).

7.4 Limitations

7.4.1 Test design and analysis. Limitations in test design and analysis included internal consistency and reliability, lack of replicate questions, and the elimination of one question that was deemed unfair.

7.4.1.1 Internal consistency and reliability. Cronbach's alpha coefficient (Cronbach, 1975) was not determined for the two-tiered multiple choice test. Thus, there is no measure of internal consistency and reliability. As discussed in Chapter 6, the minimum sample size suggested by Yurdugul (2008) is n=100. As there was only 21 participants in the study, an unbiased estimation of the alpha coefficient would not be possible (Yurdugul, 2008).

7.4.1.2 Replication of test questions. Only one scuba question and flight question were asked for each of the following contexts: descending, equalization during descent, ascent, and equalization during ascent. It would have provided better assessment data to have asked at least two or more scuba and flight questions for each context. However, the test had been determined to be too long in previous sessions of the scuba programme and such questions were not added.

7.4.1.3 Elimination of test questions. Question number 25b did not have a correct answer, nor was there an "other" box to provide a correct answer. Although one student responded with the correct answer, the question was not included in the analysis.

The previously identified alternate conception that the Eustachian tube is open during equalization was not used as a distracter in any of the test questions. As a consequence, students holding this alternate model were not identified.

7.4.2 Feedback methods. In many instances, student analyses of the post-test helped to provide a clearer understanding of alternate conceptions. As students were only asked to analyse similarities and differences in three questions, many other alternate conceptions may have been missed. Furthermore, some students may have provided more telling feedback if other methods of responding (such as interviews) had been used.

Chapter 8: Interpretation of Results, Limitations and Pedagogical Implications

8.1 Analysis of the Progression of Model Building Throughout the Teaching Intervention

Clement (2000) presented a simplified model of the learning process that encouraged students to develop intermediate models when trying to understand the scientific or target model. Intermediate models may include mixed models (Freyberg and Osborne, 1985), where two models are held simultaneously, and one may supersede the other as time passes (Freyberg and Osborne, 1985). However, alternative science conceptions can be tenacious (reviewed in Adadan and Savasci, 2011) and difficult to change. In order to track the student conceptions of pressure and Boyle's Law, identify intermediate models and tenacious alternate conceptions, Gobert and Clement's (1999) "drawing to learn" strategy was employed.

The results of this study support Gobert and Clement (1999) in that the drawings of student models in this study could be used to track changes in conceptions throughout the teaching intervention and to identify tenacious alternate conceptions. For example, comparing each of the initial student conceptions in the order of the lessons taught (Appendicies E, F, G, H, I, J, K, R and V) can help students and teachers recognize alternate conceptions (such as internal pressure orientations), ascertain difficulties in transferring concepts from one context to another, and identify concepts that are well understood.

These process-folios of drawings were also useful in assessing student conceptual understanding of pressure and Boyle's Law, identifying instructional sequences that aided students in transferring concepts from one context to another, and those that were less successful in doing so.

8.2 Evidence of Student Learning

Evidence that learning occurred during the teaching intervention is supported by the analysis of the process-folios, assignments and post-tests.

8.2.1 Group analysis of process-folios. Evidence of learning occurred through the analysis of the process-folios by considering the number of correct predictions based on explanations close to target models. "Close to" target models includes models that may be missing one representation (such as internal and external numeric representations of pressure) but use pressure system explanations.

Table 8.1.

Frequency of student responses with predictions based on target models.

Diagnostic	Number of Responses	Number of Correct Predictions	Number of explanations **close to** target models
Appendix E	19	3 (These students predicted that liquids were incompressible, or compressible to a negligent extent, and gases were compressible.)	0
Appendix F	18	3	1
Appendix G	20	11	7
Appendix H	20	13	13
Appendix I	20	14	14
Appendix J	17	9	5
Appendix K	20	16	9
Appendix R	17	0	0
Appendix V	18	14	11

The numbers of students making predictions close to the target model increased from the initial lesson on pressure systems (Appendix F) to the balloon in a vacuum demonstration

(Appendix I). When the context changed to a balloon at depth ascending to the water's surface (Appendix J), there was a marked decrease in students providing explanatory responses close to the target models. The change in context from a vacuum chamber to water was apparently difficult for students.

In the next lesson, students were asked to predict changes in lung volume when a diver breath holds (Appendix K). This lesson is very close in context to the previous lesson, and more students were able to provide explanations close to target models.

The pen-and-paper model of an underwater balloon brought to the surface and a scuba diver's change in lung volume when breath holding during ascent included the same concepts, i.e. as ambient pressure decreases, volume increases, and the same context, i.e. the contribution of water to ambient pressure. Also, students had previously received lessons and demonstrations on these concepts.

Sixteen out of 20 students were able to predict that lung volume would increase. Three of these students cited the previous demonstration as helping them build their models, and two students cited previous discussions and demonstrations. This mini-sequence appeared to have been successful, as students were able to at least predict that lung volume would increase, and in the cases where macroscopic and/or microscopic visualizations were not given, the previous lesson was cited by students as assisting them with their predictions.

When predicting physiological models of ear squeeze and equalization (Appendix R), none of the students were able to provide explanations in keeping with target models. This is likely due to unfamiliarity with ear anatomy and physiology (Mak, Yip and Chung, 1999). As the intent of this lesson was to determine students' initial conceptions of the ear drum under pressure differences, no lessons that would scaffold conceptual development of ear anatomy and physiology and how the tympanum moves under different pressure situations were given. This may point to the value of lessons that include physical models to introduce the concepts of pressure in physiological contexts.

The frequency of students providing explanations of the model ear in a vacuum (Appendix V) improved, as the previous lessons covered the concepts of ear anatomy and physiology and the movement of the ear drum under different pressure situations.

8.2.2 Development of student conceptions. Though the data reported was a summary of initial conceptions at the beginning of each lesson for all the participants, the development of conceptions of pressure and Boyle's Law could be observed for each student using the process-folios. Tenacious alternate conceptions could also be identified through the process-folios.

Many students showed changes in microscopic, macroscopic and symbolic understanding throughout the teaching sequence. For example, the progression of conceptual development of pressure from linear reasoning, internal orientation to systematic reasoning can be shown by looking at the initial conceptions of Student 69297 throughout the teaching sequence (Figure 8.1a-h). This student also showed a progressive sophistication in how she drew her models, wrote explanations and critiqued models against the scientific model given.

This student had a tenacious alternate conception of a linear reasoning of pressure, specifically, an internal pressure orientation that did not appear to start to change until the lung barotrauma lesson (Figure 8.1 g).

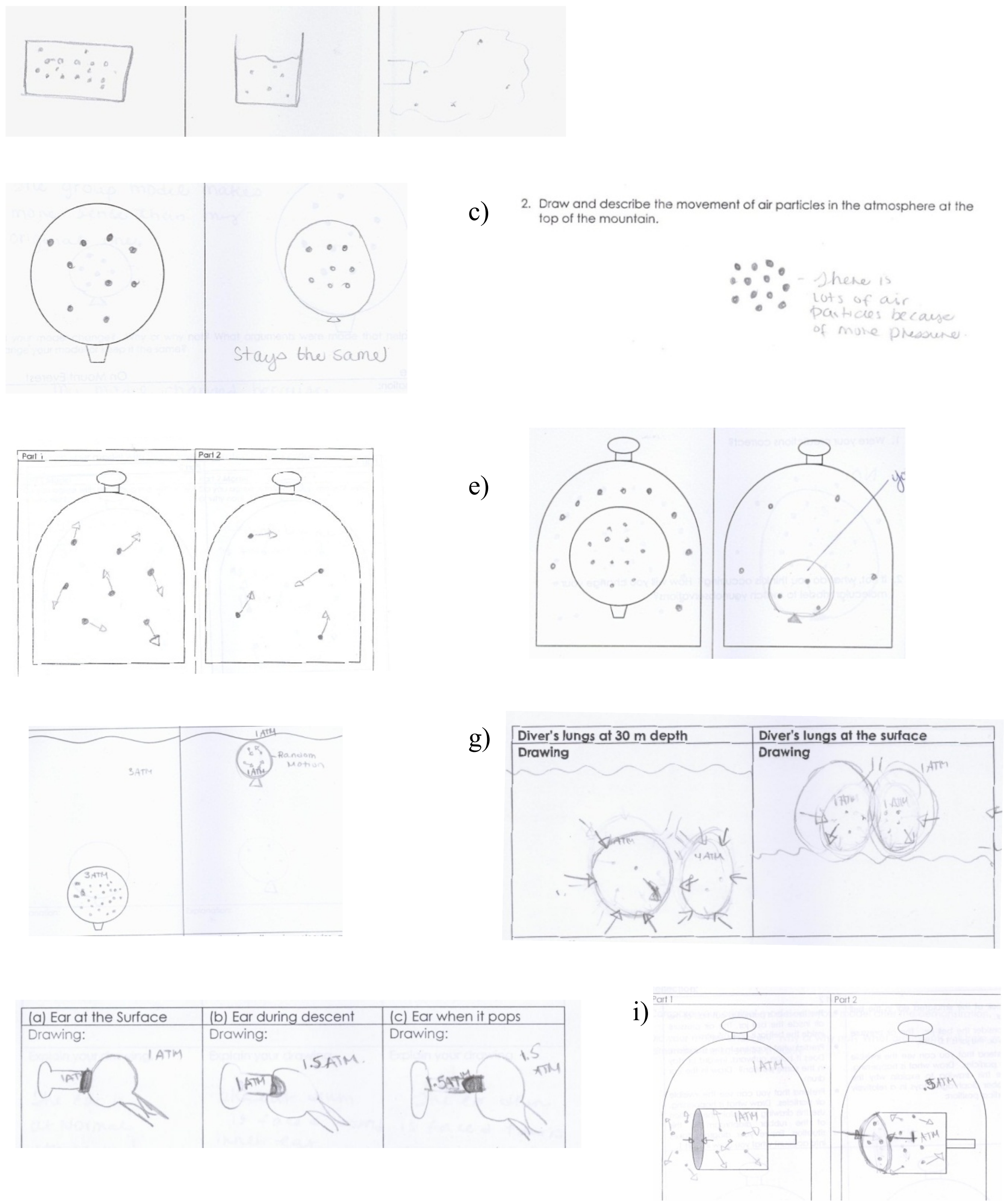


Figure 8.1. Development of conceptual understanding of pressure and Boyle's Law for student 69297.

a) Particulate nature of matter, with prediction that gases and liquids are non-compressible in a syringe (Appendix E).

b) Linear reasoning of pressure, internal orientation with conflicting written description of volume changes in the balloon (Appendix F).

c) Air pressure increases with elevation alternative conception (Appendix G, Dove, 1998)

d) Air in a vacuum chamber, close to scientific models, no symbolic representation (Appendix H)

e) Conceptions of a balloon in a vacuum. Internal orientation, with air particles described as moving with "random motion" (Appendix I).

f) Conceptions of a balloon surfacing from depth. Internal orientation still apparent (Appendix J)

g) Conceptions of lung barotrauma. Starting development of pressure systems model (Appendix K).

h) Initial conceptions of the ear. No microscopic understanding. Convex tympanum at equilibrium. (Appendix R)

i) Physical model of the ear in a vacuum chamber. Prediction of tympanal movement using the three representations (Appendix V).

Students who were characterized as "proficient" at learning science (for example, 77079) were able to change their alternate conceptions more quickly and were better able to use concepts of pressure in different contexts. Many of these students were able to critique their models when compared to target models by using the three representations (macroscopic, microscopic, symbolic) and pressure systems in their critiques.

Students who were characterized as "weak students" or students having EAL challenges had difficulties changing alternate conceptions. These students may have held mixed models based on alternate conceptions (for example 11252) and had difficulties critiquing their models compared to target models using the three representations and pressure systems (for example, Student 29425).

8.2.3 Student evaluation of writing conceptions. One student mentioned the value of using the process-folio and explained, "All the demonstrations and learning sequence sheets were useful in helping me learn the concept of Boyle's law. These were useful because it give me a step-by-step guide on exactly what happened."

8.2.4 Post-test scores. The average class percentage was 75% for post-test 1 and 76% for post-test 2. Whereas the average class pre-test 1 and pre-test 2 scores were 39 and 30%, respectively.

Eighteen students received 60% or greater on both post-tests. Two participants (11252, 81886) did not receive 50% or greater on post-tests 1 and 2. These two students were EAL and identified as having major difficulties in the four core skills, namely, reading, writing, speaking and listening. One participant (29425) received 30% on post-test 1 and 58% on post-test 2. This student was not identified as EAL, but written explanations indicated English language difficulties. This student was characterized by the collaborating teacher as a, "…very weak student" that had difficulties with conceptual understanding of science.

The process-folios provided indicators of student understanding that supported findings in the post-test scores. For example, Student 26951 showed progressive conceptual development throughout the teaching intervention, and received high scores on the post-tests, but also reverted to an internal orientation in certain contexts on the post-test. Student 29425 showed difficulties in changing alternate conceptions and critiquing initial conceptions throughout the teaching intervention, which was confirmed by post-test scores.

8.3 Physical Models and Demonstrations

Models that appeared to aid student conceptual understanding of pressure and Boyle's Law were identified by having students: (a) comment on experiences that helped them remember the correct answers for tests (Appendices X and Y), (b) evaluate demonstrations and experiments during the scuba diving activity (Appendix Z) and (c) describe experiences or demonstrations they found useful for understanding and thinking about the unit overall (Appendix AA).

8.3.1 Student analysis of post-tests 1 and 2. To identify student models, demonstrations and experiences that helped students remember target models of pressure and Boyle's Law, students were asked to pick one question they answered correctly in both pre- and post-test 1, and discuss experiences that helped them remember the concepts in order to answer this question correctly (Appendix X, Question 1). They were also asked to pick one question they answered incorrectly the pre-test 1 and correctly in the post-test 1, and discuss experiences that helped them remember the concepts to answer the question correctly the second time (Appendix X, Question 3).

These same analysis questions were asked for post-test 2 (Appendix Y, Questions 1 and 3).

Twenty-one student responses were analyzed. The frequency of lessons, demonstrations and activities cited by students to help them remember target models to answer test questions correctly are summarized below.

8.3.1.1. Useful lessons, demonstrations and experiences cited for post-test 1. In the responses to Questions 1 and 3 of the post-test 1 analysis (Appendix X), 19 answers noted classroom lessons or diagrams as being helpful in answering the post-test questions. Scuba diving was noted four times. The syringe demonstration was noted three times. The bell jar experiment was noted three times. The in-class balloon experiment was noted two times.

It should be noted that the students who scuba dived completed a separate evaluation for the experiments, that showed the experiments to be helpful. They may not have repeated this information on this post-test 1 evaluation.

There were five students that did not answer, or provide experiences, for question 1 of the post-test analysis and eight students that did not answer or provide experiences in question 3 of the post test 1 analysis.

8.3.1.2 Useful lessons, demonstrations and experiences cited for post-test 2. In the student analysis post-test 2, 15 answers noted classroom lessons or diagrams as being helpful in answering the questions.

Six noted that the scuba diving helped them to correctly answer post-test questions. Of these, five were non-scuba diving students. This in itself is remarkable, as non-scuba diving students cited scuba diving examples such as, "hamburger lung", "pool side demonstrations", and scuba diving in general.

The other student that did participate in the activity stated that for question 15, "Experience I used when answering the question first time was a helium balloon floating on the ceiling." This gave her an incorrect answer. Then she goes on to say that the, "Experience I used second time was relating it to a bottle ascending from a deep pool", which was a scuba demonstration she observed. (Again, it should be noted that the scuba students did a separate evaluation for the experiments that showed which demonstrations they found helpful, but they did not necessarily repeat this information on this evaluation.)

There were six students that did not answer, or provide experiences, for question 1 of the post-test 2 analysis and seven students that did not answer or provide experiences in question 3 of the post test 2 analysis.

8.3.2 Useful scuba demonstrations. Of the eight scuba diving students, five noted the ear drum experiment as useful. Three noted the cylinder experiment as useful. Two students noted the bottle example as useful. Of the five students noting the ear drum experiment, one noted that learning to equalize their ears was very important. One student did not fill in the evaluation.

Student comments indicate that the ear physical model appeared to aid student learning because students could physically feel what was happening to them as they watched the model. In other words, a humanistic element (Mahaffy, 2005) was added to the model that aided conceptual understanding. The following are two representative examples of student comments concerning the ear model:

"That would be the demonstration w/ the plastic bottle and the ear drum model thingy. Because those objects represent our body (body parts) and it's hard to forget Boyle's Law ($P\uparrow V\downarrow$ or $P\downarrow V\uparrow$) when you actually feel what will happen to your body when you go down to high pressured atm."

"Honestly, learning how to equalize my ears and the pre demonstrations were all useful in my learning because not only was I able to understand the concept of pressure even more, but I could actually feel the pressure differences."

Students who thought the cylinder experiment was useful described the macroscopic visualizations of the demonstrations useful, "Thu [sic] upside down cylinder was useful because it showed the volume of the bubble decreasing as we went deeper."

The collaborating teacher thought that the macroscopic visualization of the cylinder experiment was useful, but indicated that there was far less accuracy and precision in the measurements compared to the syringe experiment. He also felt that comparing the two experiments was worthwhile as both the syringe and cylinder are subject to a combination of ambient pressures which can be accounted for through calculations (or symbolic representations) and clearly show the changes in volume with pressure (macroscopic representation).

Both the collaborating teacher and the divemaster indicated the ear model was a "particularly useful demonstration" as students could feel the differences in pressure in their ears as they watched the model tympanum. The collaborating teacher explained that, "This model combines the macroscopic and humanistic elements, and if we had students look at the pressure gauges during the demonstration, the symbolic would be included as well." The dive master suggested sending the model and videotapes of the demonstration to PADI for use in their diver certification courses (D. Alderson, personal communications, 2010).

8.3.3 Demonstrations cited in the overall evaluations. Six students noted the syringe demonstration as helpful. This demonstration helped one student change his alternate conception that gases aren't compressible. He wrote, "I enjoyed the lab with the syringe and the books. Helped prove gas can be compressed with pressure. Also like the cylinder experiment. Helps demonstrate pressure."

Seven students noted that scuba diving was helpful, and of these four were non-scuba students.

Five noted the bell jar experiment as helpful. In one case, the student describes relating the macroscopic to the symbolic, "It would be the bell jar vacuum demonstration and the scuba diving. It was effective because we, as a class, saw what happened compared to just doing calculations and substituting stuff on the formula." Two students pointed to this experiment for helping them to understand pressure and volume changes with increased elevation. As they stated, "The balloon in the vacume [sic] chamber demonstration was useful because It helped me understand what happens to gas in the atmosphere" and "The bell jar vaccum [sic] apparatus experiment was very helpful because it stimulates what would happen to a balloon if it went to 0.5 atm.".

Three students noted the value of the ear squeeze/equalization/reverse block model, and one non-scuba student described ear equalization (though it is unknown which model was used). Two students mentioned reverse block, "I saw how the reverse block effects the ears and how it causes the ear drum to go outwards. It made me understand how dangerous it is to go underwater when you have a cold." This may be because the tympanum of the model becomes so swollen (it looks like it will burst), that is, the target is explicit (B. Lewthwaite, personal communication, date unknown) and the humanistic orientation is added because of the danger of loss of hearing when diving with a cold.

Two students noted all demonstrations as helpful, and one student cited the computer model of the syringe experiment that showed all three representations as being valuable for learning.

8.3.4 Air pressure lesson. Not one student indicated that the lesson on air pressure was helpful for their understanding. This lesson did not have any physical demonstrations.

8.4 Small and Large Group Discussions

Out of eighteen responses, 16 students found sharing ideas useful. However, many students did not find the small group discussions helpful.

Seven students found the small and large group discussions to be a useful process of developing conceptual understanding for many students. Two examples of this view are included here:

"I think the process of discussing the topics in small and large groups were helpful with learning the subject because it help us to understand and it explained more just being with a group."

"Sharing what other think would happen and comparing it to my own predictions opened my mind to different ideas. Also, after knowing the correct answer and comparing it to my own, I learn my mistakes and the proper way of solving the problem."

One student thought that, due to time limitations, small group discussions were not as effective:

"I think that if we took our time in our small or large groups, it would've been more helpful to discuss but as we were rushed during that time, it wasn't as effective."

Seven students also thought that the small group discussions were not useful for understanding. They thought that small groups were repetitive, wasted time, and students used the small group sessions as a chance to socialize rather than work on the task at hand:

"I don't think this process was too important, it was good to get into groups and see each others ideas and maybe rethink what you thought. After a while when we started understanding the topic more I didn't find it very useful"

"I think the small group discussions can be eliminated in the process because it consumes a lot of time and basically (most of the time) we write [the] same thoughts in the large group discussions."

"I actually found that very useless because my thought[s] were very identical to those of my group and almost the rest of the class. Also it was very time consuming and was frustrating."

"Not small groups because if someone had an idea, we all just agreed because we didn't know what else to say. But the large groups helped- we had more ideas and I chose the one that made the most sense to me."

"Not realy [sic], because most students didn't discuss. When you give a class an opertunity [sic] to talk, they talk, but not about school."

The collaborating teacher thought that individual, small, and large group discussions were beneficial because they helped students to think critically, and he could directly confront experiences brought up by students that may help form alternate models. He also thought that the class discussions were less effective as students were writing their conceptions numerous times. In addition, he noted that the continual writing was time consuming although necessary to the research study, caused fatigue, and became monotonous for many students. He suggested that he would continue small and large group discussions without having students write every part of the process.

8.5 Student Evaluations of the Scuba Activity

All of the students who participated in the scuba activity thought it was useful for their learning. The activity was described as "fun", which they felt aided their learning, and helped demonstrate pressure and volume relationships. One student responded, "...it is fun and you can physically see the experiments and get a good idea on what Boyle's Law really meant."

A student described a difficulty with the scuba activities, where students did not quite have the skills to start the experiments, "... it's fun to experience, however hard to concentrate on a lesson when it's your first time diving and you're getting used to it." In order to improve the scuba activity, it may be beneficial for students to get used to obtaining neutral buoyancy by completing neutral buoyancy exercises, practice ascending and descending, and by swimming around the deep end in the middle of the water column before attempting experiments.

The students who did not go scuba diving watched the activities and helped divers with their experiments. These students were asked if they would recommend the scuba activity. Surprisingly, all of these students also recommended that diving activity as useful for learning:

"...I would also encourage people to go in the water, too! On the surface, I got to understand how, effects of reverse block but it was boring waiting for results and watching people dive. So it would be more exciting to witness everything, even the slight ear pain."

"Yes, because it will really help you understand the concept of Boyle's law and give you knowledge about ears if you don't equalize and breath properly when ascending and descending."

"Yes because actually seeing what happen[s] with pressure make[s] it very easy to understand and remember"

"Yes I would because you can learn a lot from it because scuba diving is hands on and hands on learning is a great way to learn things"

"Yes, because scuba diving is fun and at the same time we could learn a lot from it."

The collaborating teacher also advised that the scuba diving activity was an excellent activity to help build conceptual understanding. However, he cautioned that it was expensive and may not be feasible due to budgetary constraints.

As described by Freyberg and Osborne (1985), learning is not only a cognitive endeavour. Many factors such as student attitudes, self esteem, and mental health affect learning (Freyberg and Osborne, 1985). Though student comments addressed the cognitive domain, students also addressed the affective domain, describing the scuba activity as "fun", which they felt aided in learning. Student comments from previous sessions indicated that the activity was something they'd "never forget". It appears that the scuba activity may have a positive effect on learning through the affective domain (R. Renaud, personal communication, 2012).

8.6 Analysis of Student Conceptions

8.6.1 Learner difficulties with using models. As discussed in the literature review, the ability of learners to use models effectively may be impeded by a number of factors (Adadan and Savasci, 2012; Coll, France and Taylor, 2005). These factors include, but are not limited to the following: difficulties in describing and critiquing models in detail; mistaking models as literal versions of reality; difficulties in applying the model to different contexts; mixing models; connections to life experiences leading to alternate conceptions

(Freyberg and Osborne, 1995); difficulties with coherent translations from one representation to another (Treagust, Chittleborough and Mamiala ,2003). Examples of these difficulties were also observed in this study.

8.6.1.1 Difficulties in drawing and explaining macroscopic, microscopic and symbolic visualizations. Though students were asked to draw models with macroscopic, microscopic and symbolic representations, many times their drawings were missing one of the representations, or their explanations contradicted their drawings. Even when copying down the target/scientific model, one of the representations was often missing and what was drawn by the teacher and explained was not what was necessarily copied by the student.

For example, when drawing initial conceptions of the balloon in a vacuum chamber (Appendix H), Student 36843 wrote that she thought the balloon would expand, but drew a balloon the same size (Figure 8.2). She also stated that, "I thought the air particles in and out of the balloon were the same." This statement was later clarified, and it was found that the student thought the numbers of air particles inside and outside were the same, yet she drew less air particles inside the balloon, indicating she may have originally thought air was evacuated from the balloon.

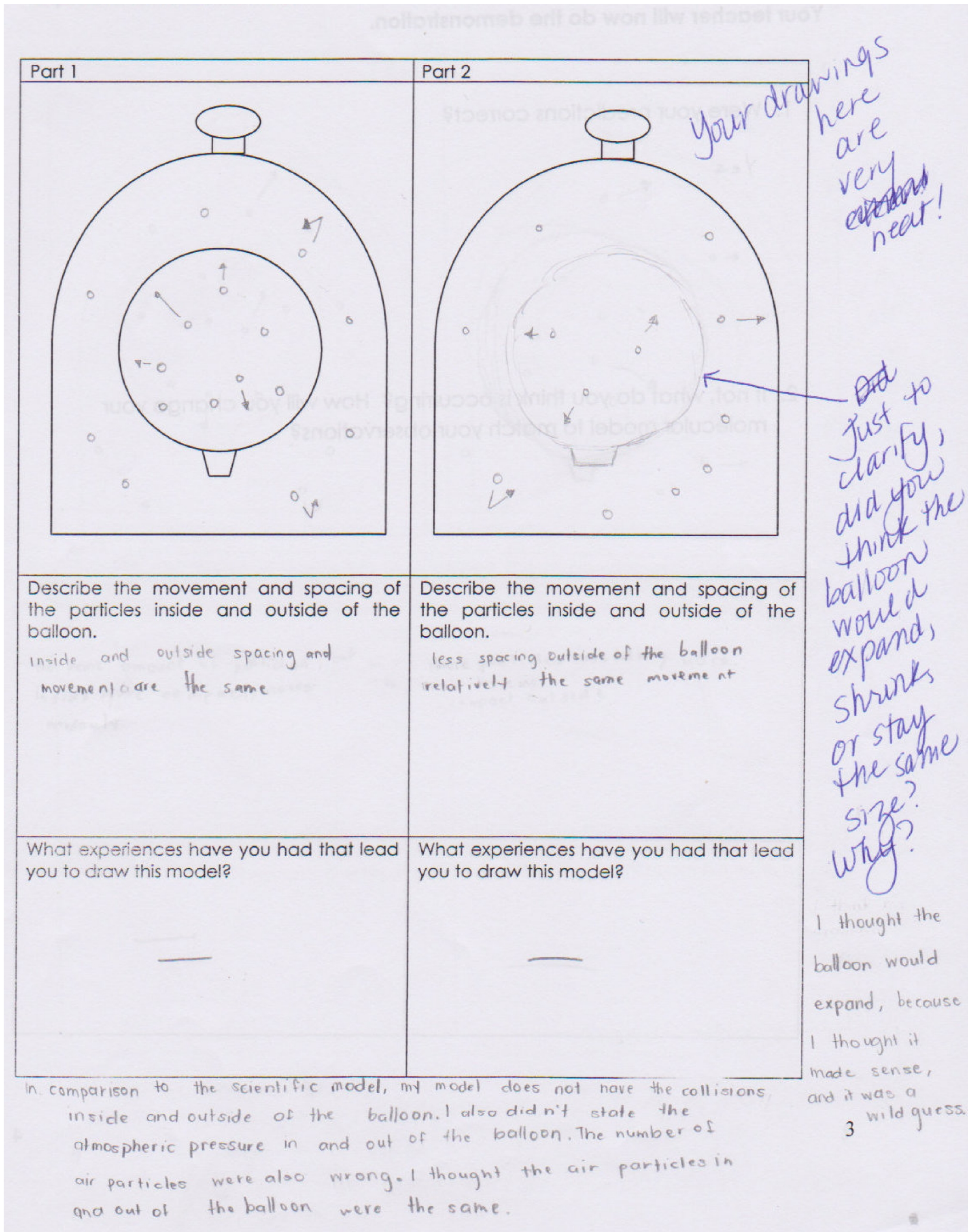


Figure 8.2. Initial conceptions, discrepancy with written explanations and diagrams.

When drawing the scientific model, the collaborating teacher paid particular care to show and explain that the number of external air particles decreased by about half, and the relative decrease in ambient particles should be shown. He also gave internal and ambient symbolic representations for each part of the demonstrations. When drawing the scientific model, Student 36843 did not noticeably decrease the number of ambient air particles. Nor did she show the symbolic internal and ambient pressures (Figure 8.3).

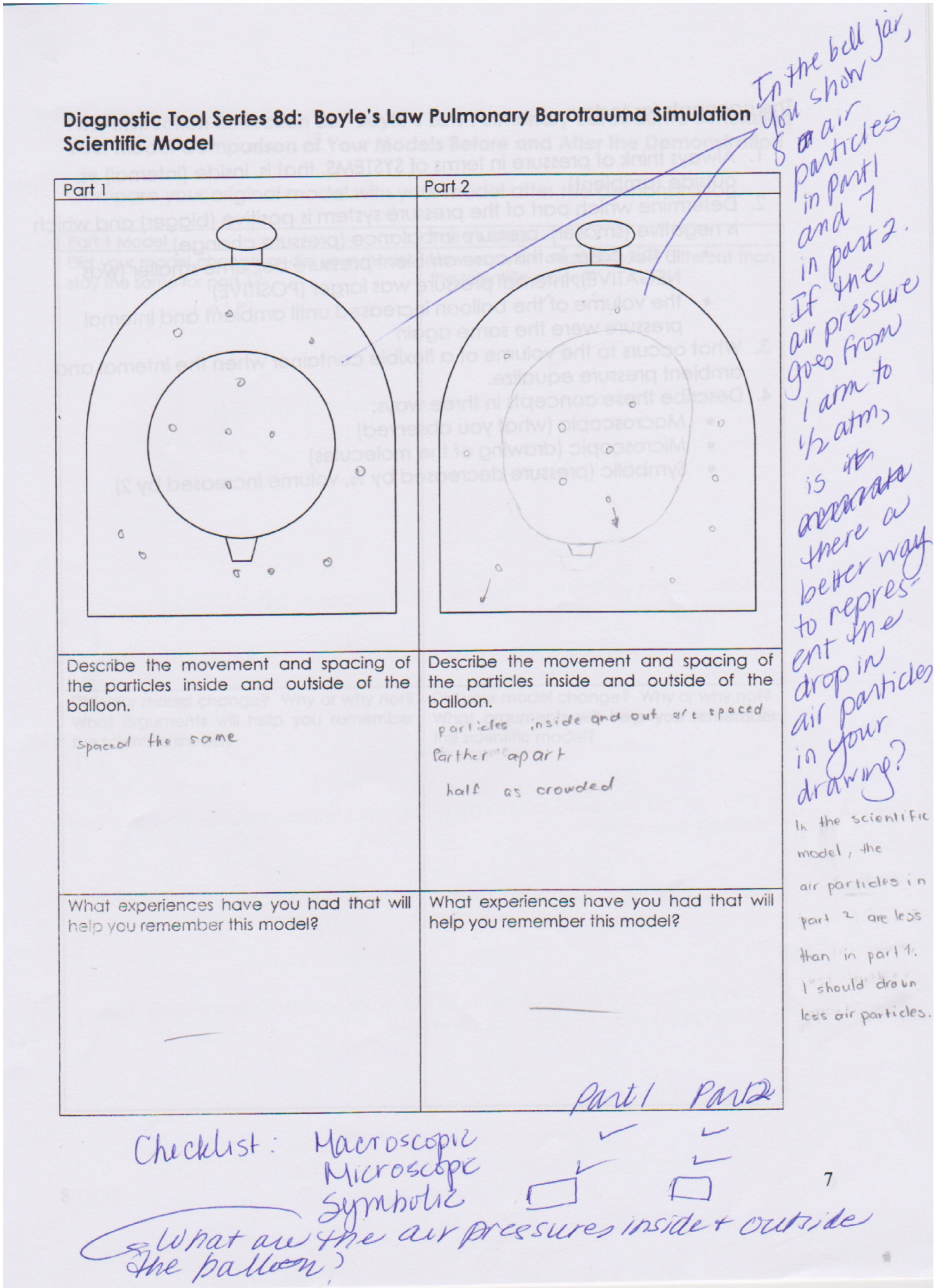


Figure 8.3. Inconsistencies with drawing scientific models.

As many students forgot to include one of the representations (most often the symbolic representation) in their diagrams, even when copying down the scientific model, a "checklist" was suggested so that students included all three representations to the best of their ability.

8.6.1.2 Difficulties with critiquing models. Students were asked to compare and critique their models (Figures 8.2 and 8.3) to further develop model building skills (Taylor, 2000) and to reinforce the relatedness between the three representations (Chandrasegaran, Treagust and Mocerino, 2008). In the balloon in a vacuum demonstration, only five students critiqued their models in writing. Those that critiqued their models were fairly thorough, discussing spacing of particles (relative densities), motion, internal and external pressures, symbolic representations of internal and external pressures, and relative numbers of particles in each situation (Figures 8.2 and 8.3).

It is unknown if the other students had difficulties critiquing models or were exhausted or rushed through the process. From this point in the intervention onwards, students rarely critiqued their models on paper as course time was limited.

However, there is evidence to suggest that students who demonstrated understanding of pressure and Boyle's Law at the end of the teaching intervention, such as Student 36843, could critique their models based on the three representations and pressure systems (Figures 8.2 and 8.3). Students (such as Student 29425) with difficulties understanding the three representations and pressure systems also had difficulties copying down the scientific model and comparing their initial conceptions (Figure 8.4) with the scientific model (Figure 8.5).

In this case, the original model looks similar to the target model. In the scientific model, there were no ambient particles represented for the balloon at the surface. Though the balloon increased in volume, the balloon was drawn smaller. (This may be due to the limited space provided, and would be a limitation in design.) However, there was no critique of ambient air particles at the surface; differences in symbolic representations between initial conceptions and the target model; and what "1/3 sized arrow" refers to (most likely an indicator of external pressure, which is not indicated in the target model). The only critique given was, "It was different from my own model because of the size of the balloon."

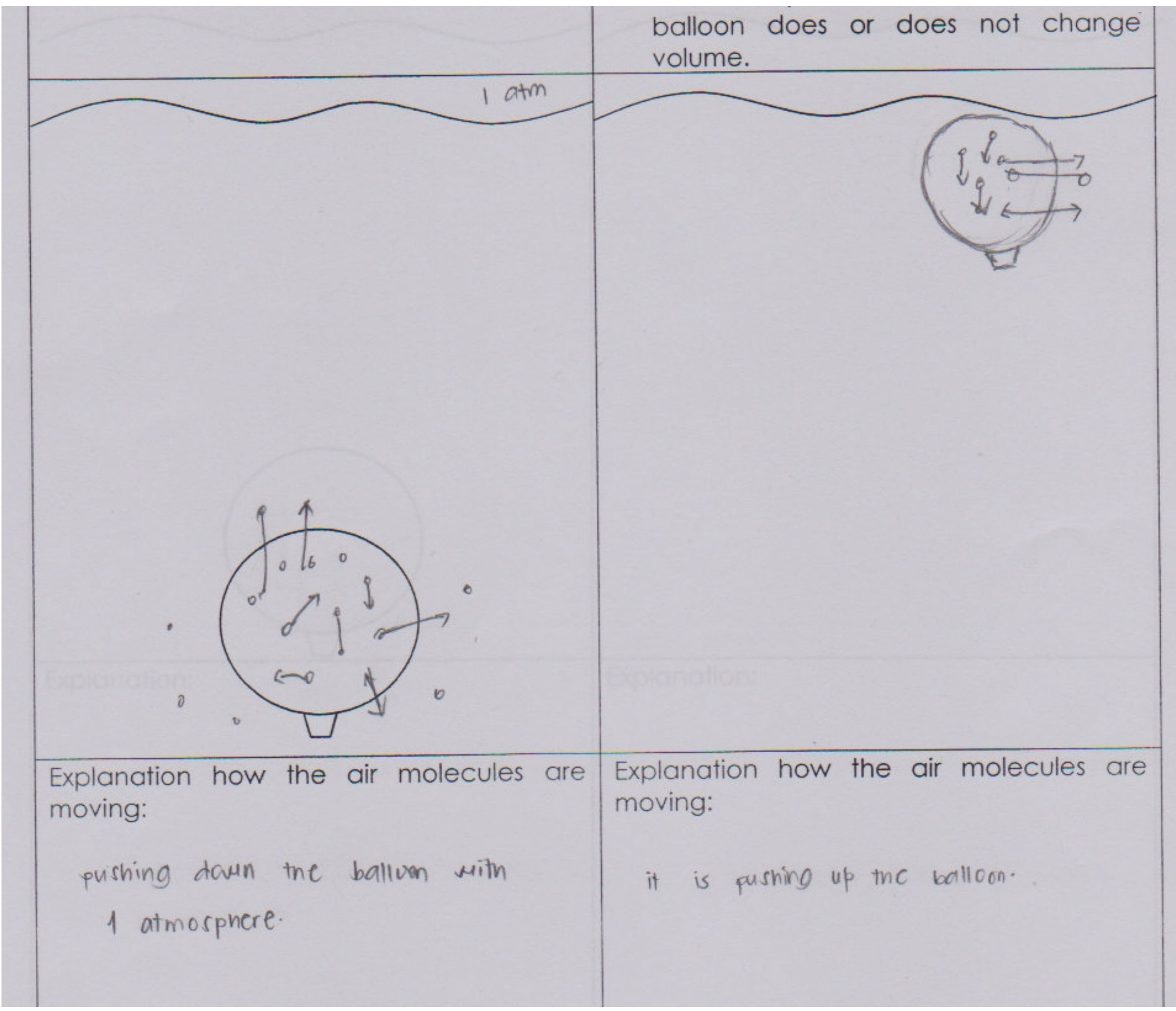
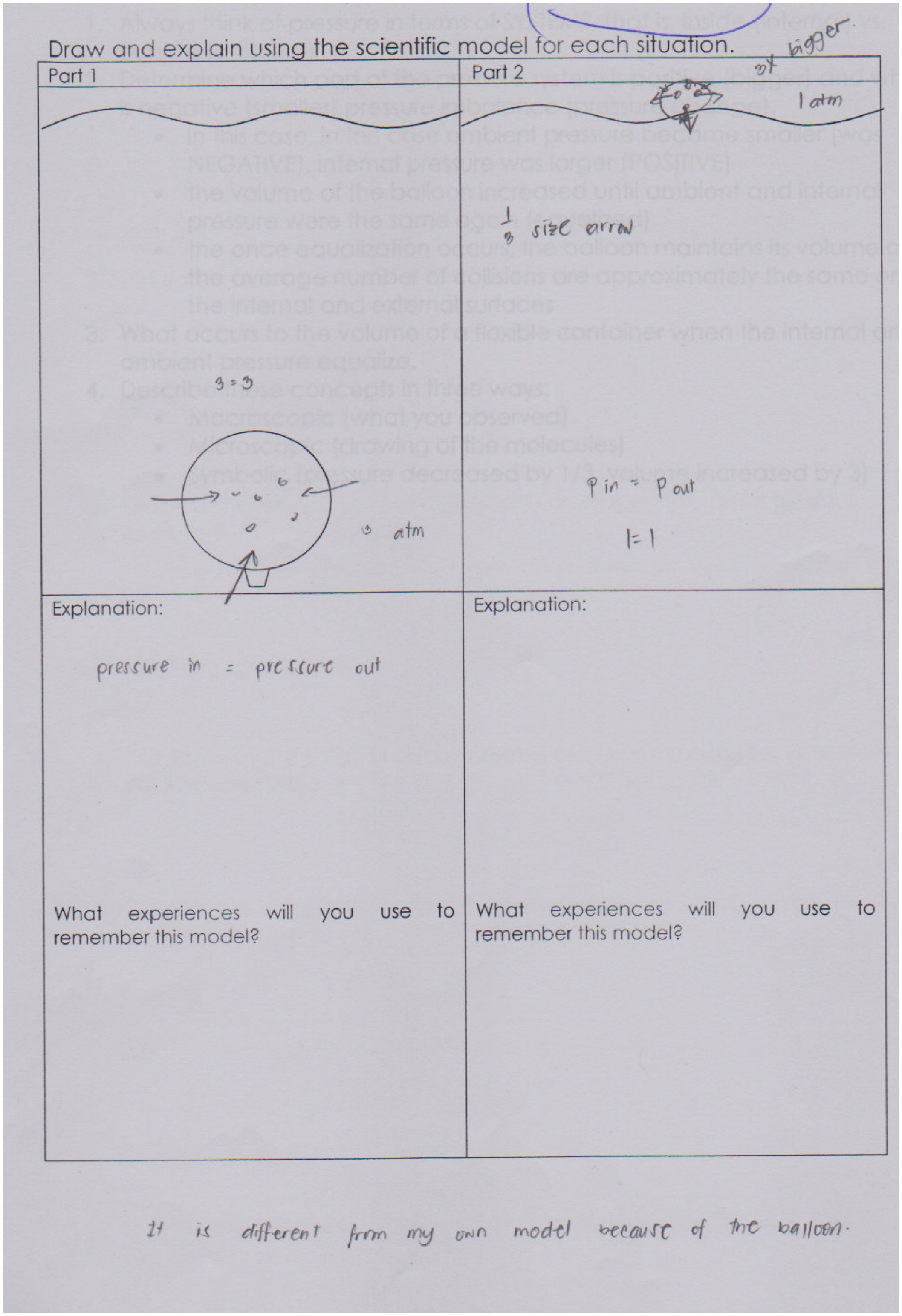


Figure 8.4. Initial conceptions of an underwater balloon brought to the surface by student 29425.



Draw and explain using the scientific model for each situation.

Part 1	Part 2
3 = 3 atm	bigger 3x 1 atm 1/3 size arrow P in = P out 1 = 1
Explanation: pressure in = pressure out	Explanation:
What experiences will you use to remember this model?	What experiences will you use to remember this model?

It is different from my own model because of the balloon.

Figure 8.5. Student 29425 scientific model and comparison of the scientific model with initial conceptions.

8.6.1.3 Models as exact versions of reality. As the same numbers of internal and external air particles were used in teacher models, students may have thought that when equalized, there were the same number of air particles inside and outside of a balloon in a vacuum chamber, despite the discussion of this particular limitation by the collaborating teacher. This reinforced conception (Freyberg and Osborne, 1995) was identified when one student (36843) compared her model. She concluded, "The number of air particles were also wrong. I thought the air particles in and out of the balloon were the same". This is also an example of reinforced alternate conceptions (Freyberg and Osborne, 1995), where students may misinterpret teacher information.

8.6.1.4 Difficulties of applying models to different contexts. As previously discussed, when some students drew their conceptions of solids, liquids and gases in square boxes (or frames), many drew solids with no spaces between particles, liquids with larger spaces between particles and gases with the largest spaces between particles (Figure 4.1). When asked to visualize liquids and gases in a syringe and predict compressibility, eight students thought that the liquid and gas particles were packed together, similar to a solid.

This change in context is one example where students had difficulties applying their models. This may also provide evidence to support the two-perspective outcome (Freyberg and Osborne, 1995), where different models are used for everyday life and for textbook or examination problems. Conceivably, the models of solids, liquids and gases shown in a frame (with no real-world context) would be a textbook/test answer. The visualization of the liquids and gases in the syringe during the demonstration could be the models used for everyday life.

8.6.1.5 Mixing Models. There is evidence of students mixing models. In some cases, tenacious alternate models were combined, in others, there was a mix of target models and alternative models. For example, Student 11252 mixed two tenacious alternate conceptions, that a balloon would contract in a vacuum and that air particles were skewed to the top of the vacuum chamber (Figure 4.23). Student 30913 mixed target models of a balloon in a chamber with no air evacuated to an external, compression model of pressure when air is evacuated from the chamber (Figure 4.26).

This mixing of models may be explained using Freyberg and Osborne's (1985) suggestion that new models and existing models are held simultaneously. Over time, one model may obtain greater importance than the other (Freyberg and Osborne, 1985).

8.7 Suggestions for Improvement of Lessons

8.7.1 Analysis of the particulate nature or matter lesson. Students may not have a good understanding of the relative spacing particles compared to particle size for each of the states of matter. For example, when drawing the relative spacing between particles of solids, liquids and gases, it may be beneficial for students to discuss and find methods to visualize the relative sizes of the particles compared to the distances between these particles.

8.7.2 Suggestions to improve the lung barotrauma teaching sequence. The physical model of a balloon in vacuum demonstration and the underwater balloon brought to the surface exercise included the same concepts. That is, as ambient pressure decreases, volume increases. Also, students had previously received lessons on this concept when comparing air pressure from the bottom of a mountain to the mountain top (Appendix G) and discussing the change in balloon volume going up a mountain (Appendix F). The context was then changed to a scuba-like scenario where water provided ambient particles rather than air.

Thirteen students were able to provide explanations in keeping with target models when predicting the change of volume of the balloon in a vacuum. Only five of these students were able to transfer that model to the new context.

The other seven students who previously provided explanations in keeping with target models were not successful in transferring target models to the new context. It appears that changing the cause of ambient pressure from the atmosphere (Appendix H) to water (or more correctly, a combination of water and the atmosphere) was enough to cause difficulties for students. This may have occurred because learners can find it difficult to navigate a change in context (Coll, France, and Taylor, 2005). Furthermore, the demonstrations up to this point in the unit may not have been explicit enough to aid students in the transfer of knowledge in one context to another context. As discussed in the previous section, there was evidence of students reverting back to initial alternative models (for example, Student 62357) or mixing models (for example, Student 84816).

Given the initial lack of success for students transferring target models to the scuba context, and that only one student cited the previous lesson as helping to form personal models in keeping with target models, this particular two-day teaching mini-sequence was not effective. At this point in the teaching sequence, it may have been better to have reviewed the lesson from the previous day, and discuss how water pressure changes at depth (Besson, 2004). Then students could watch a scuba demonstration of a balloon brought to the surface, or watch a documentary about salvage diving where students can see the changing volume of the balloons used to float wreckage to the surface. Footage of balloons used to float wreckage from the bottom of the ocean floor would provide a humanistic aspect (Mahaffy, 2005) to the lesson. Given that many of the experiences sited as helpful to learning are humanistic in nature (being first-hand experiences), and that the one story of a student explaining the unfortunate explosion of breast implants convinced a small group to change their models, the humanistic appears to assist students in learning target models.

After watching the video, students could then create their own models, discuss and critique their models based on the video footage. After discussing the target model, students may also benefit from comparing the similarities between the previous lesson (the balloon in a vacuum chamber) to this lesson.

8.7.3 Suggestions to improve the ear barotraumas teaching sequence. To facilitate model building, it is suggested that one use an ear demonstration model where air is pumped into a bell jar. Given the results from the lesson progression that included the balloon in a vacuum demonstration (Appendix I) and the scuba balloon exercise (Appendix J), it may at first glance appear that suggesting a new demonstration may not be the most effective method for facilitating model building. However, as the ear model has an explicit target (an exaggerated ear drum) and the students received previous lessons on water pressure, the interim demonstration may actually be effective.

8.8 Overall Limitations of Study Design and Suggestions for Improvement

8.8.1 Reliability or rigor. As there were only 21 participants in this study, there is little basis for generalization. Furthermore, as students missed lessons for various reasons (such as illness, appointments, field trips, or at one point, a school-wide blackout), feedback from all 21 participants did not occur.

8.8.2 Validity or trustworthiness. Though investigator triangulation and follow-up clarification questions were employed to improve the trustworthiness of the study, many times it was difficult to interpret student understanding and the knowledge underpinning student conceptions.

When analyzing student conceptions, the researcher and external examiners would discuss discrepancies in interpretation until consensus occurred. In the event that consensus was not achieved, multiple interpretations were offered. However, even in cases where consensus occurred, this does not necessarily guarantee that the interpretation of the student conceptions were correct. It is likely that having more external examiners could provide more viewpoints which may be closer in reflecting the actual conceptions of students.

Also, as there were five different examiners and the collaborating teacher analyzing student responses, there would be less consistency than situations where the same examiners reviewed all of the data (Zeedyck, *et. al.,* 2003).

Having students write follow up responses was not the best means for students to clarify their thinking, as some students may have had difficulties expressing their ideas in written form (for example, EAL students and students who drew diagrams that contradicted their written explanations). Furthermore, students may not clearly remember their initial conceptions or recall that their initial conceptions may have changed, given that written responses were provided after the lesson rather than at the time of writing conceptions, which occurred before the lesson.

As the researcher and external examiners were not in-class, nor was there video of classroom instruction, the in-class teaching of alternate conceptions resulting from specific pedagogical methods and/or the use of everyday language were difficult to distinguish and may have been missed. As interviews with the teacher to discuss wording and modeling did not occur everyday, the reports of in-class discussions would not be as complete as having video to refer to. To improve validity and reliability, it may be useful to use a different method of triangulation such as written evidence, in-class video and interviews (Zainal, 2007) along with investigator triangulation to analyze student conceptions.

8.8.3 Pre- and Post-Test Analyses. As previously discussed, due to small sample sizes, small numbers of analogous questions per concept, and the elimination of one question in post-test 2, Cronbach`s alpha (Cronbach, 1975) was not calculated for the two-tiered multiple choice tests. Furthermore, due to time limitations, other measures that could be used to determine changes in pre-and-post-test scores such as variance of means (reviewed in McMillan, 2008) was not calculated. Such calculations may have been a better indicator of pre-post test gains.

8.8.4 Time limitations and fatigue. Time and fatigue were identified as two factors that adversely affected the quality of student responses.

8.8.4.1 Inexperience with teaching strategies designed by the researcher. This is the first time the collaborating teacher taught chemistry using many of the strategies designed by the researcher. It took time for both the teacher and students to become familiar and comfortable with these approaches and routines.

8.8.4.2 Fatigue. In one month of teaching time, students wrote approximately 20 booklets, which included cognitive probes, assignments, lab write-ups and tests. The collaborating teacher reported that both he and the students were mentally exhausted at approximately day 9 of the study, and as the winter holiday was approaching, students were busy with the wrap-up of other units from other subjects in which they were enrolled.

8.8.4.3 Time limitations. Aside from exhaustion, as time was of the essence, students needed to "rush through" their responses to the clarification questions. In order for the teacher to be able to finish teaching other units, students were asked to take "short cuts" in terms of explanations (brief, point form) and drawings (such as drawing "representative particles"). Many times students did not have the chance to give detailed comparisons of their initial models versus scientific models. Also, the winter holiday, a school-wide blackout, and school activities interrupted the teaching sequence as planned.

In further studies, it would be prudent to use a smaller number of cognitive probes, and/or find another way to record and analyze student model building such as video recording lessons and small and large group work.

8.9 Pegagogical Implications

Despite the limitations discussed in chapters 6 and 7 and the limitations discussed earlier in this chapter, the teaching sequence appeared to aid students in their understanding of pressure and Boyle's Law.

8.9.1 The use of multiple representations to aid conceptual understanding. The use of macroscopic, microscopic and symbolic representations appeared to aid students in the understanding of pressure and Boyle's Law. Perhaps some of the most compelling evidence comes from the students themselves. All 21 respondents to the evaluation of the use of multiple representations stated that this was useful for understanding concepts. It is important to note that the three students who did not show noticeable improvement also responded that the multiple representations were useful for their learning. Below are representative comments from the students:

"… the four orientations really explained what was happening to the object (being experimented). The four orientations also help me to really imagine/picture what was happening inside or outside the object."

"At first it wasn't helpful because I was very confused at what I was doing, but as we learned it became easier and helped me remember the image of it."

"… doing these explanations w/ those concepts let the teacher know that the students really understand the logic/concept of what they are doing."

"… it helps me visualize everything which helps me learn more efficiently."

The collaborating teacher shared the opinions of his students. He found these assignments useful for helping him to identify students who were proficient at calculations, but had no conceptual understanding.

8.9.2 The use of multiple representations in assignments. As previously discussed, evidence from this study supports the use of multiple representations in aiding the conceptual understanding of students. Furthermore, the students themselves thought that the use of multiple representations facilitated conceptual understanding. Thus, evidence from this study supports suggestions by MECY (2006) to include assignments that have students explain calculations (symbolic representations) though macroscopic and microscopic representations.

8.9.3 Agreement between multiple representations and student attitudes towards science. As described in chapter 5, many participants had difficulties forming answers to assignments 1 and 2 that showed congruency between the three representations. Some students did not provide macroscopic and microscopic representations, or they provided macroscopic and microscopic representations that did not support their calculations. This lack of consistency between the representations indicates difficulties in conceptual understanding (Chandrasegaran, Treagust and Mocerino, 2008). As identified by Treagust, Chittleborough and Mamiala (2003), this lack of coherence resulted in the development of additional alternate conceptions (notably Students 11252, 62537 and 29425). Tentatively, the results of this study suggest that a lack of effort in creating cohesion between the three representations may also be an indicator of student attitude towards scientific understanding (Chu, Treagust and Chandrasegaran, 2008).

Chu, Treagust and Chandrasegaran (2008) demonstrated that students that believe physics knowledge is conceptual (or "concepts") generally show a greater understanding and tend to do better in physics, whereas students with "weak concepts", "apparent concepts" or "formalism" beliefs (that is physics knowledge is formulaic or symbolic in nature) tend to study formulas without trying to have conceptual (or in this case, microscopic and macroscopic) understanding. These students tend to be less proficient in physics. Thus, if students are convinced that physics knowledge is conceptual (or in this case, students believe that in order to understand physics, they need to understand the interrelation of the macroscopic, microscopic and symbolic), then better understanding should result.

Tentative evidence to support this perspective was previously discussed. A student (30913) who was not necessarily proficient in chemistry completed only the calculations for the assignments, as he did not think it was necessary to have microscopic and macroscopic understanding. Nor did he have microscopic or macroscopic understanding of pressure and Boyle's Law. Even though the motivation was mark driven, he made an effort to understand microscopic and macroscopic representations, and achieved conceptual understanding of pressure and Boyle's Law as determined by the three post-test scores.

Analyzing students' alternate conceptions through the frameworks established by Freyberg and Osborne (1985) and Chu, Treagust and Chandrasegaran (2008) not only provided a lens for analysis, but important information to guide teaching strategies.

8.9.4 The use of models in different contexts. As demonstrated in the process-folios, students may have difficulties when a change in context occurs. Evidence from this study supports the suggestions of Jonassen, Peck and Wilson (1999) who discuss the importance of having students practice the concepts in multiple, real-world contexts.

8.9.5 The use of physical models. Statements by students and analysis of process-folios indicate that the use of physical models that were (a) hands-on, (b) "...explicit in its target" (Lewthwaite, personal communication, date unknown), in this case by exaggerating parts that are essential to understanding a concept and minimizing or removing other parts (such as the ear model), and (c) placed in different authentic contexts (Jonassen, Peck and Wilson, 1999) were helpful in aiding conceptual understanding. It is suggested that students use or watch physical models and then predict and explain what is occurring using multiple representations.

8.9.6 Describing limitations to models. Chandrasegaran, Treagust and Mocerino (2008) suggest that it is important to describe limitations to models. In this study, at least two limitations in the models presented became a source of alternate conceptions for students. These alternate conceptions include:

1. Absolute numbers of internal and external particles acting on the surfaces of a balloon (or other flexible container) determine volume, rather than the relative pressures caused by internal and external particles; and
2. When a container increases or decreases in volume, the initial internal pressure is maintained even at equalization.

Though both of these limitations were discussed by the collaborating teacher. There is no evidence of the limitations being recorded on paper by the students.

Both limitations (Freyberg and Osborne, 1985) were confused by at least two students as being miniature versions of real life and resulted in alternate conceptions of the microscopic cause of pressure. Having students record the limitations or using different methods to show numbers of internal and external particles and internal and external pressures with students recording limitations of these models may aid student understanding of the use of models in science, and may also help students use target models more effectively.

8.9.7 Identifying, and challenging alternate conceptions and experiences that help form alternate conceptions. When experiences were cited for building models, these experiences either reinforced scientific conceptions (such as the video of exploding breast implants, or climbing mountains, or discussions of Sherpas) or alternate conceptions (such as vacuum cleaners). Educational researchers suggest that in order to prevent the development of alternative models, it is important to identify and challenge students' alternative conceptions (Akkus, Kadyifci, and Atasoy, 2011; Hazma and Wickman, 2007; Garnet and Treagust, 1992). Evidence from this study supports this suggestion. When experiences that helped form alternate conceptions were confronted and the model compared to the scientific model, this process appeared to have aided participants in learning target models.

For example, Student 22724 originally presented a model of a vacuum where the air particles were localized to the top and moved in the same direction (Figure 4.18). The experience cited as helping to form this model was the use of a vacuum cleaner. When this experience was directly addressed by the collaborating teacher and re-framed using the scientific model, the student was able to use target models to successfully predict the change of volume in a balloon in the next lesson.

Student 30913 initially thought that air particles in a syringe were "compacted together" and that gases were incompressible. The experience cited was difficulties with an air pump. This experience was addressed by the collaborating teacher who explained that the pump mechanism was stuck and used the demonstration syringe as the "pump". Afterwards, this student was able to show target models of gases (in terms of relative spacing and movement) in all of the lessons that followed.

A third experience reported by the collaborating teacher was addressing the experiences of Student 46628, who thought that pressure increased with elevation based on her observations of a helium balloon shrinking over a period of time on the ceiling. This experience was directly addressed by the collaborating teacher, who explained that helium leaks out of the balloon over a period of days, causing it to shrink.

This student also cited the helium balloon experience when providing an incorrect answer for question 2, pre-test 1. She explained that the, "Experience I used when answering the question first time was a helium balloon floating on the ceiling." This was the experience that was challenged directly by the collaborating teacher during the teaching intervention. She was able to provide the correct answer for question 2 in the post-test because she replaced the experience that lead to alternate conceptions with an experience that reinforced target models. In this case, she stated that the "Experience I used second time was relating it to a bottle ascending from a deep pool." It appears that the direct confrontation of the humanistic experience that helped her form alternate conceptions combined with a humanistic experience that helped reinforce target models aided the student in conceptual understanding.

8.9.8 The use of two-tiered multiple choice tests for summative evaluations. As previously discussed in chapters 6 and 7, two-tiered diagnostics can provide information about student conceptions that may not be apparent in traditional multiple choice tests (reviewed Adadan and Savasci, 2012). Distracters can be developed from class observations and those indentified and described in the literature.

For example, in post-test 1, questions designed by de Berg (1995, p. 874-875) and adapted for the two-tiered multiple choice test for both the syringe and cylinder questions were useful for determining if students used arithmetic or proportional reasoning. Also, questions 4 and 19 (Appendix A) were useful for identifying linear reasoning of pressure (Basca and Grotzer, 2001).

In post-test 2, questions 11, 18, 21 and 25 were useful for identifying alternate conceptions of ear equalization. In questions 11 and 18, students were asked to determine how equalization occurred. Questions 21 and 25 dealt with reverse block, where equalization was not possible. If students thought that the tympanum was like a door, then students would answer that the ear drum let both water and air through during equalization in questions 11 and 18, and the ear drum was swollen so water and air could not enter and leave the ear in questions 21 and 25.

Furthermore, in this study, alternate conceptions of EAL students were more readily apparent in their response to the two-tiered questions than responses to long answer questions. Two-tiered questions should be a type of summative assessment considered by teachers with EAL students.

8.9.9 Time and resources. This teaching intervention took approximately four and one-half weeks and addressed learning outcomes associated with pressure and

Boyle's Law. As evidenced by the process-folios and post-tests, the development of conceptual understanding is a long process, and requires students to think about and experience these concepts in different contexts (Johnassen, Peck and Wilson, 1999). The results of this study suggest that in order to challenge student conceptions and develop conceptual understanding (where students can explain scientific concepts with respect to four representations and create congruent links between them), more time is required

8.10 Suggestions for Future Studies

As each process-folio potentially documents the partial models made by students during a lesson (Coll and Gobert, 2000), it would be of value to analyze the changes in conceptions during a lesson and throughout a teaching sequence. Analysis may reveal if a model from one student convinces others to change their models, or if students mix models during discussions. It also may provide further insights as to experiences used to create these models, and which experiences seem to be more convincing than others. This information could be used to plan lessons where the more convincing experiences could be used as examples to reinforce target models.

It would also be valuable to evaluate the scuba activity itself, either through quantitative or qualitative means, or both. Analysis could potentially reveal if the scuba activity has an impact on learning that could be measured quantitatively. Analysis could also reveal how the activity impacts learning, which would likely be a consideration when looking at budgetary constraints.

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Appendix A

Pre- and post-test 1.

ID Number: ______________________________

Instructions: Circle the letter of the correct answer for each of the following questions. If no correct answers are available, write a detailed answer in the space provided marked "Other".

1. Which of the following statements about air pressure is true?

a) Air pressure pushes down only.
b) Air pressure pushes in all directions.
c) Air does not create pressure.

Because…

a) air particles exhibit random motion.
b) air particles move downward due to gravity.
c) air particles do not hit surfaces.
d) air pressure is the same as force.

Other:

2. Atmospheric pressure _______ with increased elevation.

a) Increases
b) Decreases
c) Stays the same

Because...

a) the air particles are more crowded further up.
b) the air particles are less crowded further up.
c) the crowding of particles does not change greatly from one place to another.
d) air itself does not create any pressure.

Other:

3. **There is a greater number of collisions caused by air particles on the inside surface of a balloon compared to the outside surface. The balloon will...**
   a) Expand
   b) Contract
   c) Stay the same volume

In this case, there is ____ pressure inside the balloon and ____ pressure outside of the balloon.

a) air, no
b) positive, negative
c) negative, positive
d) the same, the same

Other:

4. **A balloon is blown and tied up. The balloon does not change shape once it is tied up. Atmospheric pressure in the room is 1 atm. What is the air pressure inside the balloon?**
   a) 0 atm
   b) 1 atm
   c) 2 atm

Because...

a) there are the same number of air molecules outside and inside the balloon.
b) air molecules are packed together inside the balloon so the balloon maintains the same shape.
c) the air molecules bouncing on the outside of the balloon keep the balloon the same shape.
d) the average number of air molecule collisions on the inside surface of the balloon inside is the same as the average number of air molecule collisions on the outside surface of the balloon.

Other:

5. The mathematical formula for Boyle's law is…

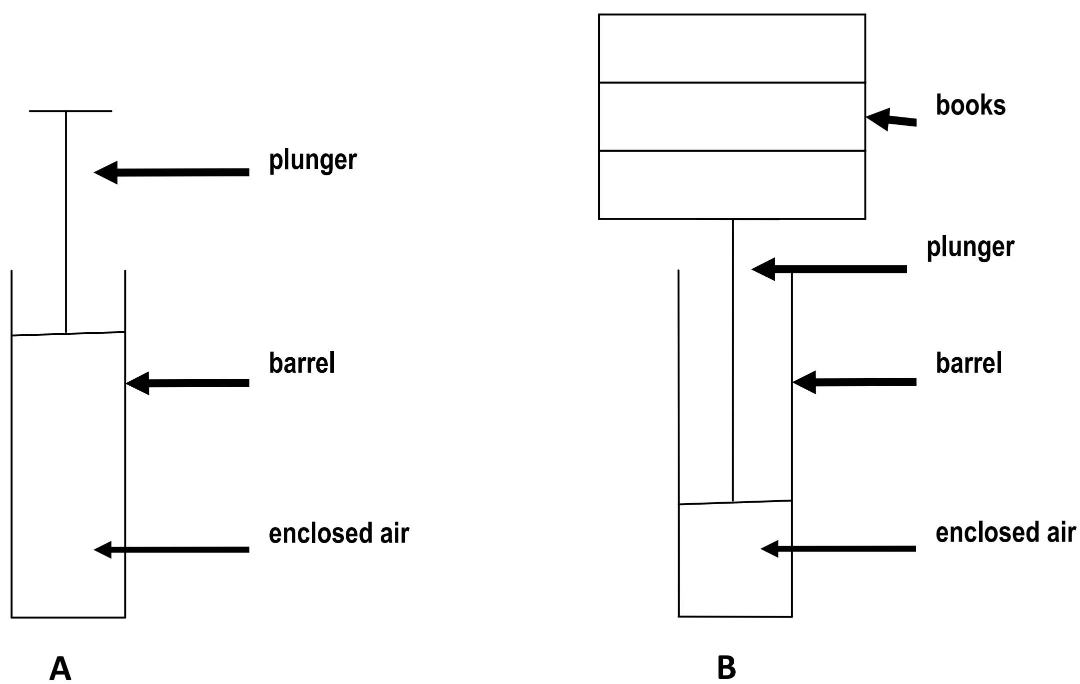
a) $V_2 = V_1(P_2/P_1)$
b) $V_2=V_1P_2P_1$
c) $V_2 = V_1(P_1/P_2)$

This formula predicts that…

a) The amount of pressure is always the same as the volume.
b) When ambient pressure increases volume increases.
c) When ambient pressure increases volume decreases.
d) There is no way to predict how the pressure will affect the volume

Other:

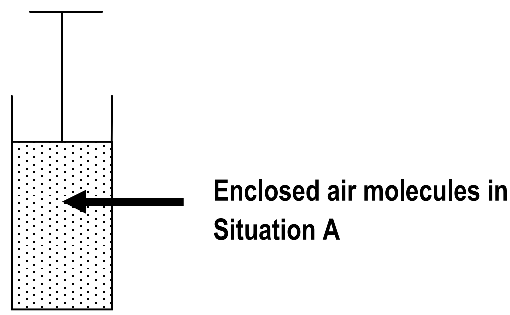
The following diagram represents a sealed syringe in two situations, A and B. In situation B, the plunger has been pushed down the barrel of the syringe without any air leaking into or out of the barrel. Answer the next two questions (questions 6 and 7) based on this diagram.

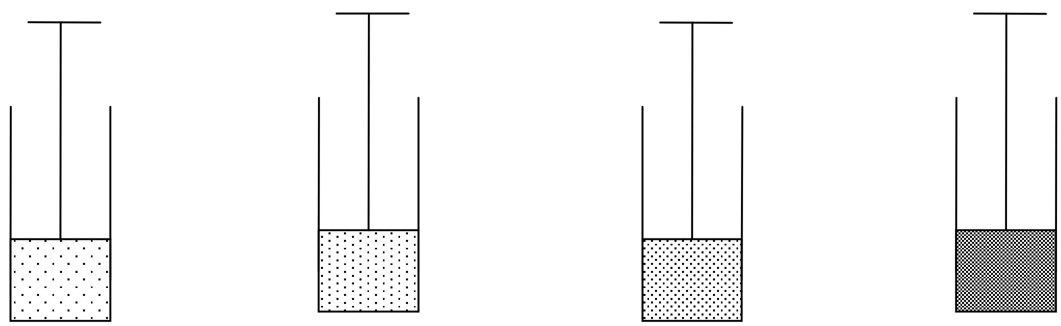


6. What happens to the volume of the enclosed air?

a) The volume of enclosed air in A is *greater* than the volume of enclosed air in B
b) The volume of enclosed air in A is *less than* the volume of enclosed air in B
c) The volume of enclosed air in A is the *same as* the volume of enclosed air in B.

Pretend you have on "molecular goggles" and can see the air molecules inside the syringe. Below are a series of pictures with accompanying descriptions that show what the enclosed air molecules would look like, with a description of the movement of the molecules. Circle the picture which best shows the air and what the enclosed air would look like in situation B.





a) Situation B	**b) Situation B**	**c) Situation B**	**d) Situation B**
Larger spaces between enclosed air molecules compared to situation A	**Similar spaces between enclosed air molecules compared to situation A**	**Smaller spaces between enclosed air molecules compared to situation A**	**No spaces between enclosed air molecules compared to situation A**

Other:

7. What happens to the pressure of the air enclosed in the syringe?

a) The pressure of enclosed air in B is *greater* than the pressure of enclosed air in A.
b) The pressure of enclosed air in B is *less than* the pressure of enclosed air in A.
c) The pressure of enclosed air in B is *the same as* the pressure of enclosed air in A.

Which of the following statements about situation B is true?

a) Compared to situation A, the average number of collisions of enclosed air particles with inside surfaces decreases.
b) Compared to situation A, the average number of collisions of enclosed air molecules with inside surfaces increases.
c) Compared to situation A, the enclosed air molecules are wedged against the inside surfaces of the syringe.
d) Compared to situation A, the average number of collisions is about the same.

Other:

A student does three experiments with the syringe system in the previous question to see what happens when different pressures are put on the plunger. The student finds the following results. Use these results
To help you with questions 8 - 11.

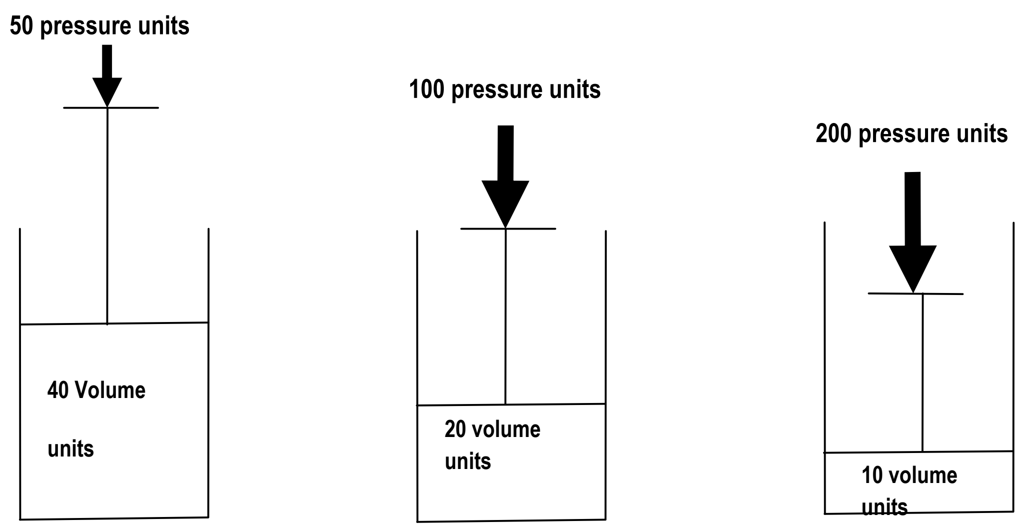


Diagram reproduced with permission from de Berg, 1995, p. 875 © Kevin Charles de Berg, 1995.

8. The student exerts 25 pressure units on the plunger as shown. The volume of the enclosed air would be ____ volume units.

a) 8
b) 16
c) 60
d) 80

Pretend you have on "molecular goggles" and can see the air molecules. Which statement best describes the spacing and movement of the enclosed air particles at 25 units pressure compared to 50 units pressure?

a) At 25 units pressure, spaces between enclosed air particles are decreased, resulting in more surface collisions.
b) At 25 units pressure, spaces between enclosed air particles are increased, and result in less surface collisions.
c) At 25 units pressure, spaces between enclosed air particles are about the same, and on average there the same number of surface collisions.
d) At 25 units pressure, there are no spaces between enclosed air particles, and there is little movement because space is completely packed.

Other:

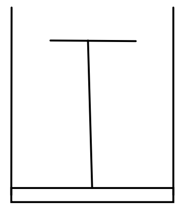
9. **The student then exerts 150 pressure units on the plunger as shown. The volume of the enclosed air would be ____ volume units.**
   a) 5
   b) 13
   c) 30
   d) 60

Pretend you have on "molecular goggles" and can see the air molecules. Which statement best describes the spacing and movement of the enclosed air particles at 150 units pressure compared to 50 units pressure?

a) At 150 units pressure, spaces between enclosed air particles are decreased, resulting in more surface collisions.
b) At 150 units pressure, spaces between enclosed air particles are increased, and result in less surface collisions.
c) At 150 units pressure, spaces between enclosed air particles are about the same, and on average there the same number of surface collisions.
d) At 150 units pressure, there are no spaces between enclosed air particles, and there is little movement because space is completely packed.

Other:

The student then exerts a pressure on the plunger which forms 5 volume units of enclosed air as shown below.



5 Volume units

10. The pressure on the plunger would be ___ pressure units.

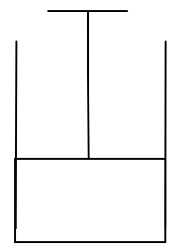
a) 25
b) 75
c) 150
d) 400

At 5 volume units, the internal pressure is equal to...

a) the pressure exerted by the student.
b) the pressure exerted by the student and atmospheric pressure.
c) atmospheric pressure.
d) the pressure exerted by the student minus atmospheric pressure.

Other:

The student then exerts a pressure on the plunger which forms 30 volume units of enclosed air as shown below.



30 Volume units

11. The pressure on the plunger would be ___ pressure units.

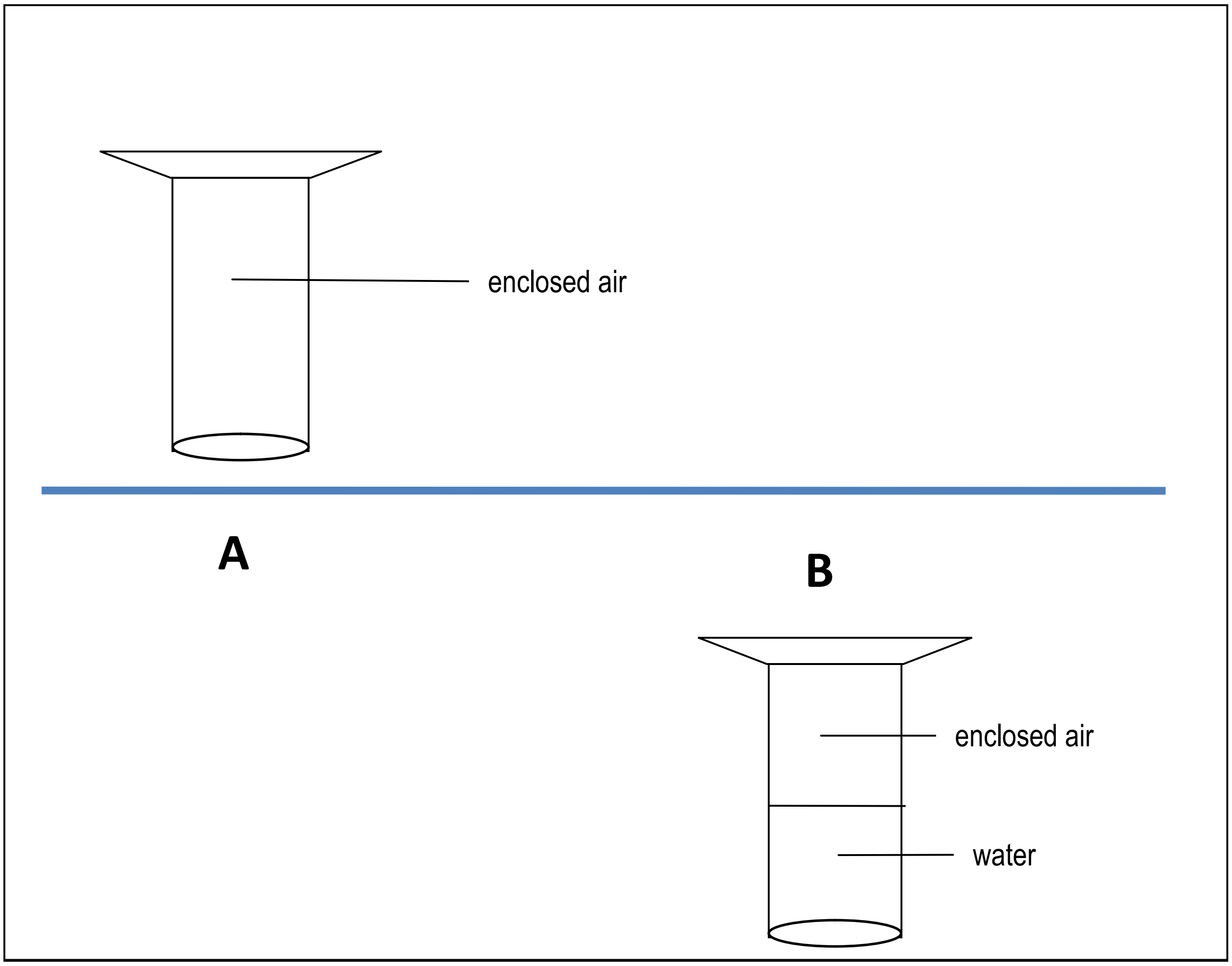
a) 7.5
b) 67
c) 75
d) 150

At 30 volume units, the internal pressure is equal to...

a) The pressure exerted by the student.
b) The pressure exerted by the student and atmospheric pressure.
c) Atmospheric pressure.
d) The pressure exerted by the student minus atmospheric pressure.

Other:

The following diagram represents an inverted cylinder in two situations, A and B. In situation A, the inverted cylinder is at the surface of the water or at a depth of 0m. The atmospheric pressure is 1 atmosphere. In situation B, the inverted cylinder is brought to a depth of 10 m (2 atm) without any air leaking into or out of the cylinder. Use these results to help you with the next two questions (12 – 13) .

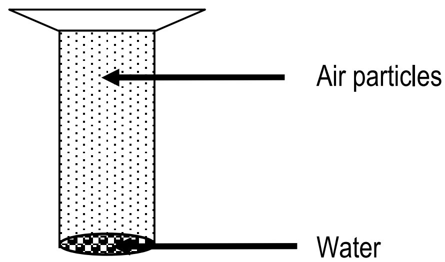


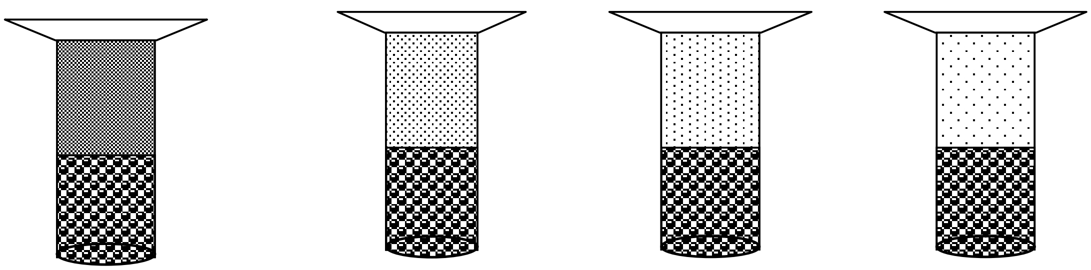
12. What happens to the volume of the enclosed air?

a) The volume of enclosed air in A is *greater* than the volume of enclosed air in B
b) The volume of enclosed air in A is *less than* the volume of enclosed air in B
c) The volume of enclosed air in A is the *same as* the volume of enclosed air in B.

Pretend you have "molecular goggles" on, and can actually see the air and water molecules. Below are a series of pictures with accompanying descriptions that show what the air and water molecules would look like inside the cylinder when brought down to a depth of 10m. Circle the picture which best shows the air and water molecules when the cylinder is brought down to 10m.

Situation A: Cylinder





a) Situation B	b) Situation B	c) Situation B	d) Situation B
No spaces between air molecules compared to Situation A	Smaller spaces between air molecules compared to Situation A	Same spaces between air molecules compared to Situation A	Larger spaces between air molecules compared to Situation A

Other:

13. In the experiment above, what happens to the pressure of the air enclosed in the cylinder?

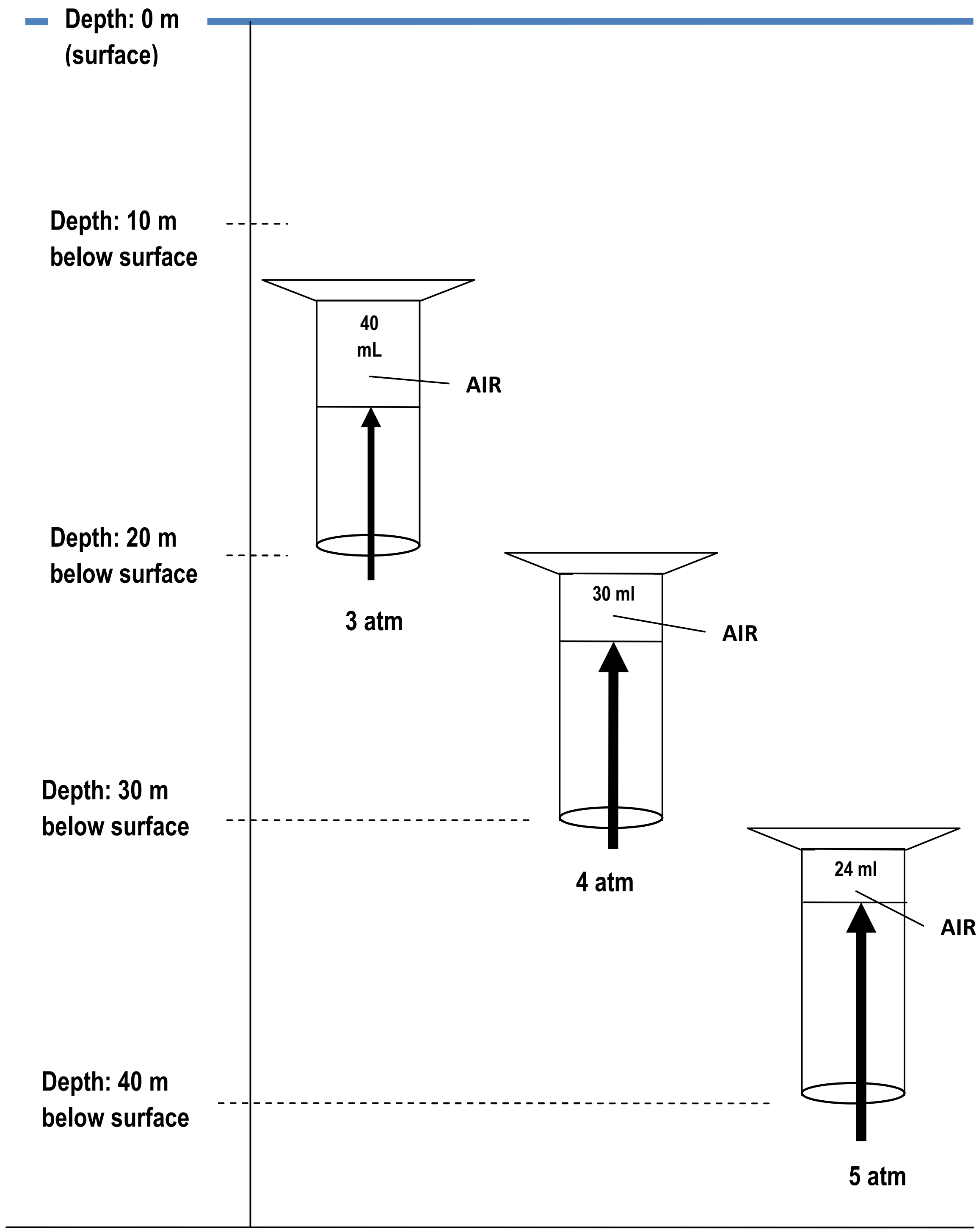
a) The pressure of enclosed air in B is greater than the pressure of enclosed air in A.
b) The pressure of enclosed air in B is less than the pressure of enclosed air in A.
c) The pressure of enclosed air in B is the same as the pressure of enclosed air in A.

Which statement about situation B is true?

a) Compared to situation A, the average number of collisions of enclosed air particles with the inside surfaces decreases.
b) Compared to situation A, average number of collisions of enclosed air molecules with the inside surfaces increases.
c) Compared to situation A, the average number of collisions of enclosed air particles with the inside surfaces is about the same.
d) Compared to situation A, the air molecules are wedged against the inside surfaces.

Other:

A student does three experiments with the inverted cylinder in the previous question to see what happens when the cylinder is brought to different depths. The student finds the following results. Use these results to help you with the following four questions (14 – 17) .



14. The student then descends to 35 m. Water pressure at this depth is 4.5 atm. What is the volume of the enclosed air space at this depth?

a) 27 ml
b) 36 ml
c) 60 ml

Pretend you have on "molecular goggles" and can see the air molecules enclosed in the cylinder. Which statement best describes the spacing and movement of the enclosed air particles when the cylinder is brought down to 35 m when compared to the surface ?

a) Smaller air spaces between enclosed air particles, greater numbers of collisions with inside surfaces.
b) Larger air spaces between enclosed air particles, smaller numbers of collisions with inside .
c) Same air spaces between enclosed air particles, same number of collisions with inside surfaces.
d) No spaces between enclosed air particles, enclosed space is completely packed.

Other:

15. What is the original volume of the enclosed air at the surface?

a) 0.08 ml
b) 14 ml
c) 120 ml

In this case, the pressure of the enclosed air space is equal to...

a) atmospheric pressure
b) water pressure.
c) atmospheric and water pressure.
d) atmospheric pressure minus water pressure.

Other:

16. The student dives to a depth such that the enclosed air in the cylinder is 20 ml. What is the pressure at this depth?

a) 6 atm
b) 12 atm
c) 267 atm

At 20 ml, the pressure of the enclosed air space is equal to...

a) atmospheric pressure
b) water pressure.
c) atmospheric and water pressure.
d) Water pressure minus atmospheric pressure.

Other:

17. At 60 ml, what is the pressure?

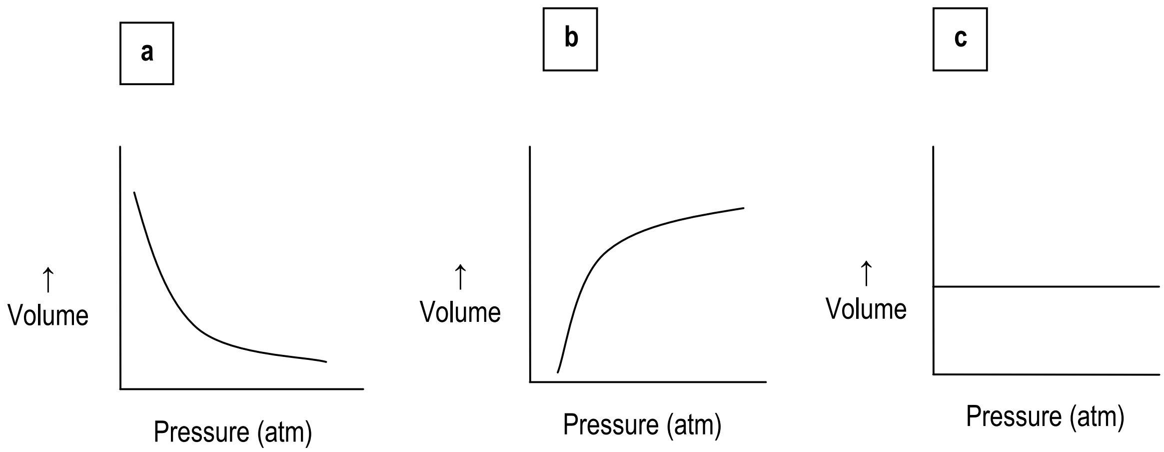
a) 0.5 atm
b) 2 atm
c) 25 atm

Pretend you have on "molecular goggles" and can see the air molecules enclosed in the cylinder. Which statement best describes the spacing and movement of the enclosed air particles when the cylinder is brought up to 10m when compared to 50m?

a) Smaller air spaces between enclosed air particles, greater number of collisions with inside surfaces.
b) Larger air spaces between enclosed air particles, smaller number of collisions with inside surfaces.
c) Same air spaces between enclosed air particles, same number of collisions with inside surfaces.
d) No spaces between enclosed air particles, enclosed space is completely packed.

Other:

18. According to Boyle's Law,which graph best shows the relationship between pressure and volume?



Because...

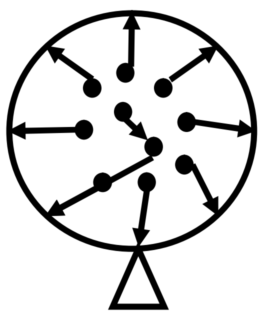
a) Pressure is directionally proportional to volume
b) Pressure is inversely proportional to volume
c) Pressure is the same as volume
d) There is no relationship between pressure and volume

Other:

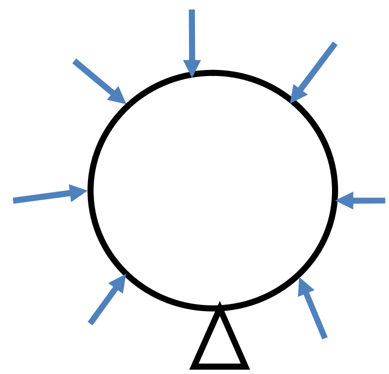
19. Atmospheric pressure in a classroom is 1.25 atm. In which situation is a balloon likely to remain the same volume?

a) Air pressure inside the balloon is 1.00 atm
b) Air pressure inside the balloon is 1.25 atm
c) Air pressure inside the balloon is 1.60 atm

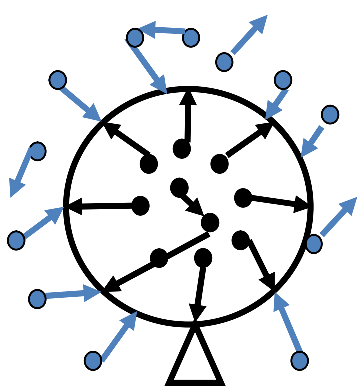
The picture that best shows the microscopic explanation as to why the balloon retains shape while it is tied up?



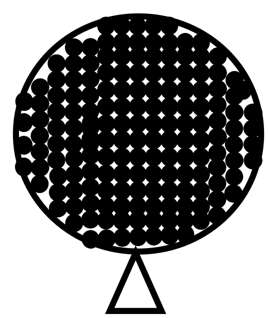
a) Air molecules inside the balloon collide with the inner surface to maintain shape.



b) Air molecules outside the balloon collide with the outer surface to maintain shape.



c) Average number of collisions of air molecules both inside and outside of the balloon are equal so balloon maintains shape.



d) Air molecules fill the balloon to maintain shape.

20. Atmospheric pressure in a classroom is 1.02 atm. In which situation is a balloon likely to expand?

a) Air pressure inside the balloon is 0.95 atm
b) Air pressure inside the balloon is 1.02 atm
c) Air pressure inside the balloon is 1.50 atm

Therefore…

a) on average, air molecules collide more often with the inside surface of the balloon than the outside.
b) on average, air molecules collide less often with the inside surface of the balloon than the outside.
c) on average, there are the same number collisions caused by air molecules on the inside and outside surface of the balloon.
d) on average, air molecules collide more often with the inside surface of the balloon, and no pressure occurs on the outside surface.

Other:

21. The air pressure in Winnipeg was measured at 101.5 kPa. While flying, in an airplane high above Winnipeg, the air pressure was measured at…

a) 103.6 kPa
b) 101.5 kPa
c) 100.2 kPa
d) 0 kPa

Because...

a) the air particles are more crowded further up.
b) the air particles are less crowded further up.
c) the crowding of particles does not change greatly from one place to another.
d) air itself does not create any pressure.

Other:

22. Which statement best describes the cause of atmospheric pressure at sea level.

a) air particles randomly hitting the surface of objects.
b) wind blowing causing pressure.
c) air does not normally create pressure.

At sea level, the atmospheric pressure is approximately…

a) 0atm
b) 1atm
c) 2 atm
d) none of the above.

Other:

Appendix B

Pre and post-test 2.

ID Number: ________________________________

Instructions: Circle the letter of the correct answer for each of the following questions. If no correct answers are available, write a detailed answer in the space provided marked "Other".

1. The middle ear is normally filled with...

a) air.
b) water.
c) mucus.

Normally, the only way for the substance named above to enter or leave the middle ear is through the...

a) tympanum.
b) ear canal.
c) Eustachian tube.
d) ear wax layer.

Other:

2. Normally, the ear drum is in which position?

a) Fairly vertical
b) Steeply curved towards the middle ear
c) Steeply curved towards the outer ear

Because…

a) The average number of collisions by air particles outside the ear drum is equal to the average number of air particles inside the middle ear.
b) The average number of collisions by air particles outside the ear drum is greater than the average number of collisions by air particles inside the middle ear.
c) The average number of collisions by air particles outside the ear drum is less than than the average number of collisions by air particles inside the middle ear.
d) Air does not exert pressure, so there is no pressure in the middle ear or ear canal.

Other:

3. In scuba diving, a pressure imbalance between an inside air space and outside the airspace is called…

a) squeeze
b) hypoxia
c) the bends
d) nitrogen narcosis

This imbalance is corrected by…

a) equalization
b) decompression chambers
c) oxygen therapy
d) the buoyancy control device (BCD)

Other:

4. Air can enter or leave the middle ear through...

a) the ear canal
b) the tympanum
c) the Eustachian tube

The "popping" sound caused when a person "pops" their ears is caused by...

a) the middle ear popping back into shape.
b) the ear canal popping out air or water.
c) the tympanum popping back into place.
d) the Eustachian tubes popping open.

Other:

5. During ascent while SCUBA diving, it is important to equalize...

a) Before you start feeling pain, approximately every meter or less.
b) When you start feeling a slight pain, or every two meters, whichever is first.
c) Whenever you start feeling pain.

Because…

a) it is unnecessary to equalize until pain occurs, only then is barotrama a danger.
b) the ears are continually equalized, reducing the risk of damage to the ear drum.
c) the ears are continually equalized, increasing the risk of damage to the ear drum.
d) equalizing too often is detrimental to the ear drum.

Other:

6. Mask squeeze normally occurs…

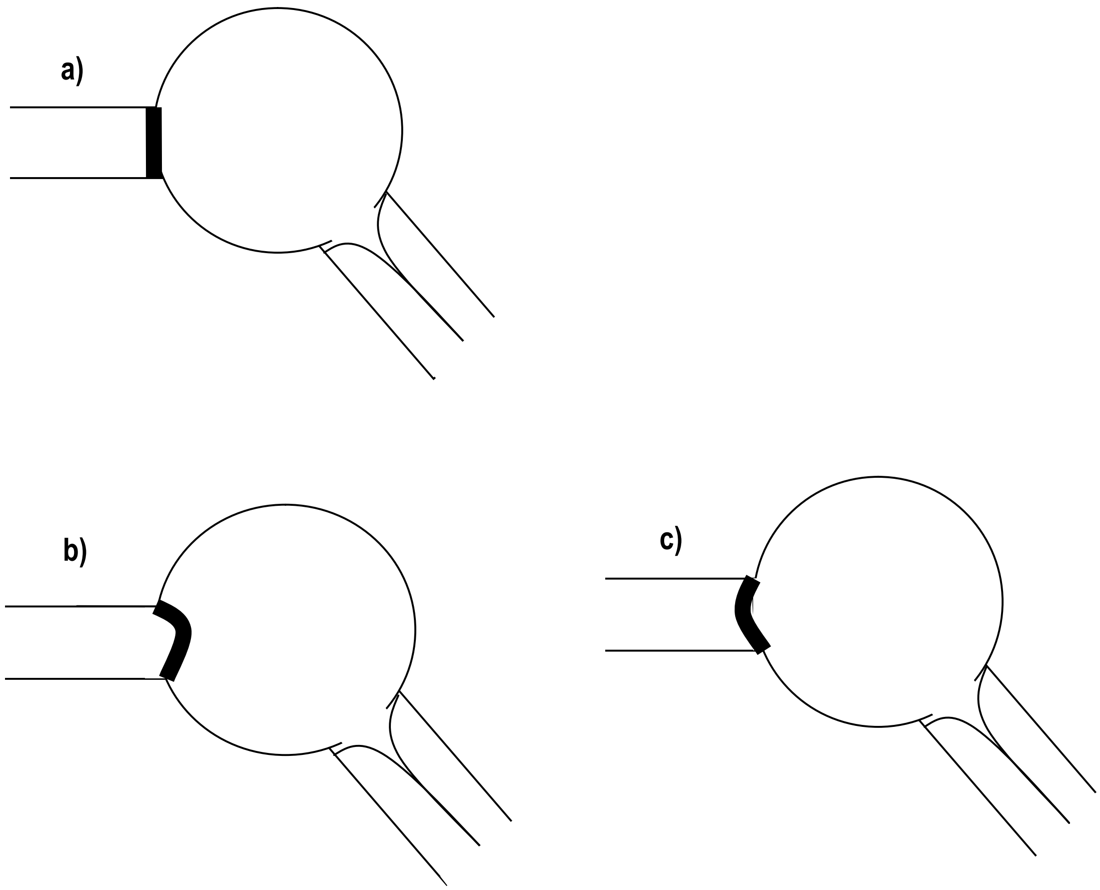
a) at the surface
b) during descent
c) during ascent

In order to correct the situation, it is important to equalize. In this case, by...

a) adding air molecules to the mask
b) taking away air molecules
c) adding water molecules to the mask
d) taking away water molecules from the mask.

Other:

7. Look at the following stylized diagrams of the ear. The ear drum is represented by a thick black line. Which picture shows the ear drum in the normal position?



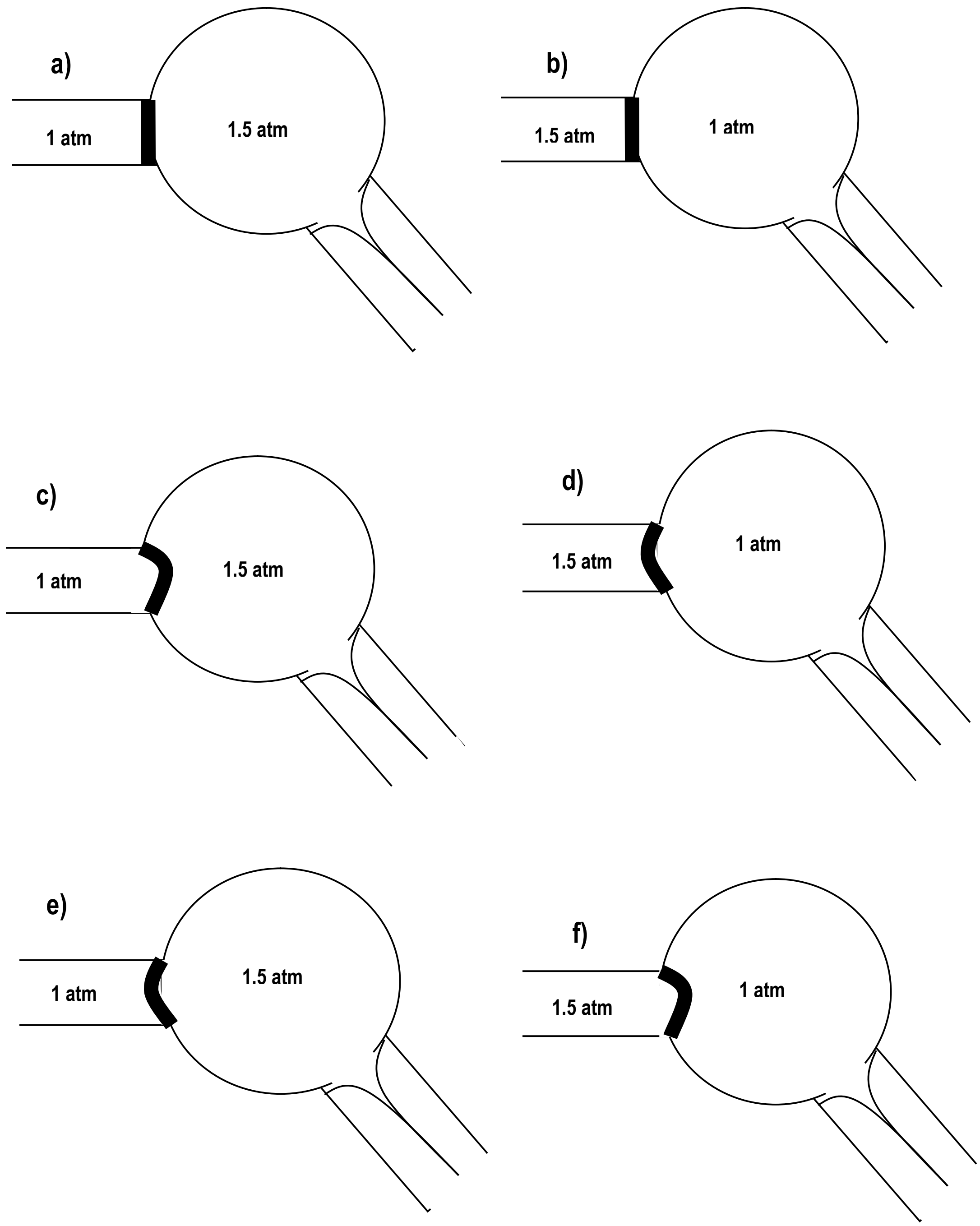
A person is at sea level, atmospheric pressure is at 1 atm. If the ear drum is in the normal position, the air pressure of the middle ear is…

a) 0 atm
b) 1 atm
c) 2 atm
d) 3 atm

Other:

A person is scuba diving in the ocean. Questions 7 and 8 involve diving downward (descent).

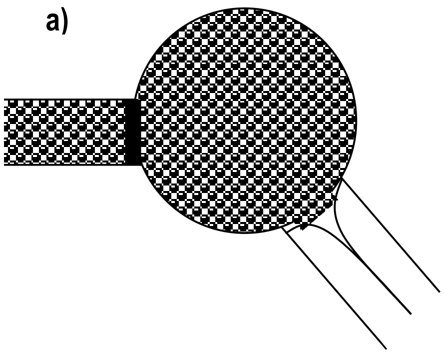
8. At the surface, the atmospheric pressure is 1 atm. She reaches a depth of 5m (1.5 atm), and experiences ear squeeze. Which picture best shows the relative pressures and position of the tympanum causing the squeeze?



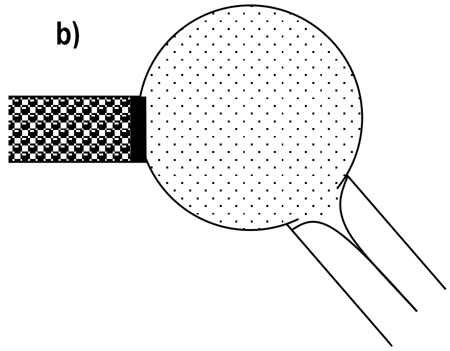
Pretend that you have on "molecular goggles" and can see into the passenger's ear.
Which picture best represents the air molecules in the middle ear and ear canal causing the ear ache at this depth?

Note: water molecules are represented by spheres ▩ air molecules are represented by small dots ⬚

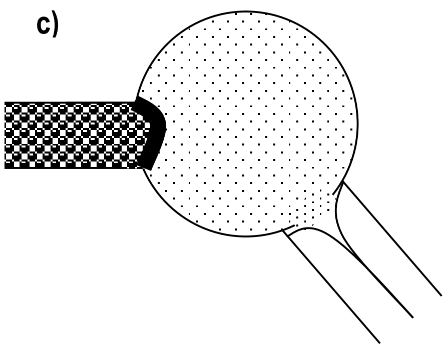
a)



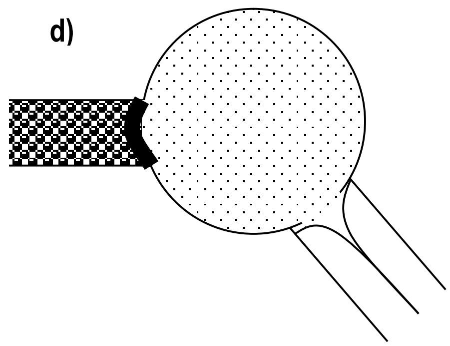
b)



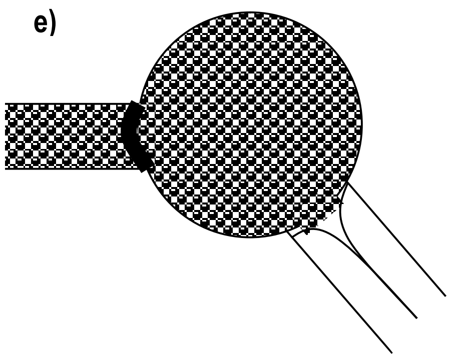
c)



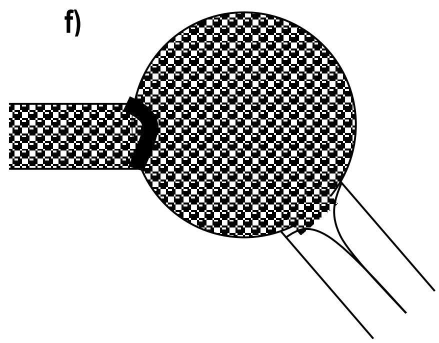
d)



e)

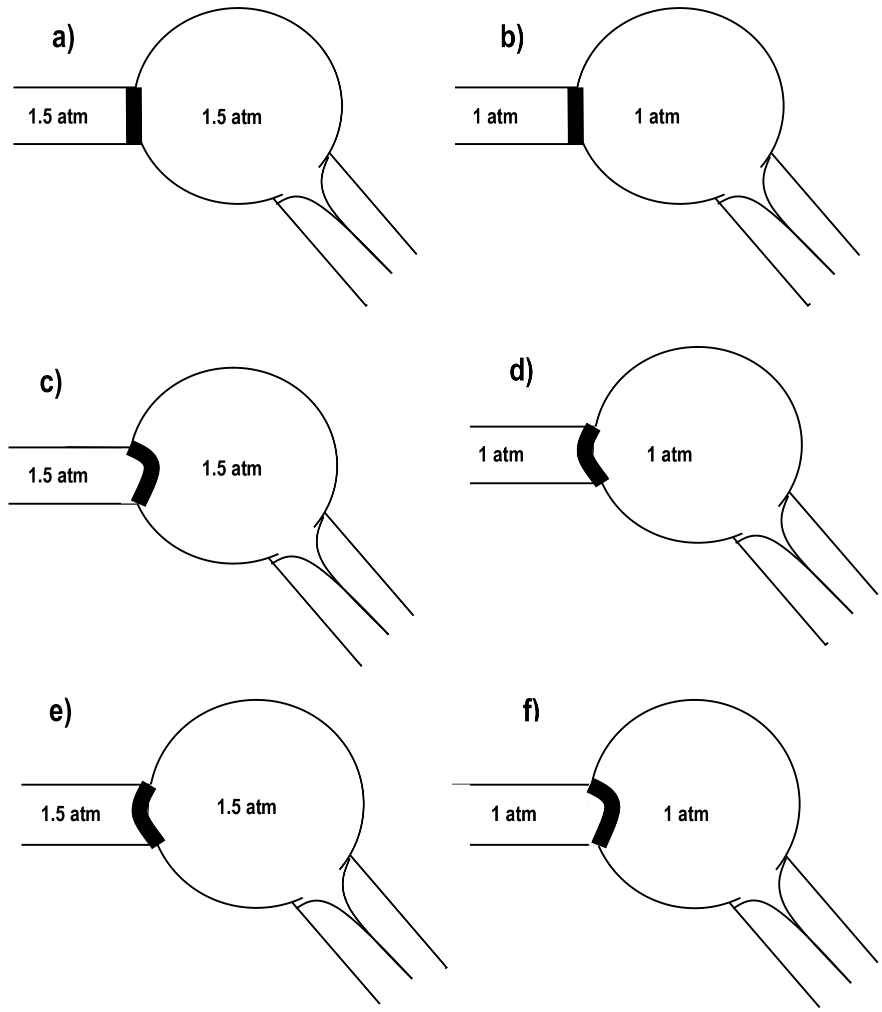


f)



Other:

9. The diver pops her ears at 5m depth (1.5 atm pressure) to relieve the pain. Which picture best represents what occurs inside the ear after the pressure has been relieved?



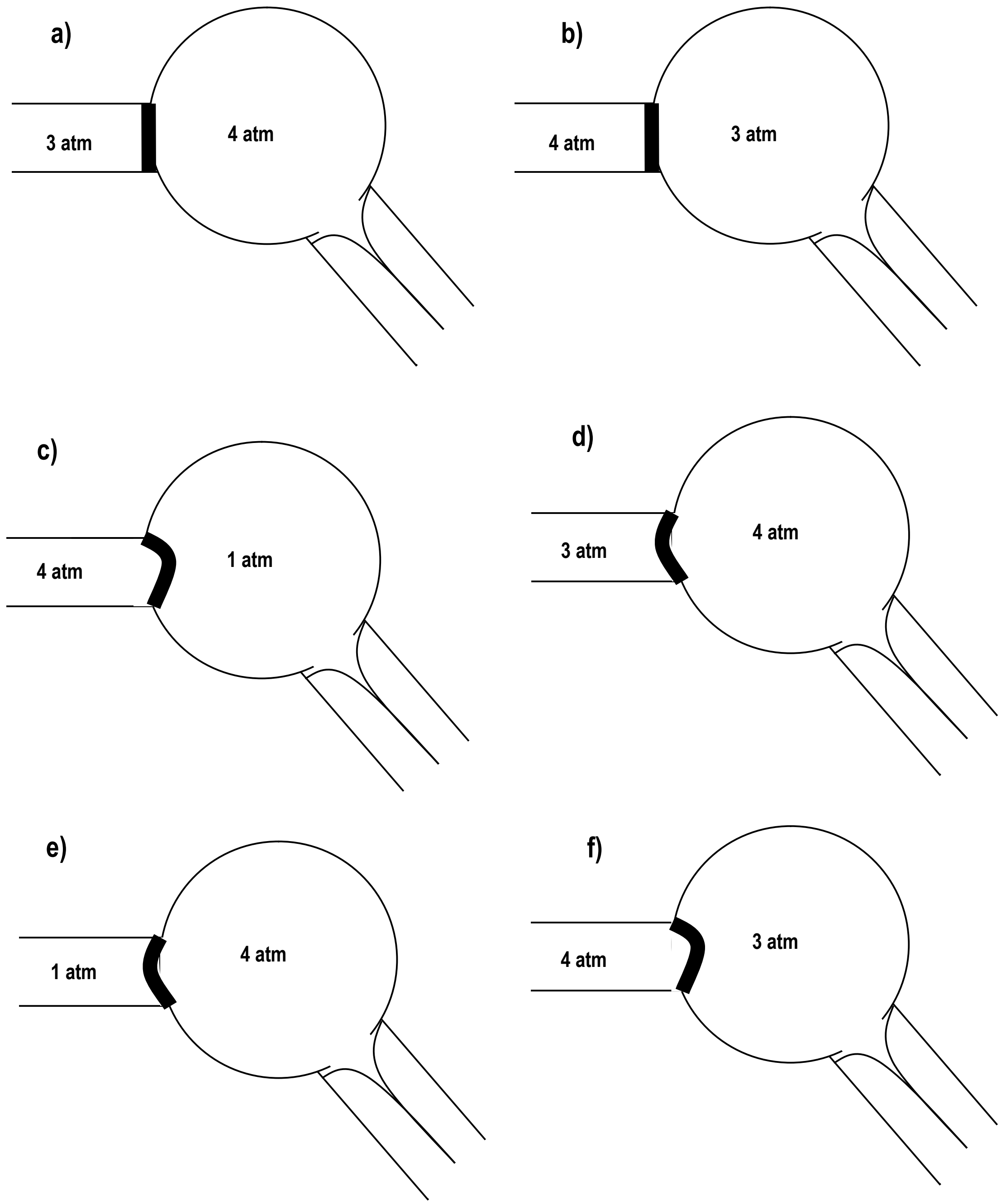
This process is accomplished by...

a) blowing water out of the middle ear through the ear drum.
b) blowing air out of the middle ear through the ear drum.
c) adding water to the middle ear via the Eustachian tube.
d) adding air to the middle ear via the Eustachian tube.

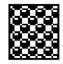
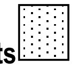
Other:

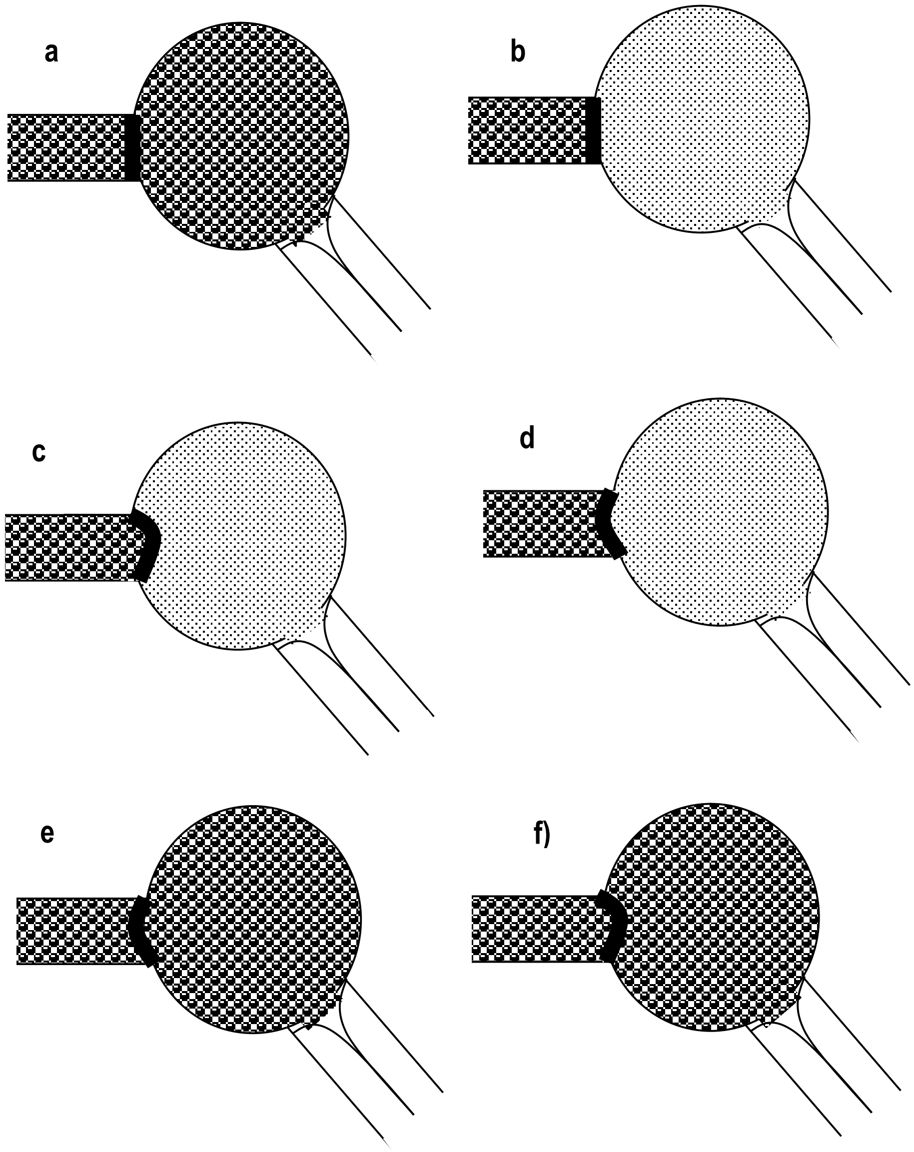
Now this person is swimming up to the surface. The next two questions (9-10) involve going up (ascent).

10. The diver reaches 30 m (4 atm), and equalizes her ears, then starts to ascend. At 20m (3 atm), the pain in her ears is unbearable. Which picture best shows the relative pressures and position of the tympanum causing the ear ache?



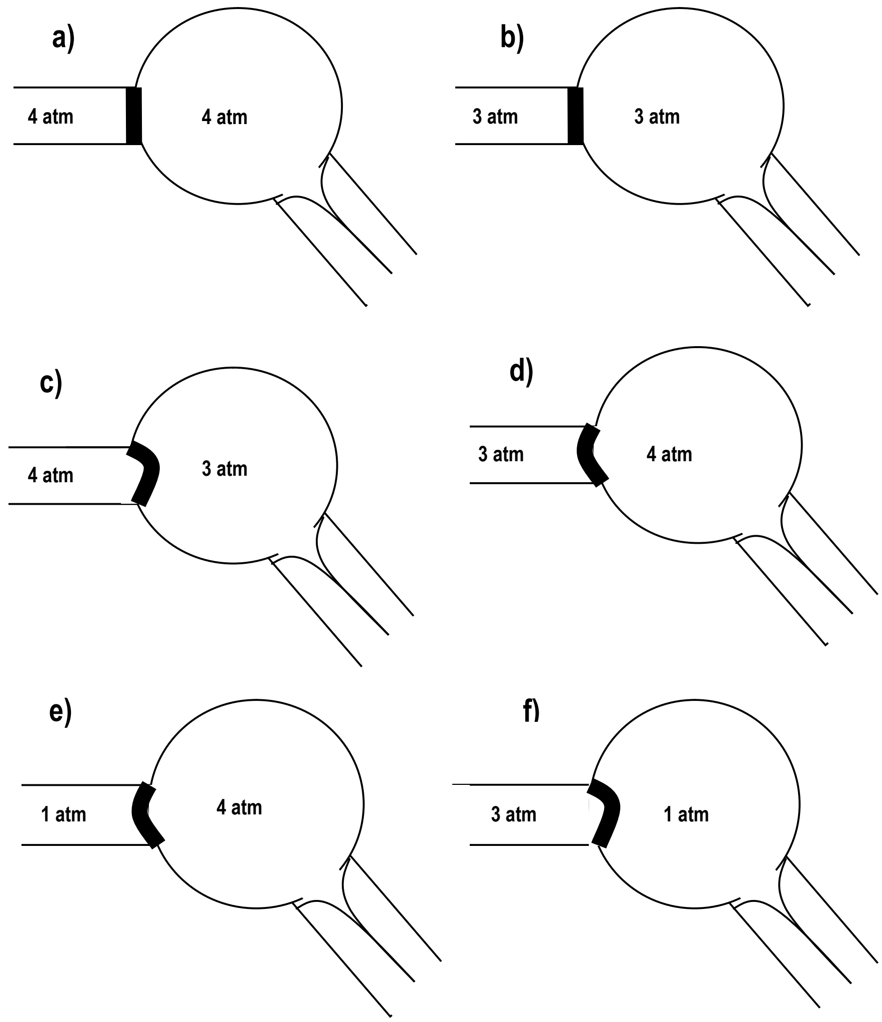
Pretend that you have on "molecular goggles" and can see into the passenger's ear.
Which picture best represents the air molecules in the middle ear and ear canal causing the ear ache at this depth?

Note: water molecules are represented by spheres  **air molecules are represented by small dots** 



Other:

11. At 20m depth (3 atm pressure) she pops her ears to relieve the pain. Which picture best represents what occurs inside the ear after the pressure has been relieved?



This process is accomplished by...

a) blowing water out of the middle ear through the ear drum.
b) blowing air out of the middle ear through the ear drum.
c) removing water from the middle ear through the Eustachian tube.
d) removing air from the middle ear through the Eustachian tube.

Other:

12. A diver experiences reverse block during ascent. The relative position of the tympanum at this point would be...

a) vertical.
b) curved towards the ear canal.
c) curved towards the middle ear.

The diver cannot equalize because...

a) the Eustachian tube is swollen closed and cannot be opened.
b) the ear drum is swollen and cannot open.
c) the middle ear is swollen and cannot pop back into shape.
d) the sinuses are swollen and cannot open.

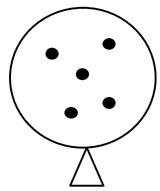
Other:

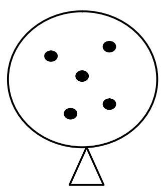
13. A scuba diver fills a balloon with air then descends to a depth of 40m (5 atm). We would expect the balloon to...

a) increase by 5 times the size.
b) decrease to 1/5 of the size.
c) stay the same size.

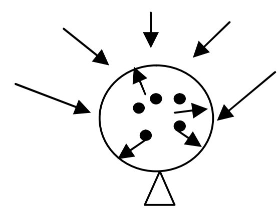
Because…

Original balloon at the surface.

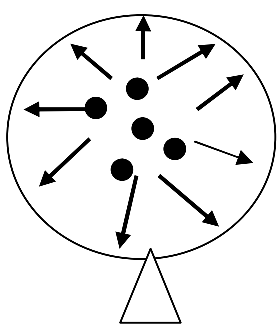




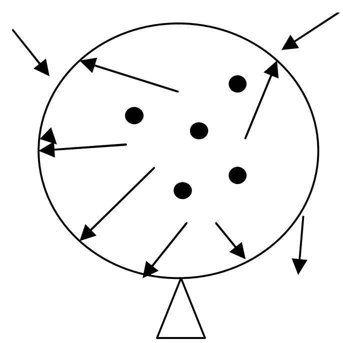
a) The balloon stays the same volume because the number of air molecules inside the balloon does not change .



b) The balloon decreases in volume because external pressure increases relative to internal pressure.



c) The balloon increases because air inside the balloon condenses resulting in greater internal pressure.



d) The balloon increases in volume because external air pressure decreases relative to internal air pressure .

Other:

14. A person holds their breath while ascending. Which of the following most accurately describes what is occurring in the lungs during the ascent?

a) The lungs would expand.
b) The lungs would contract.
c) The lungs would stay the same volume.

This diver would most likely experience...

a) no effect, because divers the lungs remain the same volume.
b) oxygen narcosis, due to the increased air in the lungs.
c) pulmonary barotrauma, due to the lungs expanding in volume.
d) hypoxia, due to the lungs decreasing in volume.

Other:

15. What should divers NEVER do while ascending?

a) Breathe out.
b) Hold their breath.
c) Breathe in and out calmly.

Because…

a) As a diver ascends, water pressure decreases and lung volume increases.
b) As a diver ascends, water pressure decreases and lung volume decreases.
c) The number of air molecules inside the lung volume stays the same regardless of water pressure.
d) As a diver ascends, water pressure increases and lung volume increases.

Other:

16. When scuba diving, order to breathe properly, the air pressure of the lungs must always be

a) less than the surrounding water pressure.
b) greater than the surrounding water pressure.
c) equal to the surrounding water pressure.

The piece of equipment responsible for ensuring proper air pressure in the lungs is the...

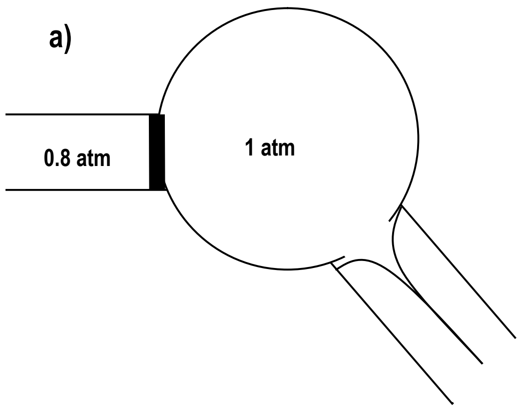
a) scuba tank.
b) buoyancy control device (BCD).
c) second stage regulator.
d) weight belt.

Other:

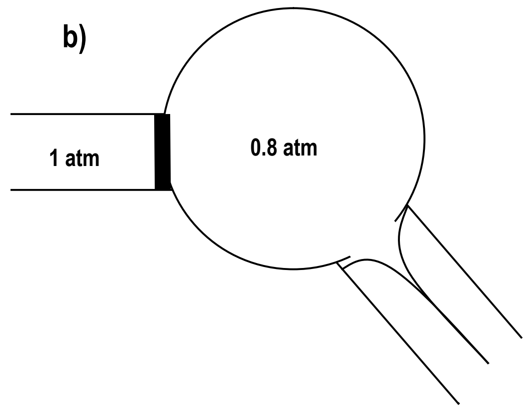
A passenger is taking a flight from Halifax (which is at sea level) to Vancouver. Questions 17-21 ask questions about the flight.

17. The passenger boards the flight and the airplane takes off. As the airplane increases elevation it reaches 6000m WITHOUT cabin pressurization. The passenger's ears are aching. Assuming the passenger's ear drums do not rupture, which picture best shows the relative pressures and position of the tympanum causing the ear ache?

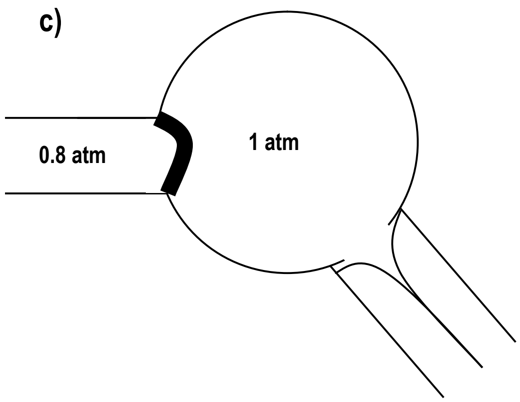
a)



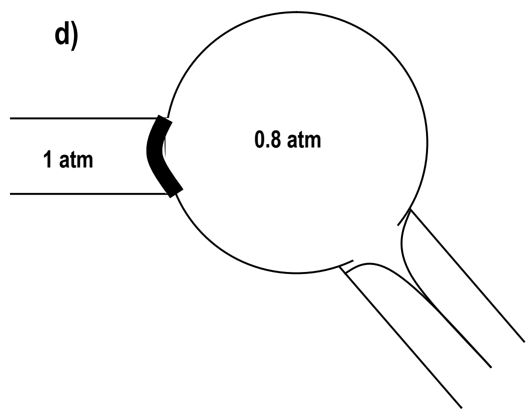
b)



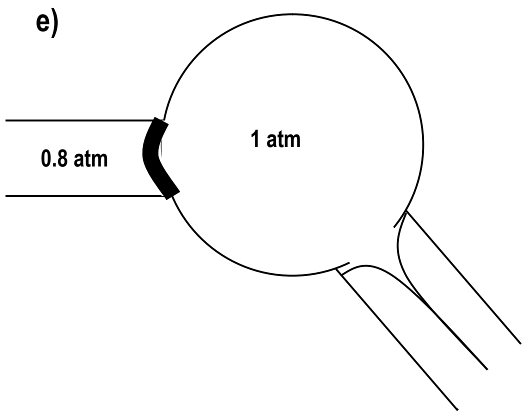
c)



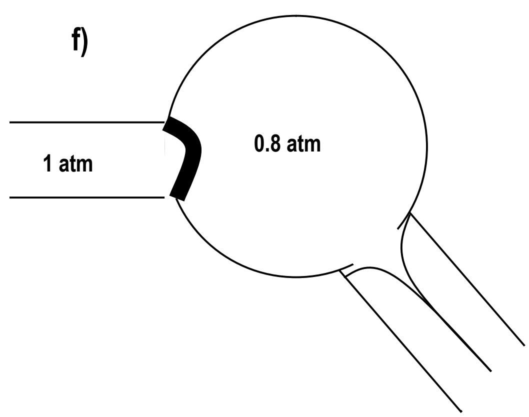
d)



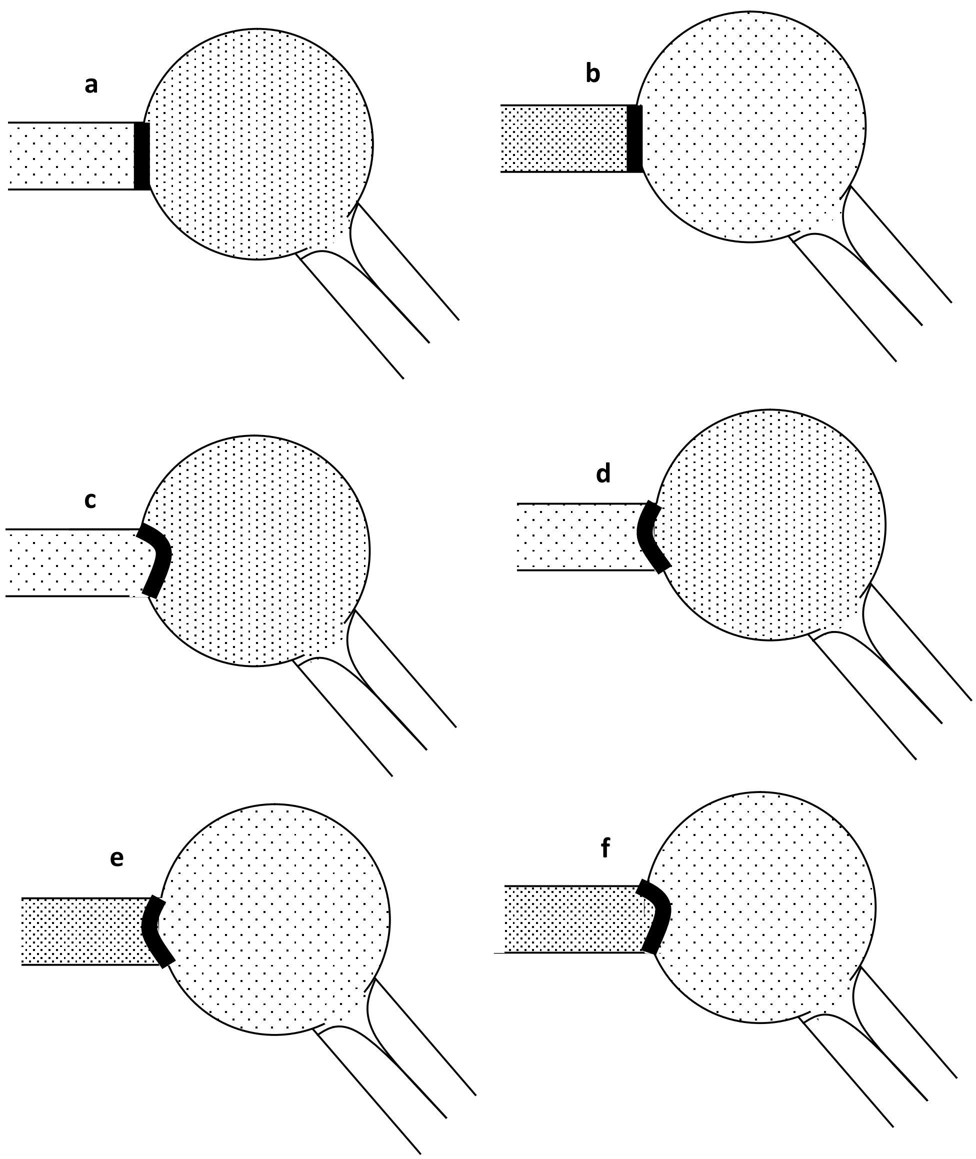
e)



f)

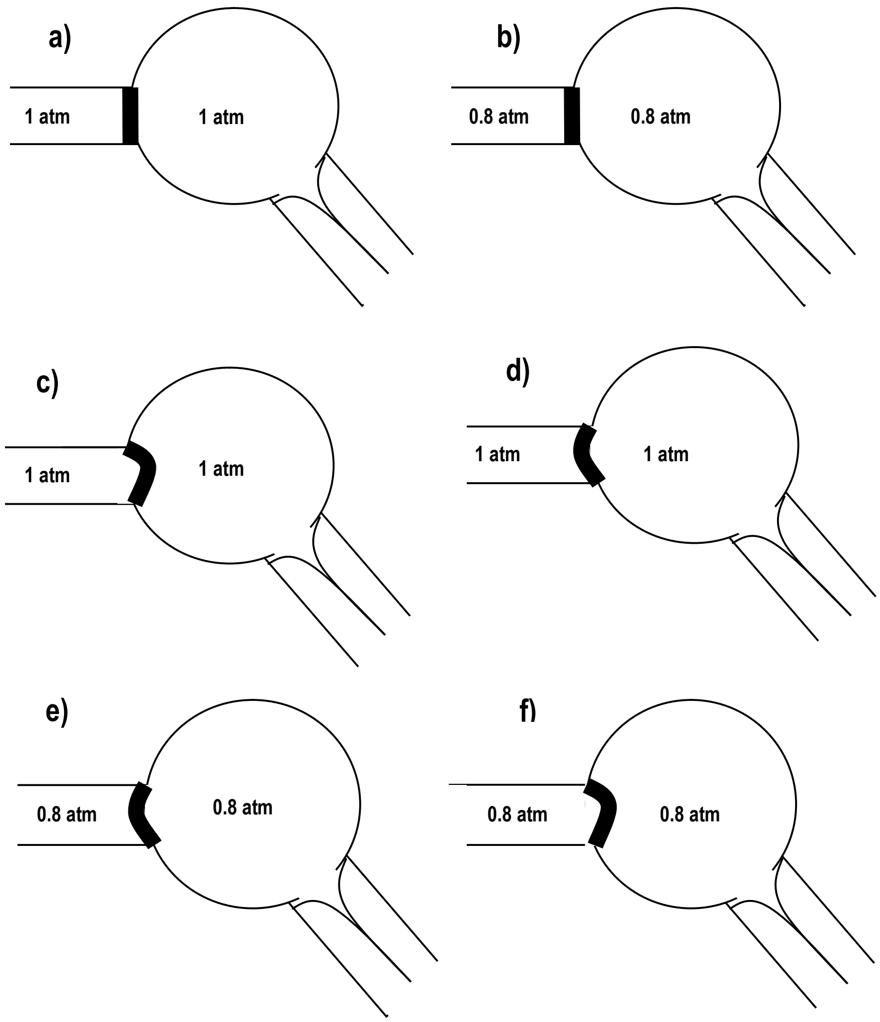


Pretend that you have on "molecular goggles" and can see into the passenger's ear.
Which picture best represents the air molecules in the middle ear and ear canal causing the ear ache at this elevation?



Other:

18. The cabin pressure at 6000 m is 0.8 atm. The passenger pops her ears to relieve the pressure. Which picture best represents what occurs inside the ear after the pressure has been relieved?

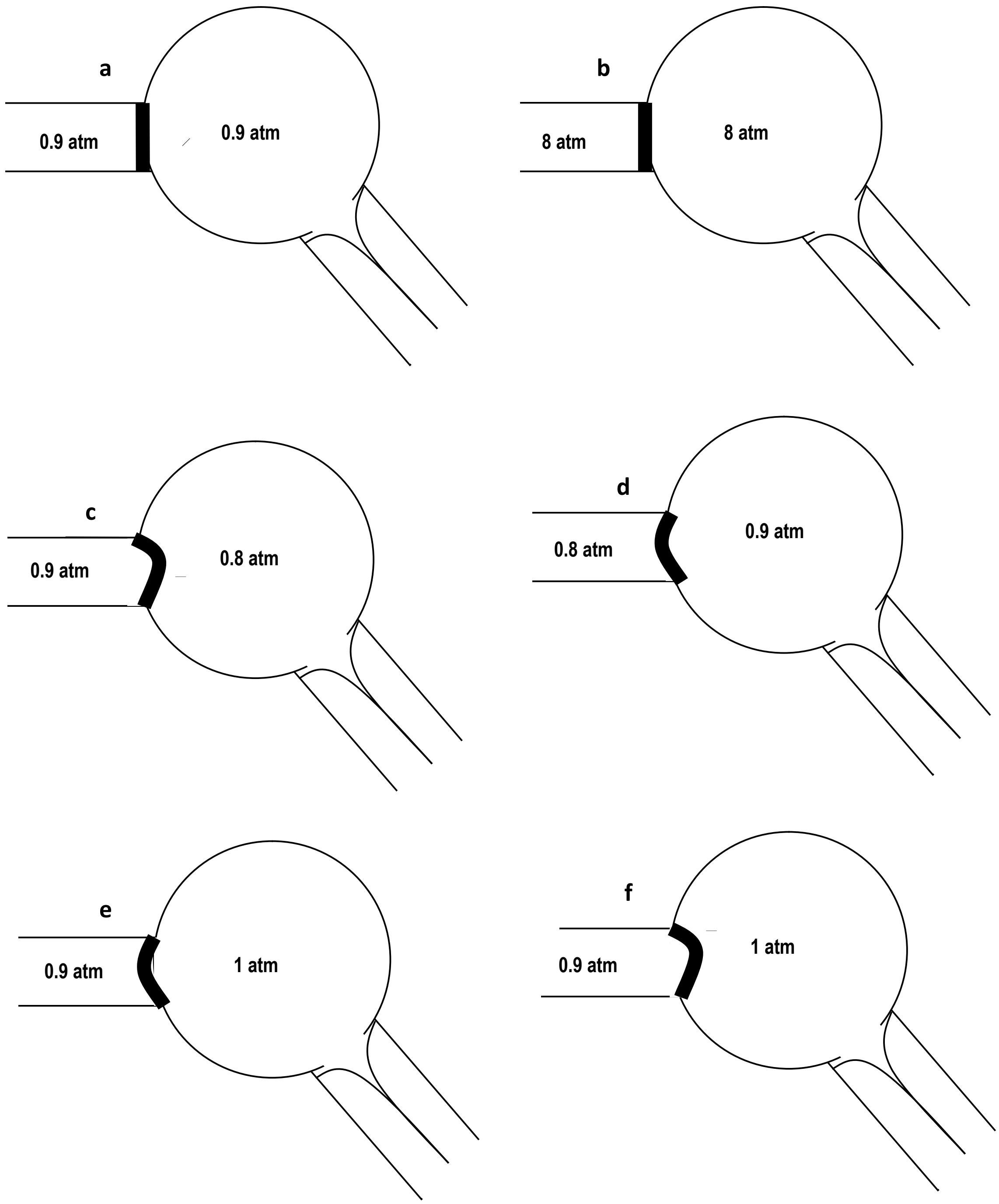


The pressure relief occurs because...

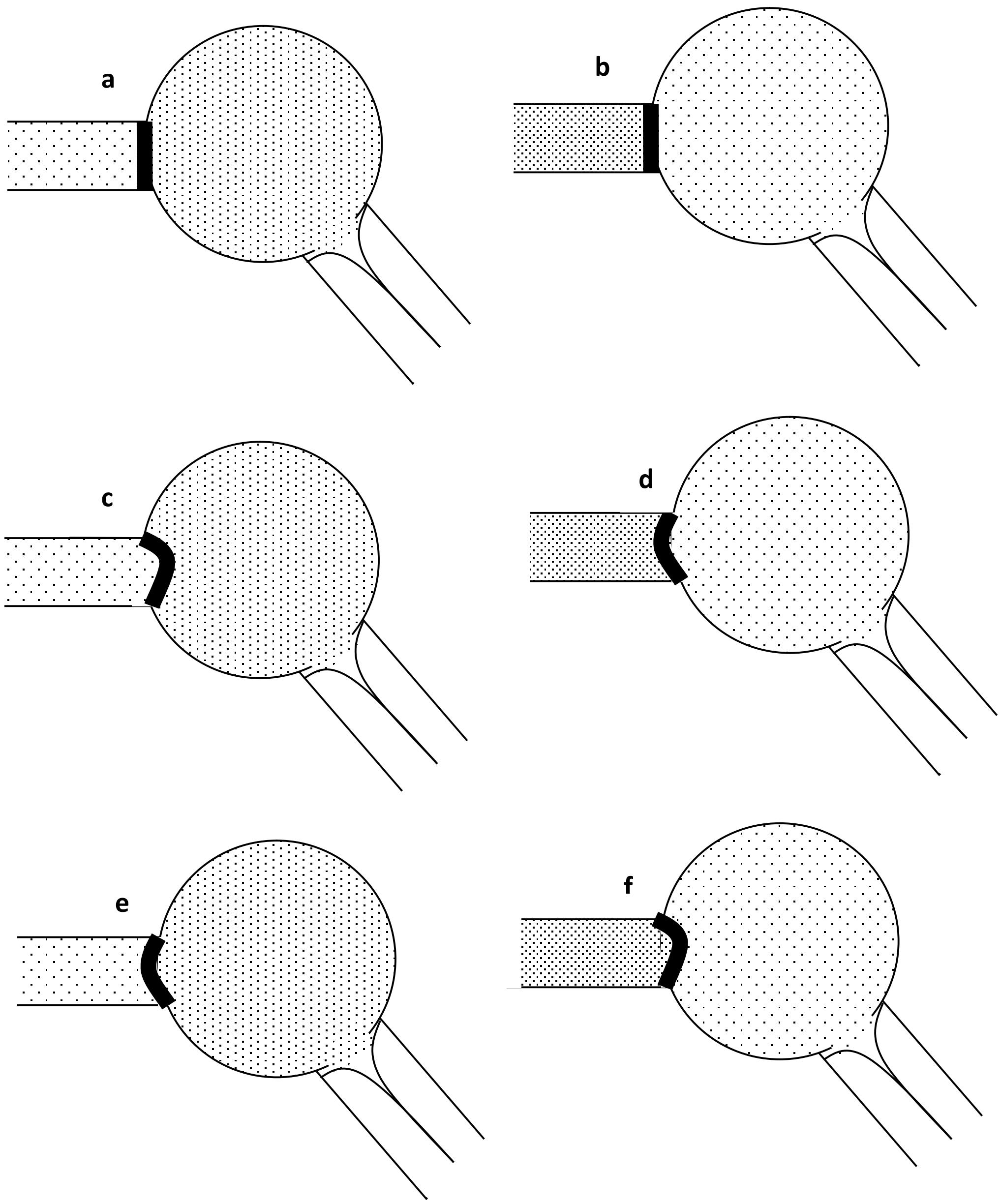
a) Air molecules are added to the middle ear through the Eustachian tube
b) Air molecules are removed from the middle ear through the Eustachian tube
c) Air molecules move from the middle ear to the ear canal through the ear drum
d) Air molecules move from the ear canal to the middle ear through the ear drum

Other:

19. The airplane is then pressurized to 0.9 atm. Again, the passenger feels pressure in her ears. Assuming the eardrum does not rupture, at this point, the position of the ear drum and relative pressures of the ear canal and middle ear are...

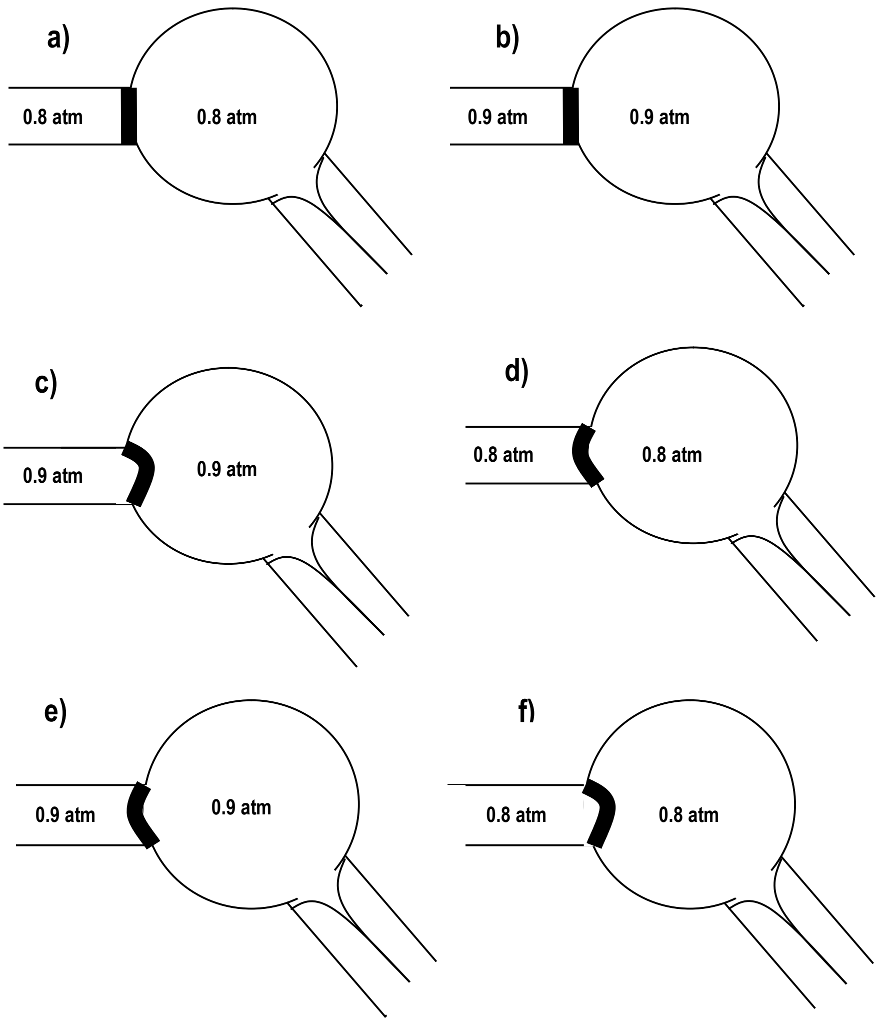


Pretend that you have on "molecular goggles" and can see into the passenger's ear.
Which picture best represents the air molecules in the middle ear and ear canal causing the ear ache at this elevation?



Other:

20. The passenger again pops her ears Which picture best represents what occurs inside the ear after the pressure has been relieved?

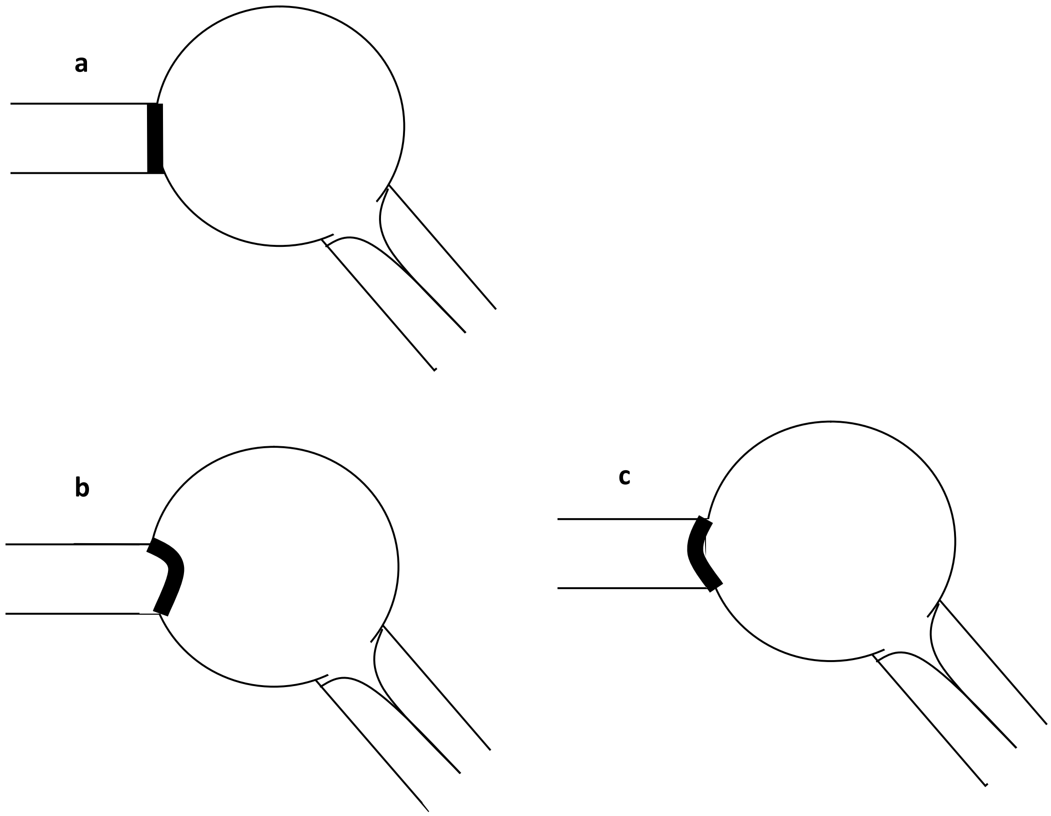


The pressure relief occurs because...

a) Air molecules are added to the middle ear through the Eustachian tube
b) Air molecules are removed from the middle ear through the Eustachian tube
c) Air molecules move from the middle ear to the ear canal through the ear drum
d) Air molecules move from the ear canal to the middle ear through the ear drum

Other:

21. A sick passenger on a flight has a stuffy nose. As the plane increases in elevation, which of the following pictures best depicts the relative position of the eardrum?



The passenger cannot pop his ears. The ear drums rupture because...

a) air cannot leave the middle ear through the Eustachian tube, preventing equalization.
b) air cannot leave the middle ear through the eardrum, preventing equalization .
c) the middle ear cannot pop back into shape, preventing equalization.
d) air cannot leave the sinuses, preventing equalization.

Other:

22. When rapid cabin depressurization occurs, which of the following is true?

a) there is positive cabin pressure and negative lung pressure
b) there is negative cabin pressure and positive lung pressure
c) cabin and lung pressure are the same

This results in...

a) air leaving the lungs causing hypoxia.
b) air entering the lungs causing pulmonary embolism.
c) air entering and leaving the lungs at the same rate causing no noticable effect.
d) air leaving the lung causing the lung to collapse.

Other:

23. The function of cabin pressurization during flight is to...

a) increase inside air pressure close to atmospheric pressure at sea level
b) decrease air pressure close to atmospheric pressure at cruising altitude
c) keep air pressure at the same as the outside at all times

This ensures that...

a) air pressure in the lungs is close to atmospheric pressure at the cruising altitude.
b) air pressure in the lungs is close to atmospheric pressure at sea level.
c) air pressure in the lungs is the same as the outside pressure.
d) atmospheric pressure in the lungs exceeds atmospheric pressure at sea level.

Other:

24. You are on a flight where the cabin is pressurized to 0.9 atm. Rapid cabin depressurization occurs, and the cabin pressure drops to 0.4 atm. The air pressure in the lungs of the passengers would become...

a) Close to 0.9 atm
b) Close to 0.4 atm
c) Close to 0 atm

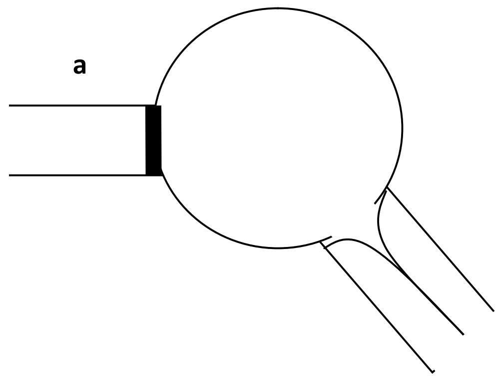
All passengers would become unconscious because...

a) air flowing from negative to positive pressure until ambient and internal pressures are equal. Passengers become unconscious due to lung over-inflation, then lung collapse.
b) air flowing from negative to negative pressure at the same rate. Passengers experience no noticeable effect.
c) air flowing from positive to negative pressure until ambient and internal pressures are equal. Passengers become unconscious due to lack of oxygen.
d) air flowing from positive to positive pressure at the same rate. Passengers experience no noticeable effect.

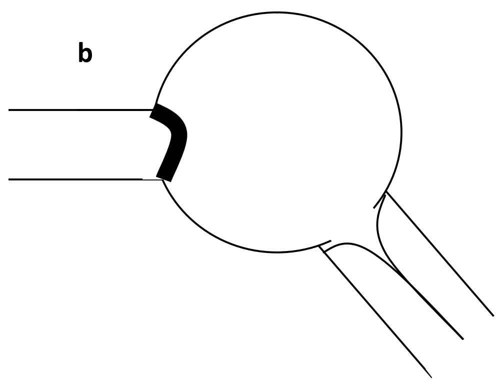
Other:

25. A sick person is on a flight and has a cold and uses a cold medicine. The passenger was able to pop his ears while at cruising altitude, but now the medication has worn off. The plane is preparing for landing and starts to descend. During descent, the relative position of the tympanum at this point would be

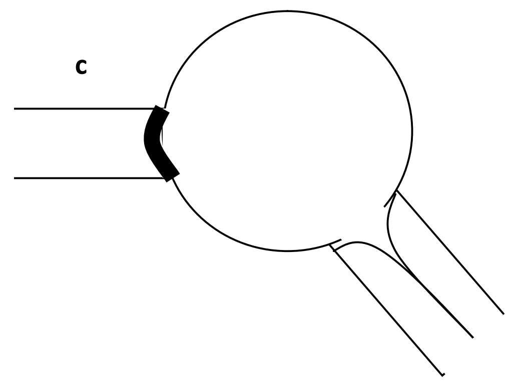
a



b



c



The passenger cannot pop his ears. The ear drum ruptures because...

a) air cannot leave the middle ear through the Eustachian tube, preventing equalization.
b) air cannot leave the middle ear through the eardrum, preventing equalization .
c) the middle ear cannot pop back into shape, preventing equalization.
d) air cannot leave the sinuses, preventing equalization.

26. The purpose of the scuba second stage regulator is to…

a) increase the air pressure from the scuba tank to the lungs.
b) reduce the air pressure from the scuba tank to the lungs.
c) ensure the air pressure is the same from the tank to the lungs.

This ensures that the air pressure in the lungs is…

a) Less than the surrounding water pressure
b) Greater than the surrounding water pressure
c) Equal to the surrounding water pressure
d) The same as the air pressure in the scuba tank.

Other:

27. What should divers ALWAYS do while ascending?

a) Breathe out while ascending.
b) Hold your breath while ascending.
c) Breathe in while ascending

Because…

a) This releases expanding air from the lungs.
b) This keeps expanding air in the lungs.
c) This releases condensed air from the lungs.
d) This keeps condensed air in the lungs.

Other:

28. A SCUBA diver experiences hamburger lung when he reaches the surface after a dive. Most likely, he…

a) held his breath during ascent.
b) exhaled during ascent.
c) hyperventilated during ascent.

This condition occurred because his lungs had...

a) over- inflated
b) over-compressed
c) shrunk
d) stayed the same volume

Other:

29. At 20m (3 atm pressure) a diver, fills up a balloon with air then swims to the surface. We would expect the balloon to…

a) Increase by 3 times the size
b) Decrease to 1/3 the size
c) Stay the same size

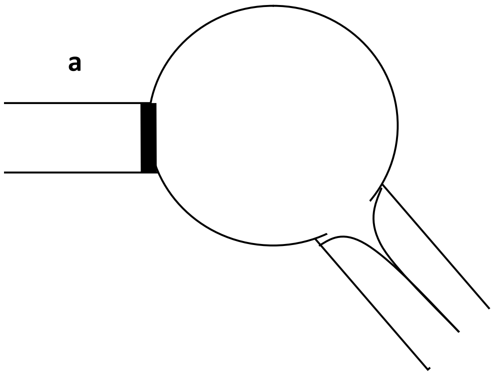
We would expect this change in volume because...

a) ambient pressure becomes less than internal air pressure.
b) ambient pressure becomes greater than internal air pressure.
c) ambient and internal pressures are the same.
d) ambient pressure changes at the same rate as internal air pressure.

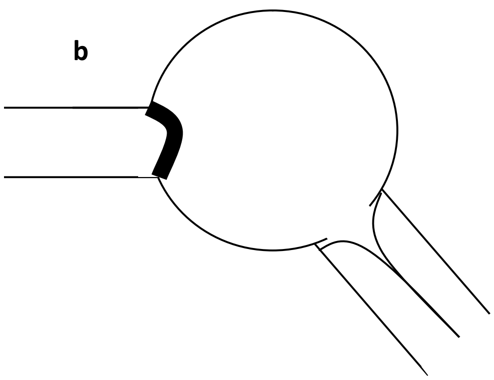
Other:

30. A diver experiences reverse block while trying to ascend. Which of the following pictures best depicts the relative position of the eardrum in this case?

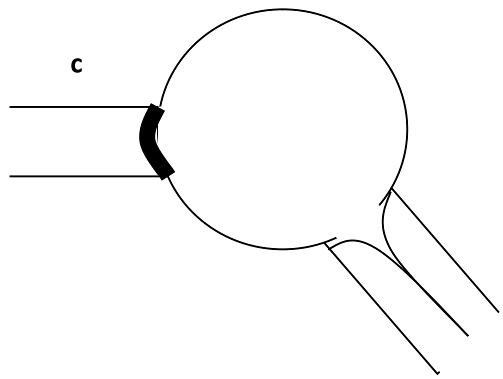
a



b



c



In this case, the diver cannot equalize and surfaces anyway. The diver's tympanum ruptures because...

a) air cannot leave the middle ear through the Eustachian tube, preventing equalization.
b) water cannot leave the middle ear through the eardrum, preventing equalization .
c) the middle ear cannot pop back into shape, preventing equalization.
d) water cannot leave the sinuses, preventing equalization.

Other:

31. If you have problems equalizing your ears during *descent*, what should you do?

a) Use short, forceful equalizations.
b) Use long, forceful equalizations.
c) Ascend then slowly, equalize gently, then descend again.
d) Descend then slowly, equalize gently, then ascend again.

This action will...

a) decrease water pressure against the ear drum, allowing another chance for the Eustachian tubes to open.
b) increase water pressure against the ear drum, allowing another chance for the Eustachian tubes to open.
c) decrease water pressure against the ear drum, allowing another chance for the ear drum to open.
d) increase water pressure against the ear drum, allowing another chance for the ear drum to open.

Other:

32. If you have problems equalizing your ears during *ascent*, what should you do?

a) Use short, forceful equalizations.
b) Use long, forceful equalizations.
c) Ascend then slowly, equalize gently, then descend again.
d) Descend then slowly, equalize gently, then ascend again.

This action will...

a) decrease water pressure against the ear drum, allowing another chance for the Eustachian tubes to open.
b) increase water pressure against the ear drum, allowing another chance for the Eustachian tubes to open.
c) decrease water pressure against the ear drum, allowing another chance for the ear drum to open.
d) increase water pressure against the ear drum, allowing another chance for the ear drum to open.

Other:

33. During descent while SCUBA diving, it is important to equalize

a) When you start feeling a slight pain, or every two meters, whichever is first.
b) Before you start feeling pain, approximately every meter or less.
c) Whenever you start feeling pain.

Because…

a) It is unnecessary to equalize until pain occurs, only then is barotrama a danger.
b) The ears are continually equalized, reducing the risk of damage to the eardrum.
c) The ears are continually equalized, increasing the risk of damage to the ear drum.
d) Equalizing too often is detrimental to the ear drum.

Other:

34. Look at the following picture of a person after scuba diving. The eyes are bloodshot and there are bruises around the eyes, particularly where the edges of the mask were in contact with his face. This condition was caused by…

Photograph of mask squeeze from the DiveAssure website:
http://www.diveassure.com/new/usa/barotrauma.html. Copyright © DiveAssure 2009.

Photograph courtesy of Lester Quayle and Rita Barton. Copyright © Rita Barton, 2004

Photograph copyright, Rita Barton, 2004.

a) a pressure imbalance in which air pressure inside the mask exceeded ambient pressure.
b) a pressure imbalance in which air pressure inside the mask was less than ambient pressure.
c) balanced pressure on both sides of an airspace that is greater than normal resulting in pain or discomfort.

Most likely this person...

a) did not exhale enough air into his mask while descending.
b) did not inhale enough air out of his mask while descending.
c) did not exhale enough air into his mask while ascending.
d) did not inhale enough air out his mask while ascending.

Other:

35. Squeeze is NORMALLY experienced in the…

a) teeth and lungs.
b) ear and lungs.
c) ear and mask.
d) teeth and mask.

Equalization occurs by __________ to balance internal and external pressure.

a) adding or subtracting air molecules from the internal space
b) adding or subtracting water molecules from the internal space
c) adding or subtracting air molecules from the external space
d) adding or subtracting water molecules from the external space

Other:

36. Cabin pressurization during flight prevents…

a) hypoxia
b) lung over-inflation
c) air embolisms

By…

a) adding air molecules to the cabin. Air molecules flow into passengers' lungs until cabin and lung pressure are equal.
b) removing air molecules from the cabin. Air molecules flow out of passengers' lungs until cabin and lung pressure are equal.
c) adding air molecules to the cabin. Air molecules flow out of passengers' lungs until cabin and lung pressure are equal.
d) removing air molecules from the cabin. Air molecules flow out of passengers' lungs until cabin and lung pressure are equal.

Other:

Appendix C

Pre-instruction diagnostic tool: Conceptions of the ear

ID Number: ____________________________

Pre-Instruction Diagnostic Tool 1: Conceptions of the Ear

1. Give examples of experiences you have had when you 'popped' your ears or had to "pop" your ears and situations you were in when your ears "popped" on their own.

2. Think about a time when your ears popped and you were not in the water, such as in an airplane, on a hill, or in an elevator. In this case, pretend you are in an airplane and start to ascend. You feel pressure in your ears, then they "pop". Draw diagrams and explain:
(a) what is happening when you are on the ground
(b) what causes the pressure while ascending, and
(c) what occurs when your ears pop.
In your diagrams, draw and label all the parts of the ear that you know. If you do not know the name of certain parts, still draw the structure, and explain the anatomy using descriptive words and labels. Be as detailed as possible in your diagrams and written explanation.

3. When scuba divers are learning how to dive beneath the surface of the water they are also taught how to pop their ears. It is imperative for divers to pop their ears whenever they are diving. Use your ear diagrams to explain:
   (a) what is happening when a diver is at the surface
   (b) what causes the pressure while descending, and
   (c) what occurs when the diver's ears pop.
   Explain what you think would happen to the inside of the ear if scuba divers didn't 'pop' their ears.

4. Have you ever popped your ears or had your ears pop while you were in water? Think about a time when you were swimming or having a bath and your head was completely under water. When you got out of the lake or tub, do you remember having water stuck in your ear, and having to pop your ears, or having your ears pop? Again, draw and label all the parts of the ear that you know. Explain what you had to do to get the water out of your ear. Use the diagram of the ear to show what was happening when your ears popped in this instance, and where you think the water was when it was in your ear.

Appendix D

Conceptions of the ear addendum

Post-Instruction Diagnostic: Conceptions of the Ear

1. Give examples of experiences you have had when you 'popped' your ears or had to "pop" your ears and situations you were in when your ears "popped" on their own.

2. What do you think is happening inside of your ear when it "pops"? Draw a diagram to explain what you think is happening to cause the "popping" sensation. Be as detailed as possible. Explain the anatomy using descriptive words and labels.

3. When scuba divers are learning how to dive beneath the surface of the water they are also taught how to pop their ears. It is imperative for divers to pop their ears whenever they are diving. Use what you know about the ear to explain why you think divers are told to pop their ears, and what is happening when this 'popping' occurs. Explain what you think would happen to the inside of the ear if scuba divers didn't 'pop' their ears.

4. Think about a time when you were swimming or having a bath and your head was completely under water. When you got out of the lake or tub, do you remember having water stuck in your ear? Explain what you had to do to get the water out of your ear. Use the diagram of the ear to show where you think the water was when it was in your ear?

Appendix E

Diagnostic tool 4: The -particulate nature of matter

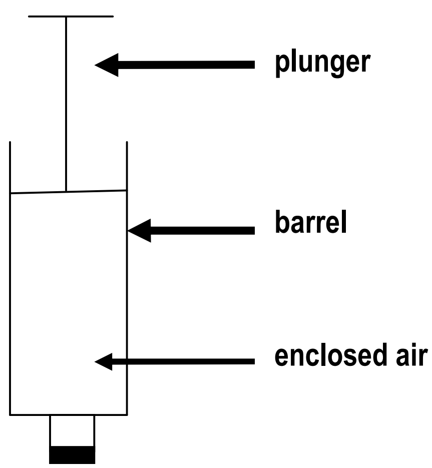
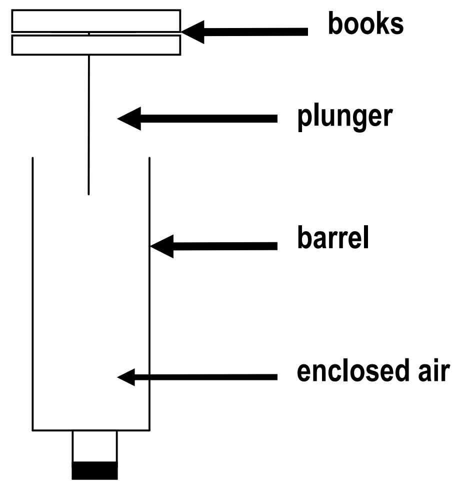
Pre-Instruction Diagnostic Tool 4: The Particulate Nature of Matter

Pretend you have "molecular goggles" and can see the particles making up a solid, liquid and a gas.

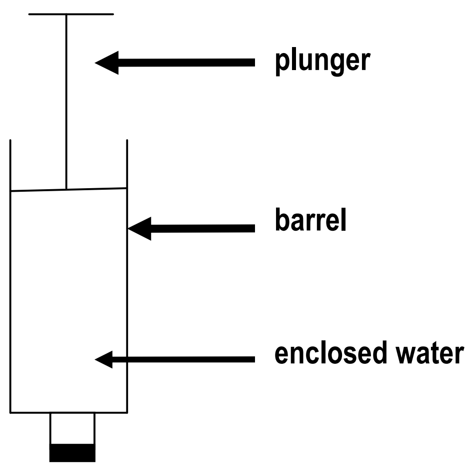
1. List physical properties of each of the following states of matter.
2. Pretend that you can see the invisible, and you have unlimited magnification. Draw the molecules for each state of matter. Be sure to show the relative spaces between the molecules, and their motion. This drawing is your "molecular model".
3. Use your molecular model to explain why solids, liquids and gases have the properties you mentioned in question 1 using your molecular model.

Solid	Liquid	Gas
1. Properties:	**1. Properties:**	**1. Properties:**
2. Molecular Model:	**2. Molecular Model:**	**2. Molecular Model:**
3. Explanation:	**3. Explanation:**	**3. Explanation:**

1. Are gases compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Explain why the plunger does not move.</td>
<td>Explain why the plunger does or does not move in this case.</td>
</tr>
<tr>
<td>Describe the movement and the relative spacing between the enclosed air particles in this situation.</td>
<td>Describe the movement and the relative spacing between enclosed air particles compared to the previous situation.</td>
</tr>
<tr>
<td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td>
</tr>
</table>

2. Are liquids compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr>
<td>
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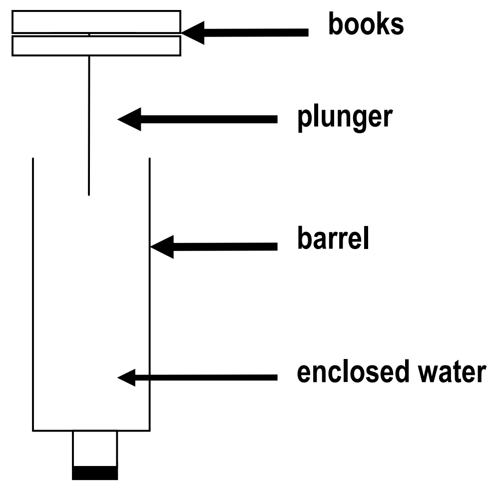
<td>
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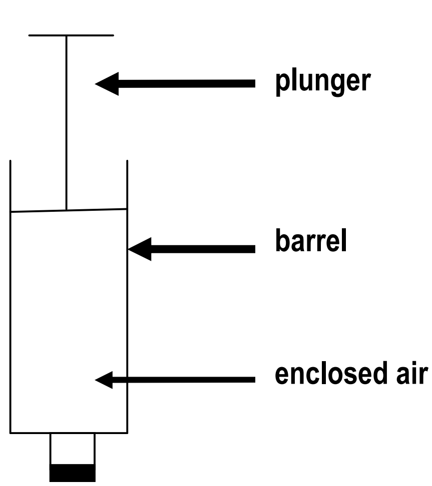
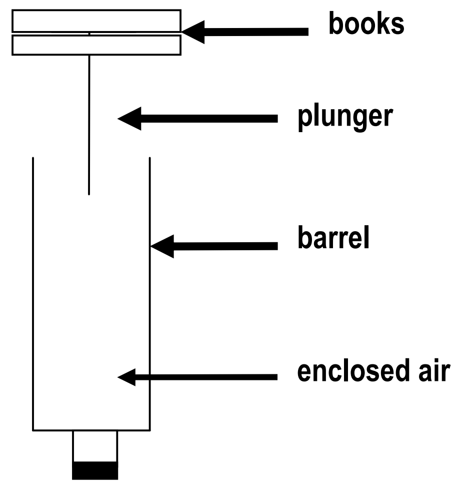
</tr>
<tr>
<td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td>
</tr>
</table>

Diagnostic Tool 4: The Particulate Nature of Matter - Small Group Consensus

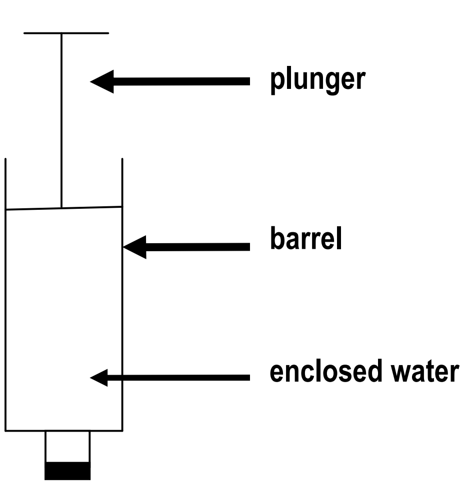
Come to a consensus in your small groups.

Solid	Liquid	Gas
2. **Properties:**	2. **Properties:**	3. **Properties:**
4. **Molecular Model:**	3. **Molecular Model:**	4. **Molecular Model:**
5. **Explanation:**	4. **Explanation:**	4. **Explanation:**

1. Are gases compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

	
Explain why the plunger does not move.	Explain why the plunger does or does not move in this case.
Describe the movement and the relative spacing between the enclosed air particles in this situation.	Describe the movement and the relative spacing between enclosed air particles compared to the previous situation.
Describe any experiences inside and outside the classroom you have had that have helped you answer this question.	

2. Are liquids compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr>
<td>
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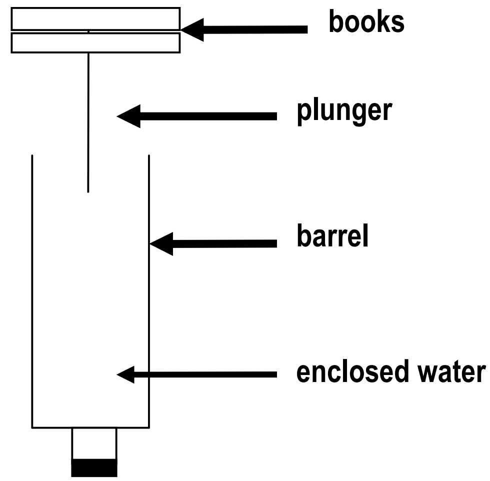
<td>
</td>
</tr>
<tr>
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<td>Explain why the plunger does or does not move in this case.</td>
</tr>
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<td>Describe the movement and the relative spacing between enclosed air particles compared to the previous situation.</td>
</tr>
<tr>
<td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td>
</tr>
</table>

Mr. Datzkiw will now do the demonstration.

1. Were your predictions correct?

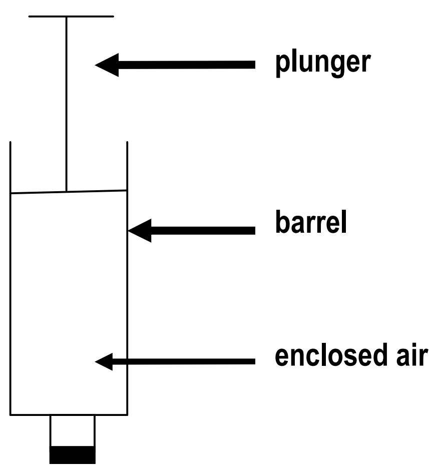
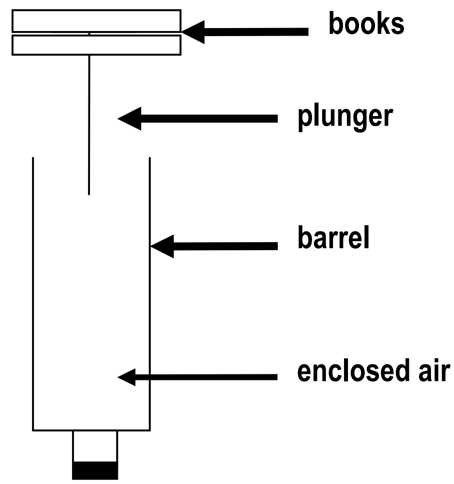
2. If not, what do you think is occurring? How will you change your molecular model to match your observations?

Diagnostic Tool 4: The Particulate Nature of Matter - Class Consensus

Come to a class consensus.

Solid	Liquid	Gas
3. Properties:	**4. Properties:**	**5. Properties:**
6. Molecular Model:	**5. Molecular Model:**	**6. Molecular Model:**
7. Explanation:	**5. Explanation:**	**5. Explanation:**

1. Are gases compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr><td>
</td><td>
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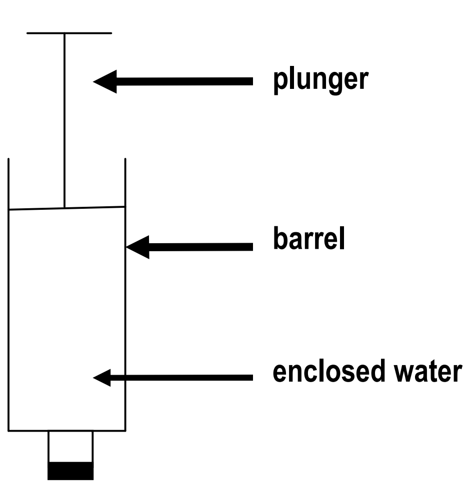
<tr><td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td></tr>
</table>

2. Are liquids compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr>
<td>
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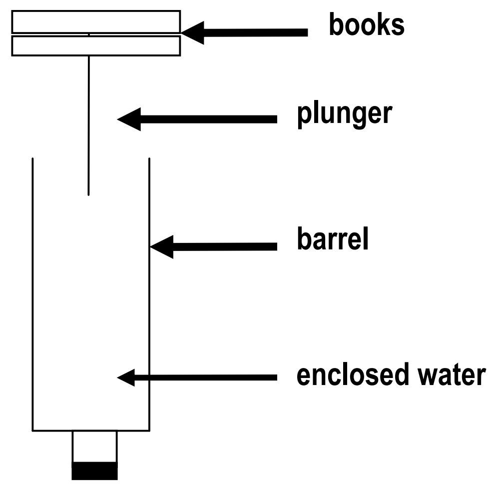
<td>
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</tr>
<tr>
<td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td>
</tr>
</table>

1. Do you agree with the class model?

2. Did your model change?

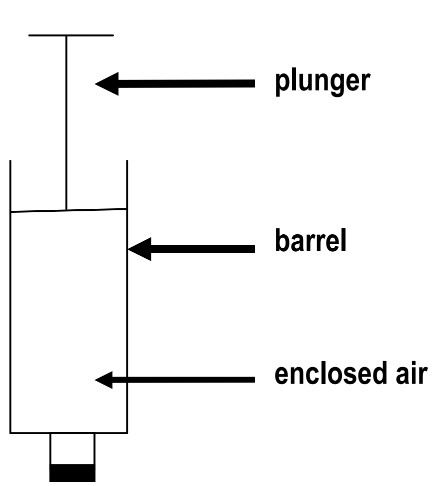
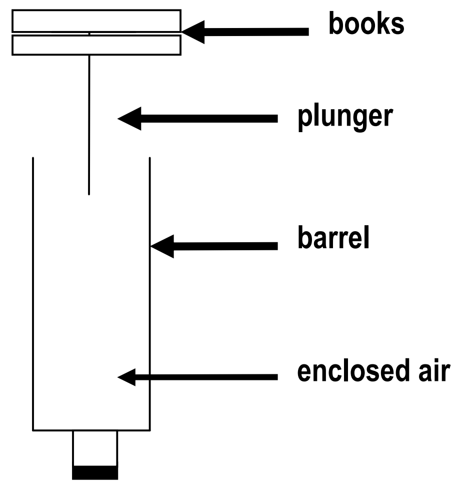
- If so, what arguments were made that helped you change your model.
- If not, were there other arguments that supported your model?

Diagnostic Tool 4: The Particulate Nature of Matter – Scientific Model

Come to a consensus in your small groups.

Solid	Liquid	Gas
4. Properties:	**6. Properties:**	**7. Properties:**
8. Molecular Model:	**7. Molecular Model:**	**8. Molecular Model:**
9. Explanation:	**6. Explanation:**	**6. Explanation:**

1. Are gases compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr><td>
</td><td>
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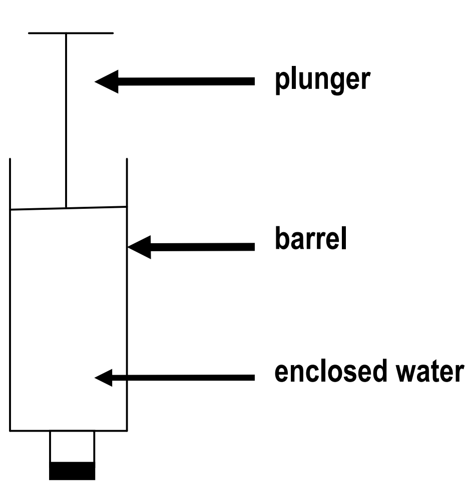
<tr><td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td></tr>
</table>

2. Are liquids compressible? In other words, do you think the plunger will go down or not? Answer the following questions below. If you don't know, make your best guess.

<table>
<tr>
<td>
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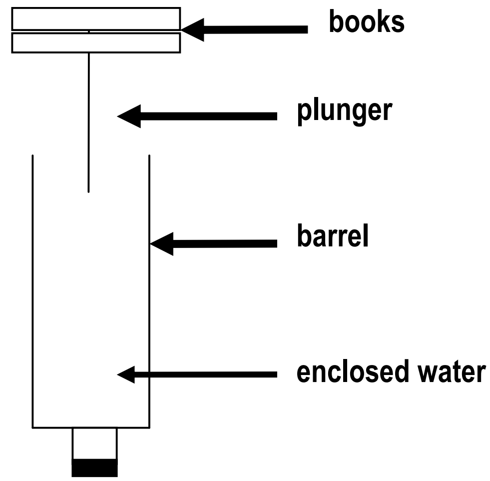
<td>
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</tr>
<tr>
<td colspan="2">Describe any experiences inside and outside the classroom you have had that have helped you answer this question.</td>
</tr>
</table>

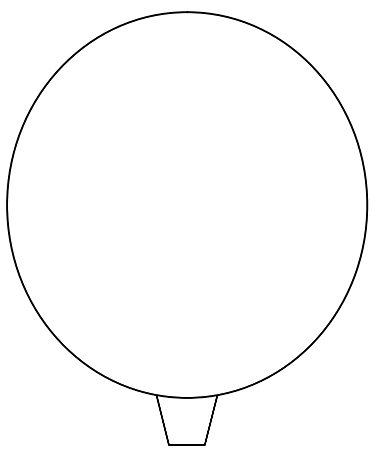
1. How was your original model of solids, liquids and gases different than the scientific model?

2. What strategies will you use to remember the scientific model?

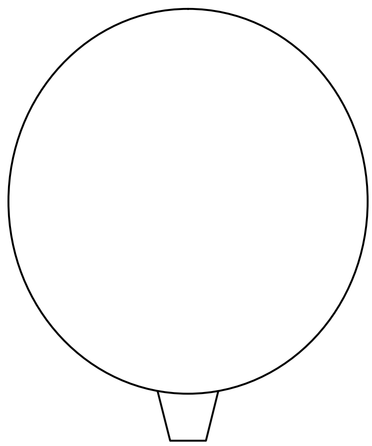
Appendix F

Diagnostic tool 5: Conceptions of pressure of a balloon on Everest

Instructions for Diagnostic Tools Series 5: Pressure Systems and Boyle's Law

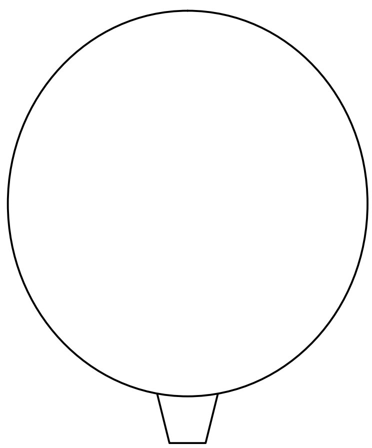
Part 1 Instructions:	Part 2 Instructions:
• Look at the balloon. • Notice that the balloon maintains its shape. Pretend that you can see the invisible, and you have unlimited magnification. Explain why the balloon maintains its shape.	• We bring the balloon to the top of Mount Everest. Pretend that the temperature at the top of Mount Everest **is the same** as when we blew up the balloon. There is **no change** in temperature. • What happens to the balloon at the top of Mount Everest? Draw the balloon the size and shape you think it would be relative to the first picture of the balloon. Again, pretend that you can see the invisible, and you have unlimited magnification. Draw what you would see, and explain your drawing.
	

Pre-Instruction Diagnostic Tool 5a:
Pressure Systems and Boyle's Law - Your Model

<table>
<tr><td>Part 1 (Short Instructions)
Look at the balloon.
Draw air particles and explain why balloon stays the same volume.</td><td>Part 2 (Short instructions)
Balloon on mountain. No change in temperature.
Draw air particles and explain why balloon does or does not change volume.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Explanation how the air molecules are moving:</td><td>Explanation how the air molecules are moving:</td></tr>
<tr><td>What experiences helped you build your model?</td><td>What experiences helped you build your model?</td></tr>
</table>

Pre-Instruction Diagnostic Tool 5b:
Pressure Systems and Boyle's Law Small Group Consensus

In your small groups, compare each students' models. As a group, decide on a model for each situation below.

Part 1	
	
Before	On Mount Everest
Explanation: What experiences were used to determine the small group model?	

Pre-Instruction Diagnostic Tool 5c: Pressure Systems and Boyle's Law
Comparison of Your Model and the Small Group Model

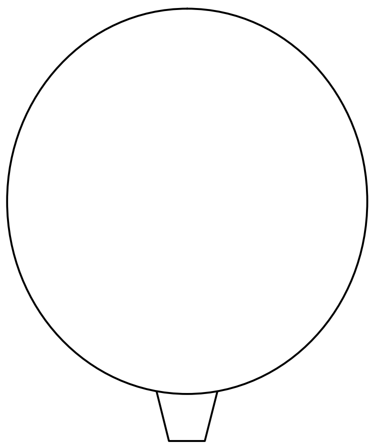
Compare your model with the model generated by your group.

Do you agree with the group model? Why or why not?   Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?

Pre-Instruction Diagnostic Tool 5d:
Pressure Systems and Boyle's Law Class Consensus

In your small groups, compare each students' models. As a group, decide on a model for each situation below.

Class Consensus



Before

On Mount Everest

Explanation:

What experiences were used to determine the class model?

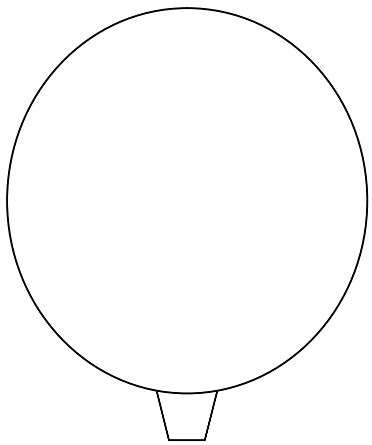
Pre-Instruction Diagnostic Tool 5e: Pressure Systems and Boyle's Law
Comparison of Your Model and the Class Model

Compare your model with the model generated by your group.

Do you agree with the group model? Why or why not?   Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?

Pre-Instruction Diagnostic Tool 5d:
Pressure Systems and Boyle's Law Scientific Model

Draw and explain using the scientific model for each situation.

Part 1	Part 2
	
Explanation: What experiences will you use to remember this model?	Explanation: What experiences will you use to remember this model?

Activity Evaluation:

1. Did you find this activity useful? Why or why not?

2. Can you suggest improvements to the activity?

3. Can you think another activity that could be used to learn this concept?

Appendix G

Diagnostic tool 6: Conceptions of atmospheric pressure

Pre-Instruction Diagnostic Tool 6a: Does Air Exert Pressure?

Part 1: You are in the classroom.

1. Does the air around you exert pressure? (Yes or no.)

2. Draw and describe the movement of the air particles in your classroom at this moment.

3. What experiences and facts did you use to build your model of air in the room?

Part 2 : You go skiing in Banff. You are at the bottom of the mountain waiting for a ski lift.

1. Draw a microscopic representation of the air at the bottom of the mountain. That is, draw and describe the movement of the air particles in the atmosphere surrounding you at the bottom of the mountain.

2. Is there air pressure at the bottom of the mountain? Explain why or why not. Use your drawing above to justify your explanation.

3. What experiences have you had that helped you draw your model of air at the bottom of the mountain?

Part 3: You then take a chair lift up to the top of the mountain. There is **no change** in temperature from the bottom to the top of the mountain.

1. Is there air pressure at the top of the mountain? Is it more, less or the same as at the bottom of the mountain? Explain why.

2. Draw and describe the movement of air particles in the atmosphere at the top of the mountain.

3. What experiences have you had that helped you draw your model of air at the top of the mountain?

Pre-Instruction Diagnostic Tool 6b: Does Air Exert Pressure?
Class Consensus

Part 1: You are in the classroom.

4. Does the air around you exert pressure? (Yes or no.)

5. Draw and describe the movement of the air particles in your classroom at this moment.

6. What experiences and facts did you use to build your model of air in the room?

Part 2 : You go skiing in Banff. You are at the bottom of the mountain waiting for a ski lift.

4. Draw a microscopic representation of the air at the bottom of the mountain. That is, draw and describe the movement of the air particles in the atmosphere surrounding you at the bottom of the mountain.

5. Is there air pressure at the bottom of the mountain? Explain why or why not. Use your drawing above to justify your explanation.

6. What experiences have you had that helped you draw your model of air at the bottom of the mountain?

Part 3: You then take a chair lift up to the top of the mountain. There is **no change** in temperature from the bottom to the top of the mountain.

4. Is there air pressure at the top of the mountain? Is it more, less or the same as at the bottom of the mountain? Explain why.

5. Draw and describe the movement of air particles in the atmosphere at the top of the mountain.

6. What experiences have you had that helped you draw your model of air at the top of the mountain?

Pre-Instruction Diagnostic Tool 6c:
Does Air Exert Pressure? Pascal's Story and Scientific Models

Part 1: You are in the classroom.

7. Does the air around you exert pressure? (Yes or no.)

8. Draw and describe the movement of the air particles in your classroom at this moment.

9. What experiences and facts did you use to build your model of air in the room?

Part 2 : You go skiing in Banff. You are at the bottom of the mountain waiting for a ski lift.

7. Draw a microscopic representation of the air at the bottom of the mountain. That is, draw and describe the movement of the air particles in the atmosphere surrounding you at the bottom of the mountain.

8. Is there air pressure at the bottom of the mountain? Explain why or why not. Use your drawing above to justify your explanation.

9. What experiences have you had that helped you draw your model of air at the bottom of the mountain?

Part 3: You then take a chair lift up to the top of the mountain. There is **no change** in temperature from the bottom to the top of the mountain.

7. Is there air pressure at the top of the mountain? Is it more, less or the same as at the bottom of the mountain? Explain why.

8. Draw and describe the movement of air particles in the atmosphere at the top of the mountain.

9. What experiences have you had that helped you draw your model of air at the top of the mountain?

Activity Evaluation:

1. Did you find this activity useful? Why or why not?

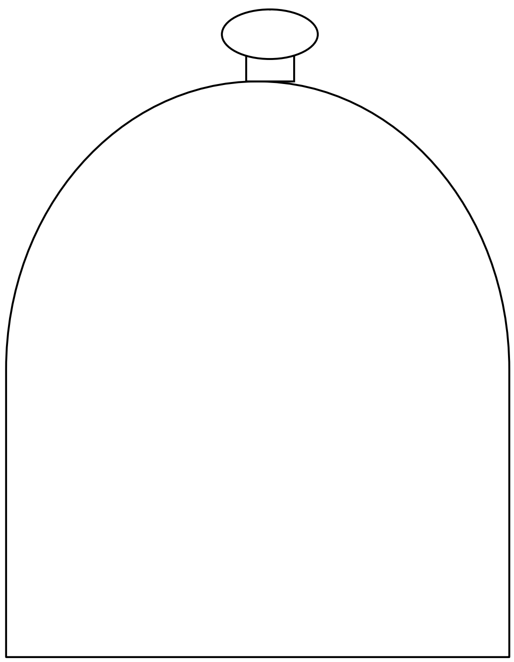
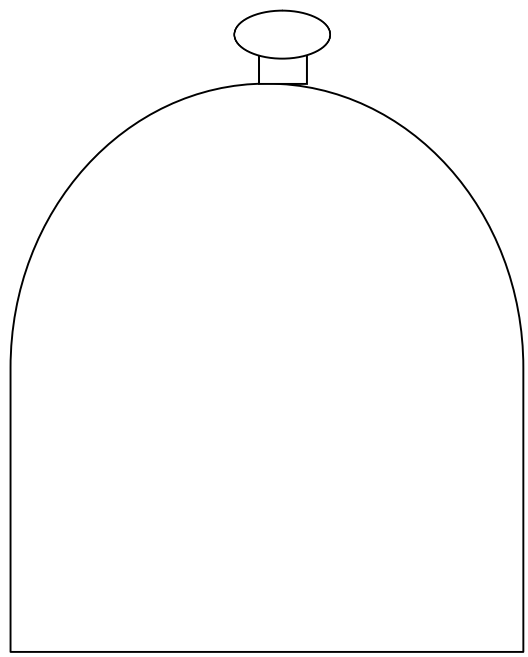
2. Can you suggest improvements to the activity?

3. Can you think another activity that could be used to learn this concept?

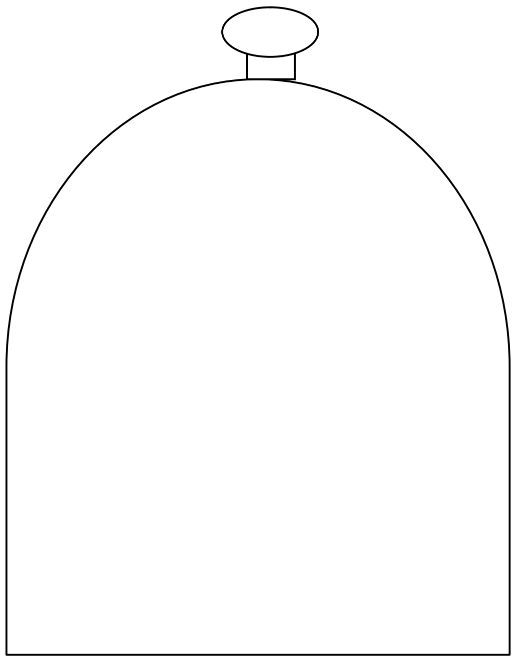
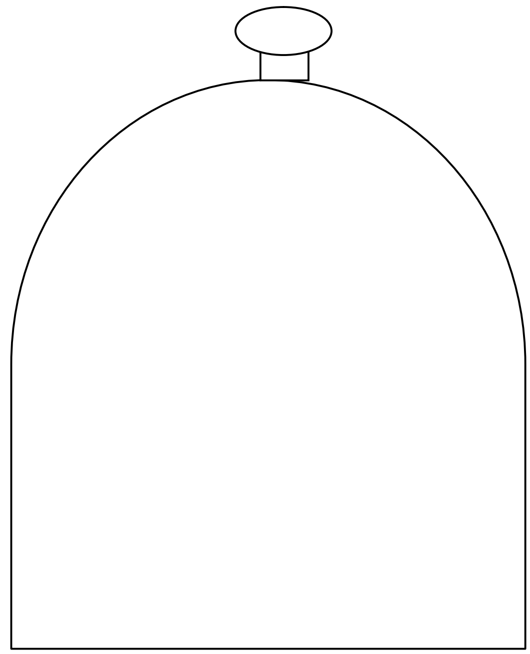
Appendix H

Diagnostic tool 7: Visualizing a vacuum

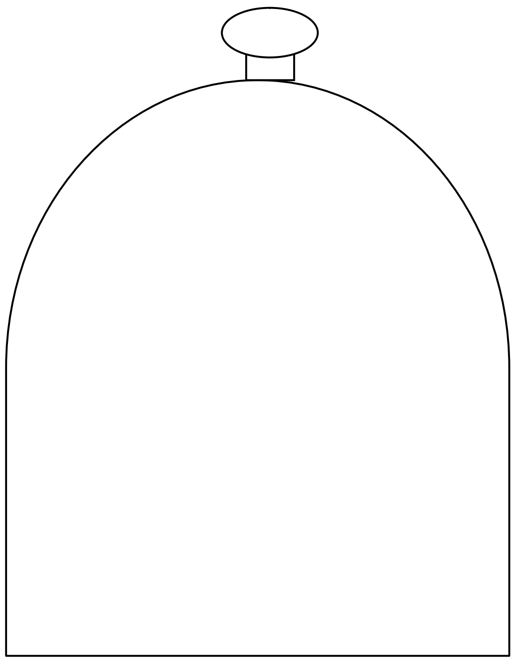
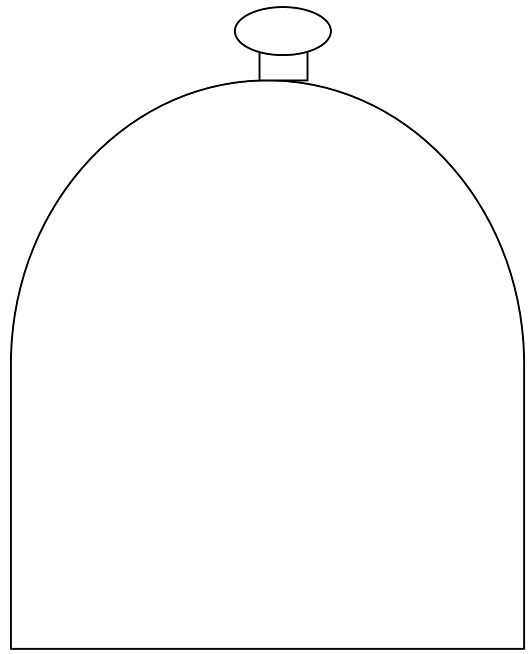
Instructions for Diagnostic Tool Series 7: Visualizing a Vacuum

Part 1 Instructions:	Part 2 Instructions:
• Look at the bell jar vacuum apparatus (with hand pump.) • Consider the bell jar. The air pressure inside the jar is 1.0 atm. Pretend that you can see the invisible, and you have unlimited magnification. Draw what is happening. That is, draw the microscopic representation.	• The teacher is pumping out half of the air inside the bell jar. • The air pressure is now 0.5 atm. Pretend that you can see the invisible, and you have unlimited magnification. Draw what is happening. If the partial vacuum is not visible, increase the magnification until it can be visualized. Ensure your diagram takes into account what you drew in Part 1.
	

Pre-Instruction Diagnostic Tool 7a: Visualizing a Vacuum – Your Model

Part 1	Part 2
	
Describe the movement and spacing of the particles in the jar.	Describe the movement and spacing of particles in the jar.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Pre-Instruction Diagnostic Tool 7b: Visualizing a Vacuum – Small Group Consensus

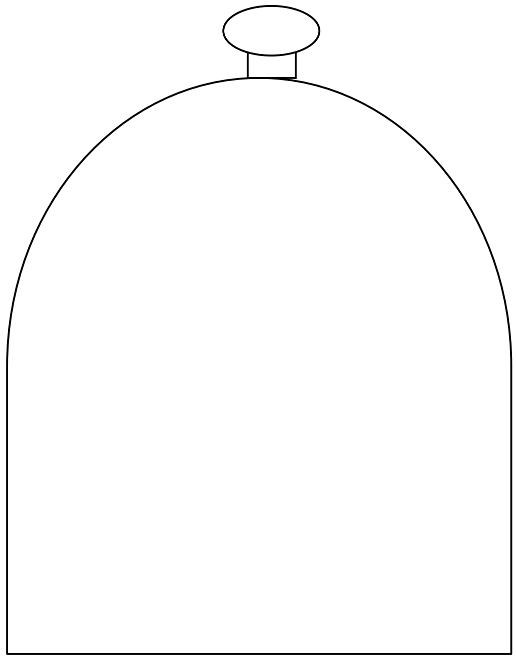
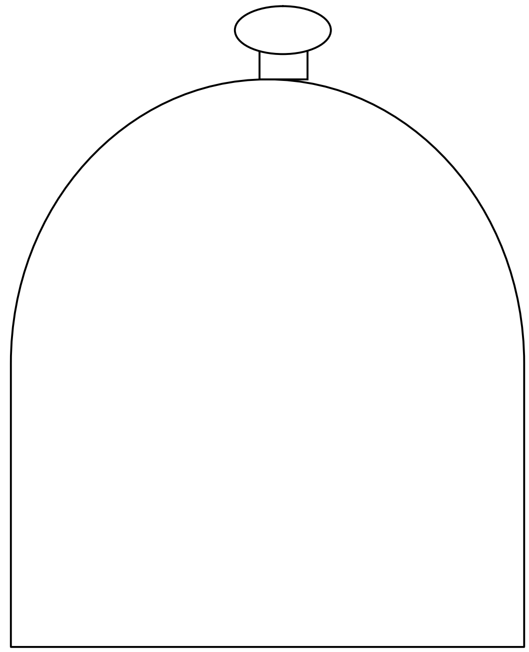
Part 1	Part 2
	
Describe the movement and spacing of the particles in the jar.	Describe the movement and spacing of particles in the jar.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Pre-Instruction Diagnostic Tool 7c: Visualizing a Vacuum – Comparison of Your Model and the Small Group Model

Compare your model with the model generated by your group.

Part 1 Model	Part 2 Model
Do you agree with the group model? Why or why not?	Do you agree with the group model? Why or why not?
Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?	Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?

Pre-Instruction Diagnostic Tool 7e: Visualizing a Vacuum – Class Consensus

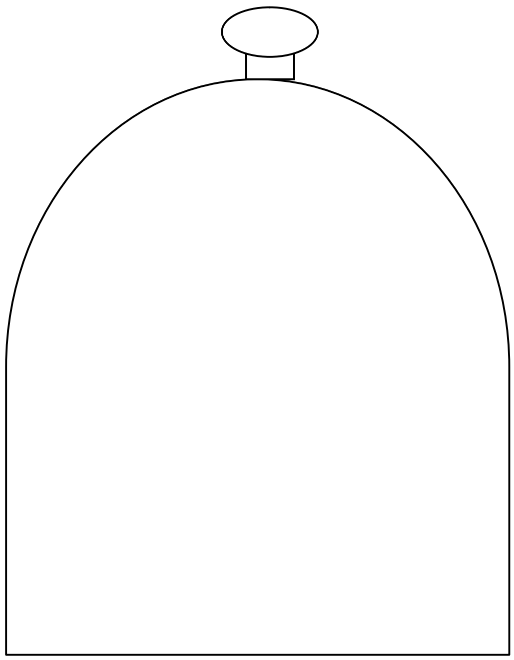
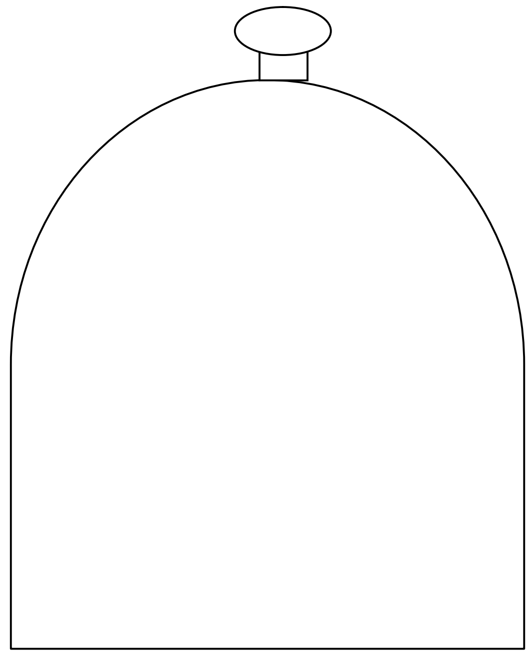
Part 1	Part 2
	
Describe the movement and spacing of the particles in the jar.	Describe the movement and spacing of particles in the jar.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Pre-Instruction Diagnostic Tool 7d: Visualizing a Vacuum – Comparison of Your Model and the Class Model

Compare your model with the model generated by your class.

Part 1 Model	Part 2 Model
Do you agree with the group model? Why or why not?	Do you agree with the group model? Why or why not?
Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?	Did your model change? Why or why not? What arguments were made that helped you change your model or keep it the same?

Pre-Instruction Diagnostic Tool 7e:
Visualizing a VacuumScientific Model

Part 1	Part 2
	
Describe the movement and spacing of the particles in the jar.	Describe the movement and spacing of particles in the jar.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Post-Instruction Reflection 7f: Visualizing a Vacuum – Comparison of Your Model and the Scientific Model

Compare your model with the model generated by your class.

Part 1 Model	Part 2 Model
How was your original model different than the scientific model?	How was your original model different than the scientific model?
Did your model change? Why or why not? What arguments will help you remember the scientific model?	Did your model change? Why or why not? What arguments will help you remember the scientific model?

Activity Evaluation:

1. Did you find this activity useful? Why or why not?

2. Can you suggest improvements to the activity?

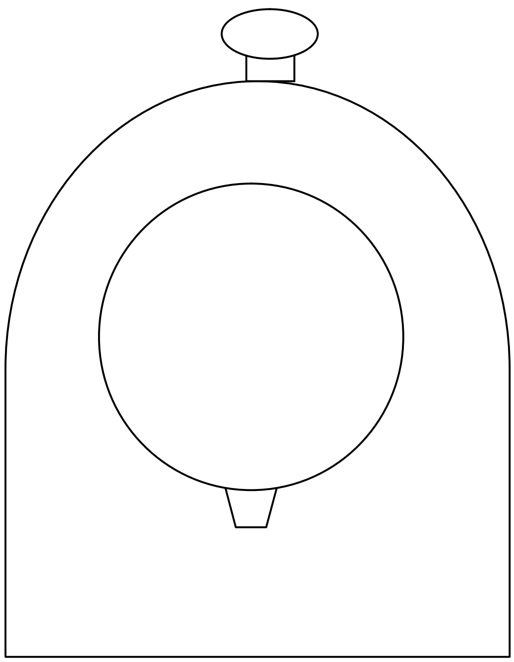
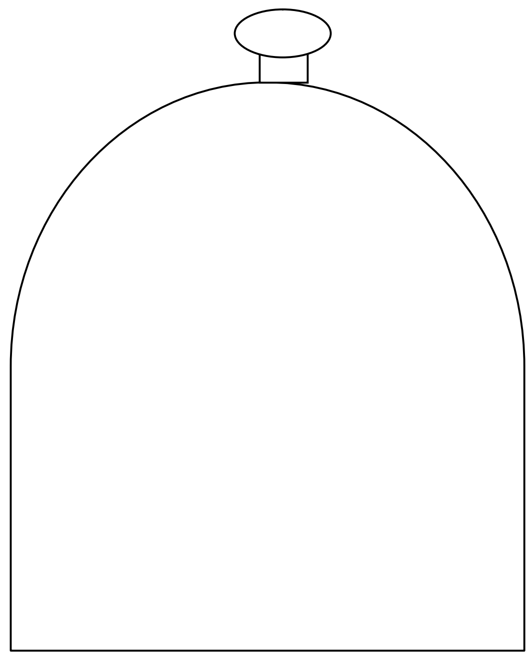
3. Can you think another activity that could be used to learn this concept?

Appendix I

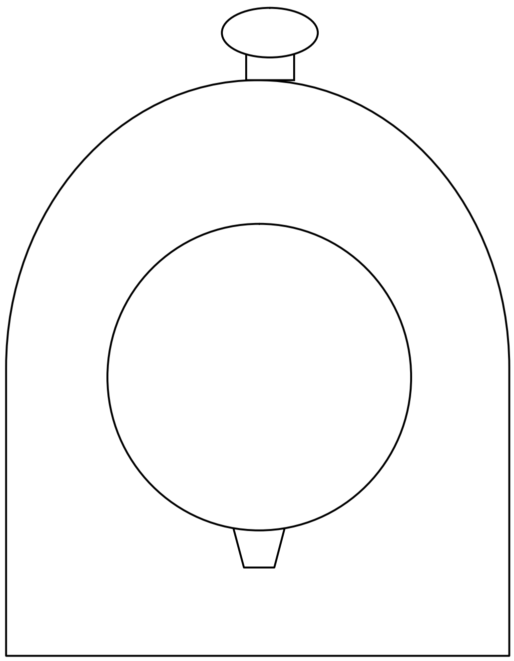
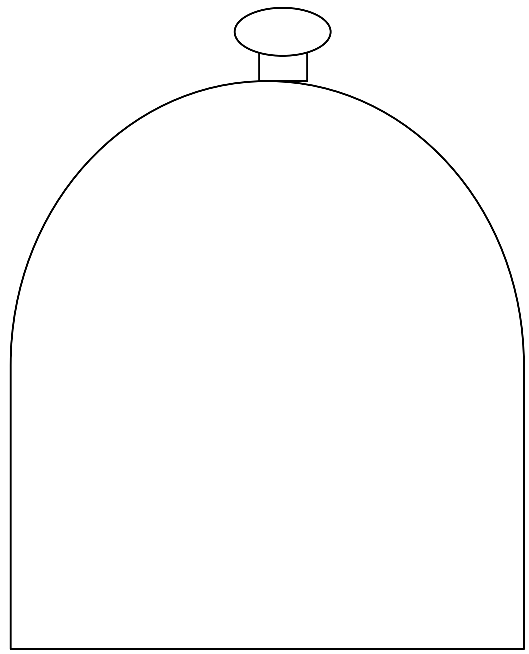
Diagnostic tool 8: Conceptions of a balloon in a vacuum

ID NUMBER: ______________________________

Instructions for Diagnostic Tool Series 8: Boyle's Law Pulmonary Barotrauma Simulation

Part 1 Instructions:	Part 2 Instructions:
• Look at the bell jar vacuum apparatus (with hand pump) and balloon inside. • Consider the bell jar. The air pressure inside the jar is 1.0 atm. Pretend that you can see the invisible, and you have unlimited magnification. Draw what is happening inside and outside of the balloon. That is, draw the microscopic representation.	• The teacher is pumping out half of the air inside the bell jar. • The air pressure is now 0.5 atm. Pretend that you can see the invisible, and you have unlimited magnification. Draw what is happening inside and outside of the balloon now. Does the balloon change size? Ensure your diagram takes into account what you drew in Part 1.
	

Pre-Instruction Diagnostic Tool Series 8a: Boyle's Law Pulmonary Barotrauma Simulation Your Prediction

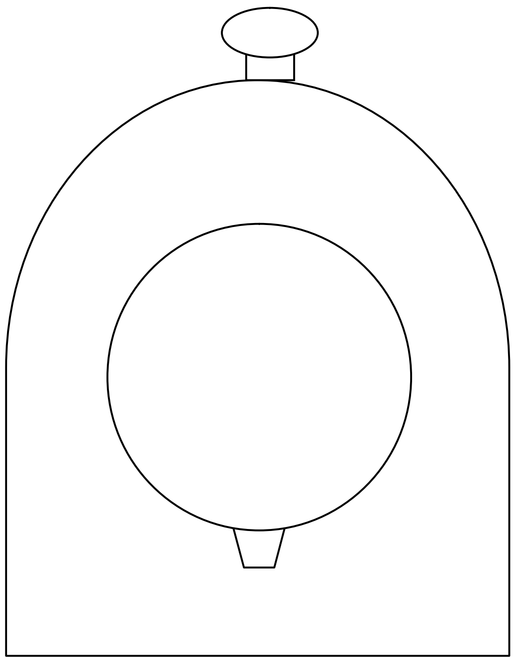
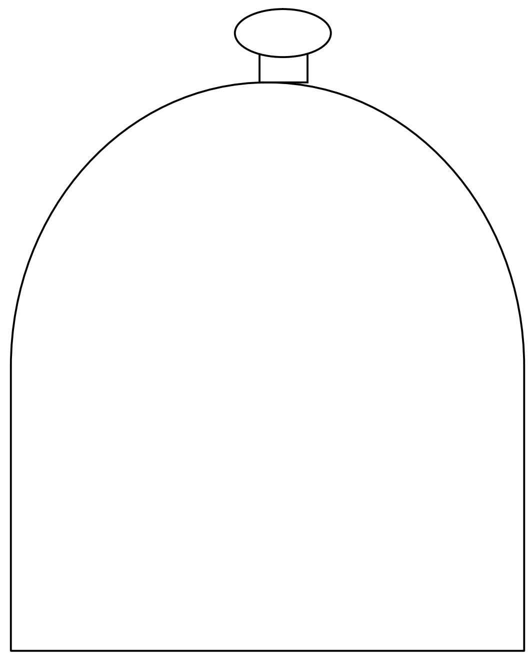
Part 1	Part 2
	
Describe the movement and spacing of the particles inside and outside of the balloon.	Describe the movement and spacing of the particles inside and outside of the balloon.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Your teacher will now do the demonstration.

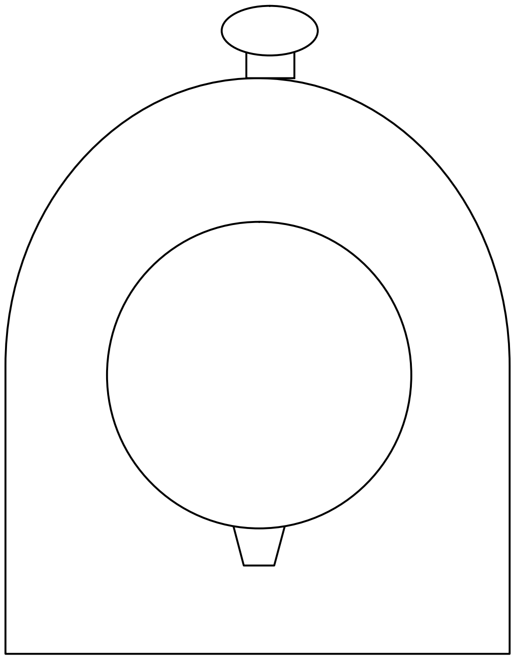
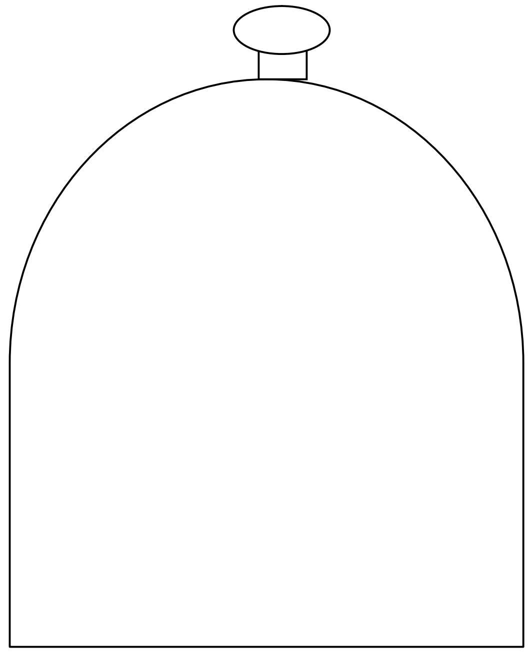
1. Were your predictions correct?

2. If not, what do you think is occurring? How will you change your molecular model to match your observations?

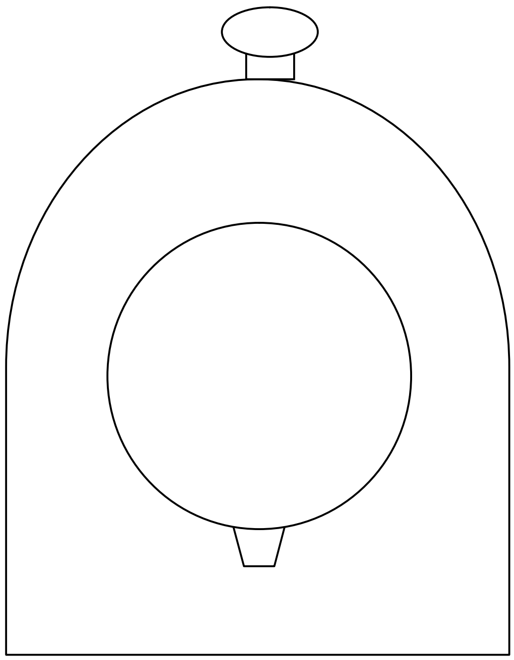
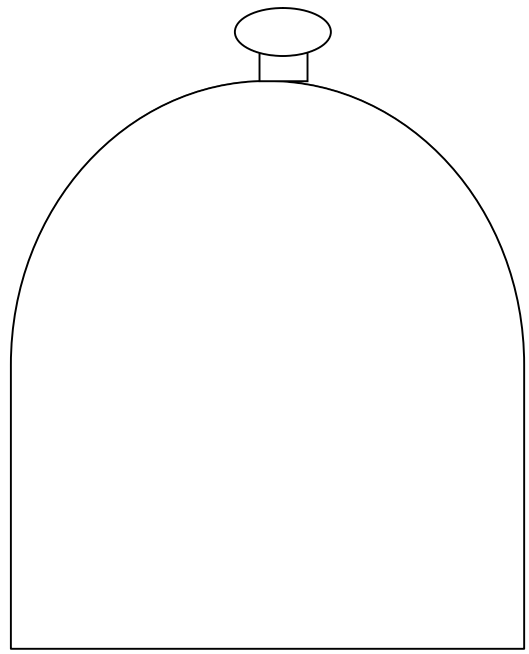
Diagnostic Tool Series 8b: Boyle's Law Pulmonary Barotrauma Small Group Explanation

Part 1	Part 2
	
Describe the movement and spacing of the particles inside and outside of the balloon.	Describe the movement and spacing of the particles inside and outside of the balloon.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Diagnostic Tool Series 8c: Boyle's Law Pulmonary Barotrauma Large Group Explanation

Part 1	Part 2
	
Describe the movement and spacing of the particles inside and outside of the balloon.	Describe the movement and spacing of the particles inside and outside of the balloon.
What experiences have you had that lead you to draw this model?	What experiences have you had that lead you to draw this model?

Diagnostic Tool Series 8d: Boyle's Law Pulmonary Barotrauma Simulation Scientific Model

Part 1	Part 2
	
Describe the movement and spacing of the particles inside and outside of the balloon.	Describe the movement and spacing of the particles inside and outside of the balloon.
What experiences have you had that will help you remember this model?	What experiences have you had that will help you remember this model?

The concepts for today:

1. Always think of pressure in terms of SYSTEMS, that is, inside (internal) vs. outside (ambient)
2. Determine which part of the pressure system is positive (bigger) and which is negative (smaller) pressure imbalance (pressure change).
    - in this case, in this case ambient pressure became smaller (was NEGATIVE), internal pressure was larger (POSITIVE)
    - the volume of the balloon increased until ambient and internal pressure were the same again
3. What occurs to the volume of a flexible container when the internal and ambient pressure equalize.
4. Describe these concepts in three ways:
    - Macroscopic (what you observed)
    - Microscopic (drawing of the molecules)
    - Symbolic (pressure decreased by ½, volume increased by 2)

Post-Instruction Reflection 8e: Boyle's Law Pulmonary Barotrauma Simulation Your Model Comparison of Your Models Before and After the Demonstration

Compare your original model with your model after the demonstration.

Part 1 Model	Part 2 Model
Did your model change or did your model stay the same for part 1?	How was your original model different than the scientific model?
Did your model change? Why or why not? What arguments will help you remember the scientific model?	Did your model change? Why or why not? What arguments will help you remember the scientific model?

Activity Evaluation:

1. This demonstration, the concepts were represented in three ways: macroscopic, microscopic and symbolic. Is thinking about science in this way useful to your learning? Why or why not?

2. Did you find this demonstration useful? Why or why not?

3. Did you find writing your own thoughts on paper first useful for your learning? Why or why not?

4. Did you find the small and large group discussions useful for your learning? Why or why not?

5. Can you suggest improvements to the activity or think of another activity that can be used to learn this concept?

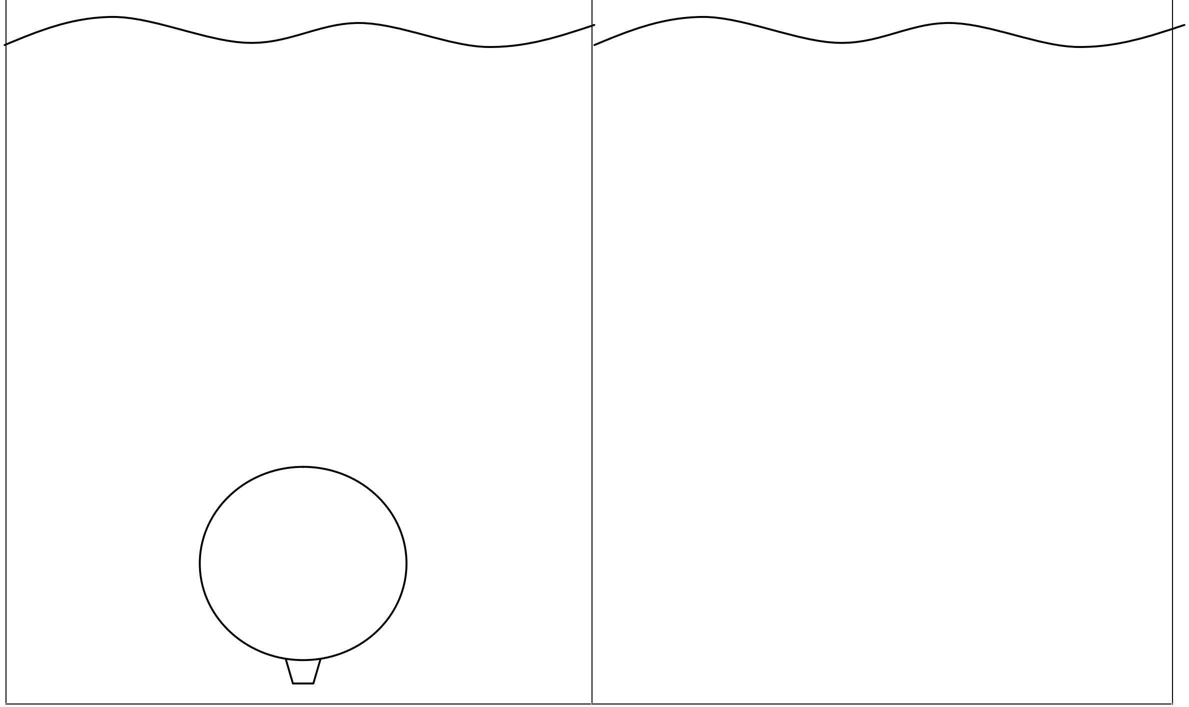
Appendix J

Diagnostic tool 9: Conceptions of a surfacing flotation balloon

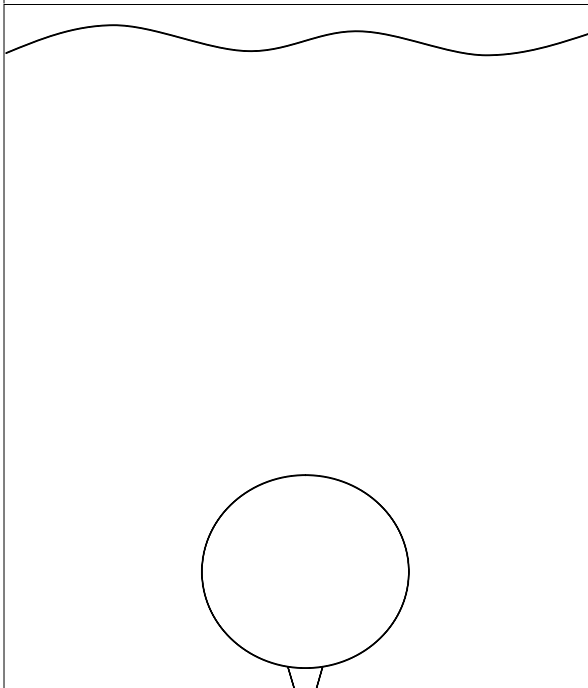
ID NUMBER: ________________________________

Instructions for Diagnostic Tools Series 9: Pressure Systems and Boyle's Law – Scuba Scenario

Part 1 Instructions:	Part 2 Instructions:
• Look at the balloon. The balloon is 20 m underwater. Water pressure is 3 atm. • Notice that the balloon maintains its shape. Pretend that you can see the invisible, and you have unlimited magnification. Explain why the balloon maintains its shape.	• We bring the balloon to the surface. Atmospheric pressure is 1 atm. There is **no change** in temperature. • What happens to the balloon at the surface? Draw the balloon the size and shape you think it would be relative to the first picture of the balloon. Again, pretend that you can see the invisible, and you have unlimited magnification. Draw what you would see, and explain your drawing.

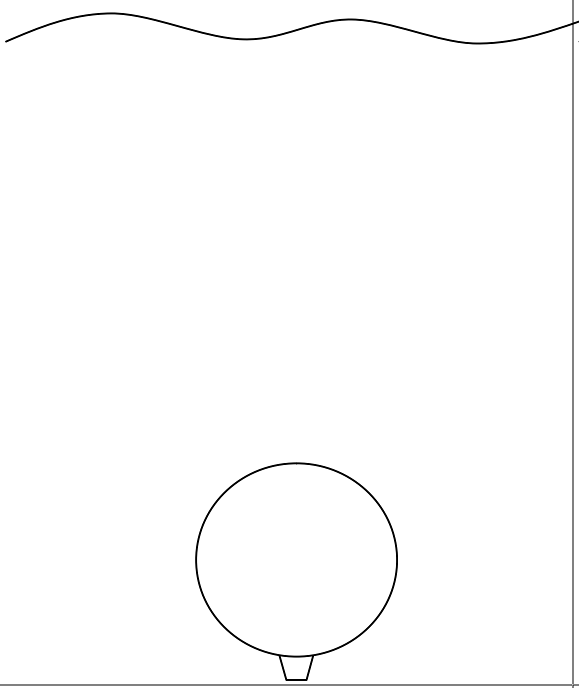


Pre-Instruction Diagnostic Tool 9a:
Pressure Systems and Boyle's Law - Your Model

Part 1 (Short Instructions)	Part 2 (Short instructions)
• Look at the balloon. • Draw air particles and explain why balloon stays the same volume.	• We bring the balloon to the surface. Atmospheric pressure is 1 atm. There is **no change** in temperature • Draw air particles and explain why balloon does or does not change volume.
	
Explanation how the air molecules are moving:	Explanation how the air molecules are moving:
What experiences helped you build your model?	What experiences helped you build your model?

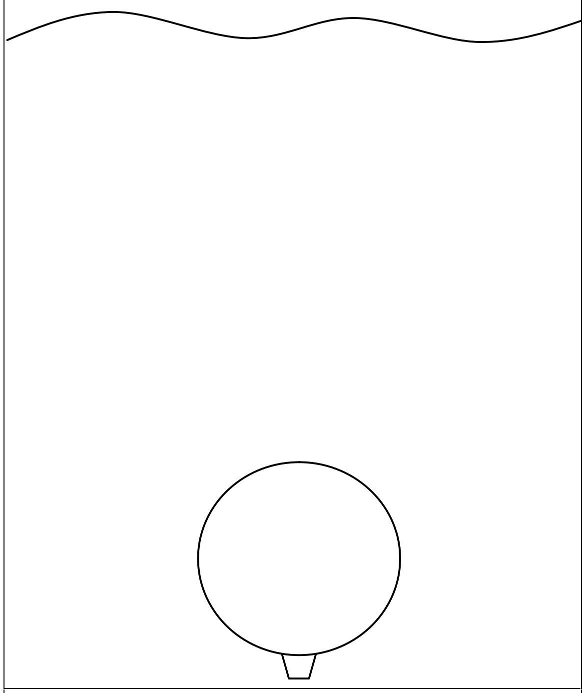
Pre-Instruction Diagnostic Tool 9b:
Pressure Systems and Boyle's Law Small Group Consensus

In your small groups, compare each students' models. As a group, decide on a model for each situation below.

Part 1	Part 2 Instructions:
	
Explanation: What experiences were used to determine the small group model?	Explanation: What experiences were used to determine the small group model?

Pre-Instruction Diagnostic Tool 9c:
Pressure Systems and Boyle's Law Class Consensus

As a class, decide on a model for each situation below.

Part 1	Part 2 Instructions:
	
Explanation: What experiences were used to determine the small group model?	Explanation: What experiences were used to determine the small group model?

Pre-Instruction Diagnostic Tool 9e: Pressure Systems and Boyle's Law
Comparison of Your Model and the Class Model

Compare your model with the model generated by your group.

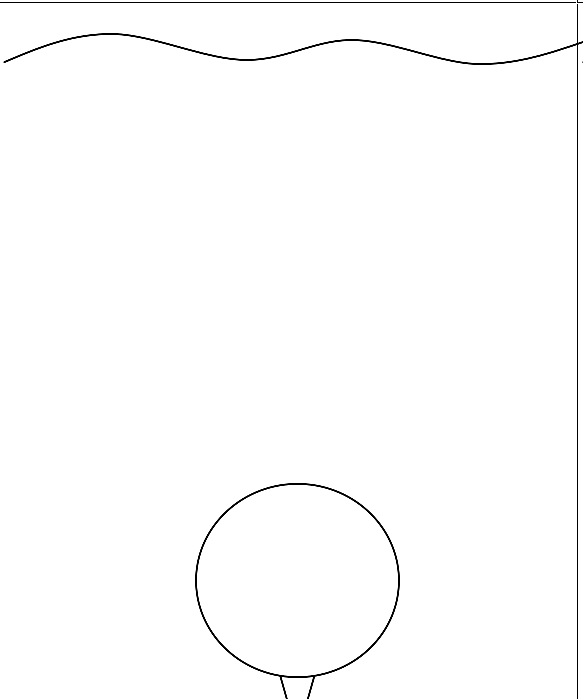
Do you agree with the class model?

Did your model change?

- If so, what arguments were made that helped you change your model.
- If not, were there other arguments that supported your model?

Post-Instruction Diagnostic Tool 9d:
Pressure Systems and Boyle's Law Scientific Model

Draw and explain using the scientific model for each situation.

Part 1	Part 2
	
Explanation: What experiences will you use to remember this model?	Explanation: What experiences will you use to remember this model?

The concepts for today:

1. Always think of pressure in terms of SYSTEMS, that is, inside (internal) vs. outside (ambient)
2. Determine which part of the pressure system is positive (bigger) and which is negative (smaller) pressure imbalance (pressure change).
    - in this case, in this case ambient pressure became smaller (was NEGATIVE), internal pressure was larger (POSITIVE)
    - the volume of the balloon increased until ambient and internal pressure were the same again (equalized)
    - the once equalization occurs, the balloon maintains its volume and the average number of collisions are approximately the same on the internal and external surfaces
3. What occurs to the volume of a flexible container when the internal and ambient pressure equalize.
4. Describe these concepts in three ways:
    - Macroscopic (what you observed)
    - Microscopic (drawing of the molecules)
    - Symbolic (pressure decreased by 1/3, volume increased by 3)

Activity Evaluation:

1. This demonstration, the concepts were represented in three ways: macroscopic, microscopic and symbolic. Is thinking about science in this way useful to your learning? Why or why not?

2. Did you find this demonstration useful? Why or why not?

3. Did you find writing your own thoughts on paper first useful for your learning? Why or why not?

4. Did you find the small and large group discussions useful for your learning? Why or why not?

Appendix K

Diagnostic tool 10: Conceptions of lung volume while surfacing

ID NUMBER: ________________________________

SCUBA Application Question: Your Answer

A scuba diver is looking at some coral 30m below the surface of the ocean. Ambient pressure is **4 atm**. He makes an emergency ascent to the surface, holding his breath the entire way. Atmospheric pressure is **1 atm**.

Assuming he makes it to the surface, what would happen to his lungs? Explain using macroscopic, microscopic and symbolic representations.

Diver's lungs at 30 m depth	**Diver's lungs at the surface**
Drawing	**Drawing**
Explanation	

Reflection: What experiences (in class or outside of class) did you use to answer these questions?

SCUBA Application Question: Small Group Answer

A scuba diver is looking at some coral 30m below the surface of the ocean. Water pressure is **4 atm**. He makes an emergency ascent to the surface, holding his breath the entire way. Atmospheric pressure is **1 atm**.

Assuming he makes it to the surface, what would happen to his lungs? Explain using macroscopic, microscopic and symbolic representations.

Diver's lungs at 30 m depth	**Diver's lungs at the surface**
Drawing	**Drawing**
Explanation	

SCUBA Application Question: Large Group Answer

A scuba diver is looking at some coral 30m below the surface of the ocean. Water pressure is **4 atm**. He makes an emergency ascent to the surface, holding his breath the entire way. Atmospheric pressure is **1 atm**.

Assuming he makes it to the surface, what would happen to his lungs? Explain using macroscopic, microscopic and symbolic representations.

Diver's lungs at 30 m depth	**Diver's lungs at the surface**
Drawing	**Drawing**
Explanation	

Reflection:

Do you agree with the class model?

Did your model change?

- If so, what arguments were made that helped you change your model.
- If not, were there other arguments that supported your model?

SCUBA Application Question: Scientific Answer

A scuba diver is looking at some coral 30m below the surface of the ocean. Water pressure is **4 atm**. He makes an emergency ascent to the surface, holding his breath the entire way. Atmospheric pressure is **1 atm**.

Assuming he makes it to the surface, what would happen to his lungs? Explain using macroscopic, microscopic and symbolic representations.

Diver's lungs at 30 m depth	**Diver's lungs at the surface**
Drawing	**Drawing**
Explanation	

Reflection: What experiences (in class and/or out of class) will you use to remember the scientific model?

The concepts for today:

1. Always think of pressure in terms of SYSTEMS, that is, inside (internal) vs. outside (ambient)
2. Determine which part of the pressure system is positive (bigger) and which is negative (smaller) pressure imbalance (pressure change).
    - in this case, in this case ambient pressure became smaller (was NEGATIVE), internal pressure was larger (POSITIVE)
    - the volume of the balloon increased until ambient and internal pressure were the same again
3. What occurs to the volume of a flexible container when the internal and ambient pressure equalize.
4. Describe these concepts in four ways:
    - Macroscopic (what you observed)
    - Microscopic (drawing of the molecules)
    - Symbolic (pressure decreased by 1/3, volume increased by 3)
    - Humanistic (pulmonary barotraumas, hamburger lung, NEVER HOLD YOUR BREATH WHEN SURFACING)
5. **NEVER EVER HOLD YOUR BREATH WHILE SURFACING FROM A SCUBA DIVE.**
6. **IF YOU LEARN NOTHING ELSE FROM THIS LESSON NEVER, EVER, EVER HOLDYOUR BREATH WHILDE SURFACING FROM A DIVE.**

Activity Evaluation:

1. This demonstration, the concepts were represented in three ways: macroscopic, microscopic, symbolic and humanistic. Is thinking about science in this way useful to your learning of pulmonary barotrauma? Why or why not?

2. We used the following sequence of events to teach you about lung barotraumas: the balloon in the vacuum chamber demonstration, the balloon underwater thought experiment, and this activity. Do you think this sequence of events was useful? Why or why not?

3. Did you find writing your own thoughts on paper first useful for your learning? Why or why not?

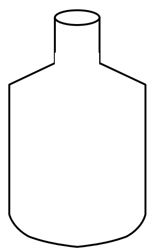
4. Did you find the small and large group discussions useful for your learning? Why or why not?

5. Can you suggest improvements to the activity or think of another activity that can be used to learn this concept?

Appendix L

Note organizer 1: Scuba pulmonary barotraumas teaching table

SCUBA: Pulmonary Barotrauma Teaching Sequence

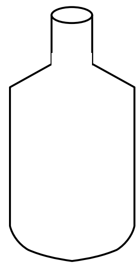
Situation	**Diagrams:** * **Macroscopic (Observe)** * **Microscopic (Molecules)** * **Symbolic (Math/Quantify)**	**Explanation**
Surface		* Lung volume 1 L
Descent **10 m depth** **(If no tank)**		* air pressure in the lungs is less than the current ambient pressure
Descent **10m depth** **(Breathing in through 2nd stage regulator)** **"Equalization"**		**2nd stage regulator functions:** 1. reduces air pressure from tank so can enter lungs at an appropriate pressure 2. ensures that the air pressure in the lungs is the same as the current ambient pressure * Adds air to **lungs** during descent

Situation	**Diagrams:** * **Macroscopic (Observe)** * **Microscopic (Molecules)** * **Symbolic (Math/Quantify)**	**Explanation**
Ascent Surface (Holding breath) **NEVER EVER DO!**		* Lung overexpansion * Pulmonary barotrauma
Ascent (Breathing out) **NEVER SURFACE FASTER THAN YOUR BUBBLES!**		

Appendix M

Note organizer 2: Cabin pressurization and pulmonary physiology

Flight: Helios Airways Flight 522

Situation	**Diagrams:** ∗ **Macroscopic (Observe)** ∗ **Microscopic (Molecules)** ∗ **Symbolic (Math/Quantify)**		**Explanation**
Runway			∗ Lung volume 1 L
Ascent **9 000m** **NO CABIN PRESSSURIZATION**	**Before (less than 0.75 atm)**	**After**	∗ Before: air pressure in the lungs is more than the current air pressure ∗ After: lung pressure and cabin pressure equalized ∗ not enough oxygen in lungs ∗ **passengers and crew suffer from hypoxia** ∗ eventually pass out
Ascent **9 000 m** **CABIN PRESSSURIZED** **"Equalization"**	**Before**	**After (0.95 atm)**	**Cabin Pressurization:** 1. Adds air to the **cabin** 2. air pressure in the cabin increases to approximately 0.95 atm ∗ try to maintain cabin pressure as close to sea level as practical, without exceeding a cabin-to-outside pressure differential of 0.58 atm. ∗ About 0.9 atm minimum requirement to breath adequately without assistance

Situation	Diagrams: * Macroscopic (Observe) * Microscopic (Molecules) * Symbolic (Math/Quantify)	Explanation
Descent Cabin depressurised		
Ascent (Breathing out)		

How Things Work, Cabin Pressure: http://www.airspacemag.com/flight-today/cit-larson.html

Appendix N

Activity: Deriving Boyle's Law

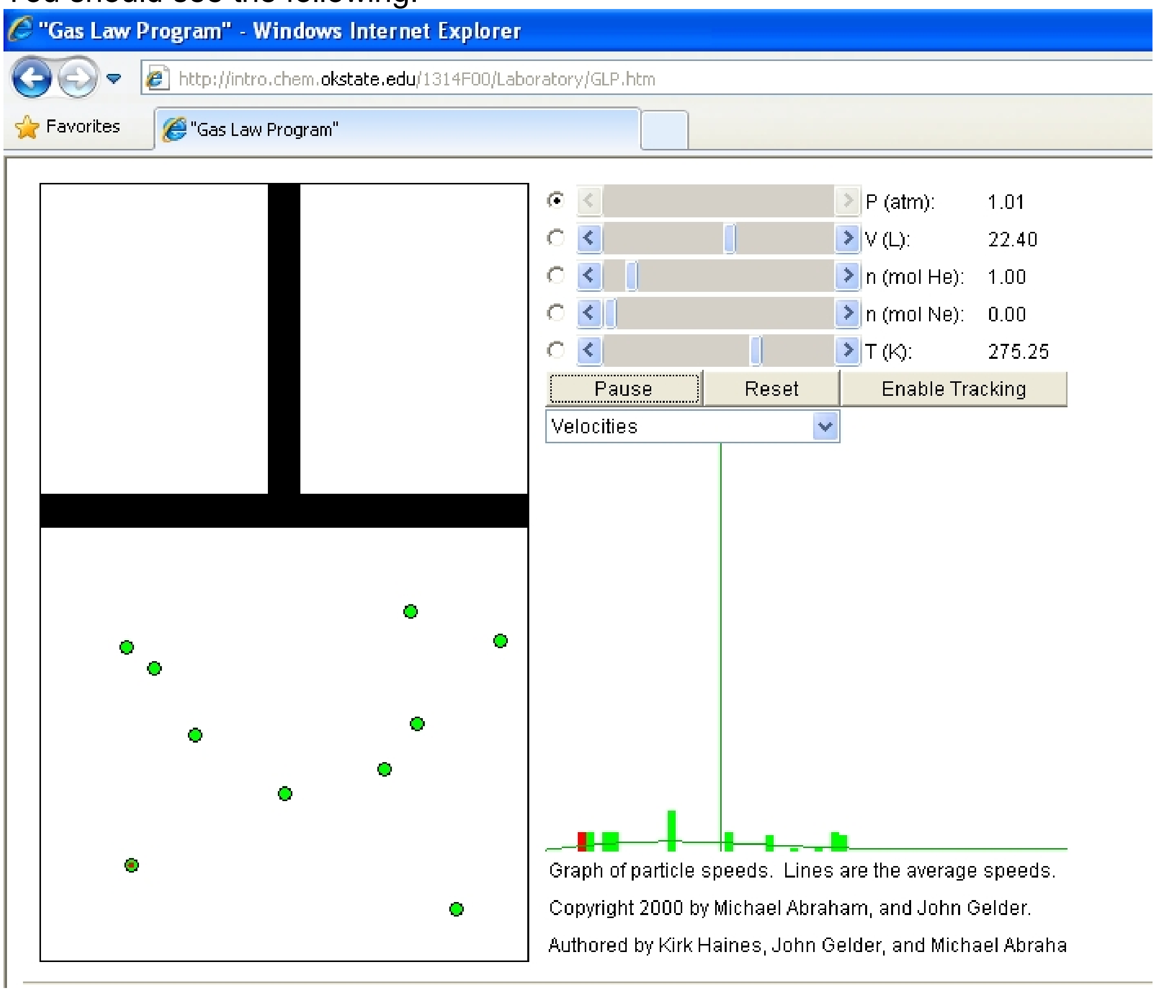
Deriving Boyle's Law

Set Up

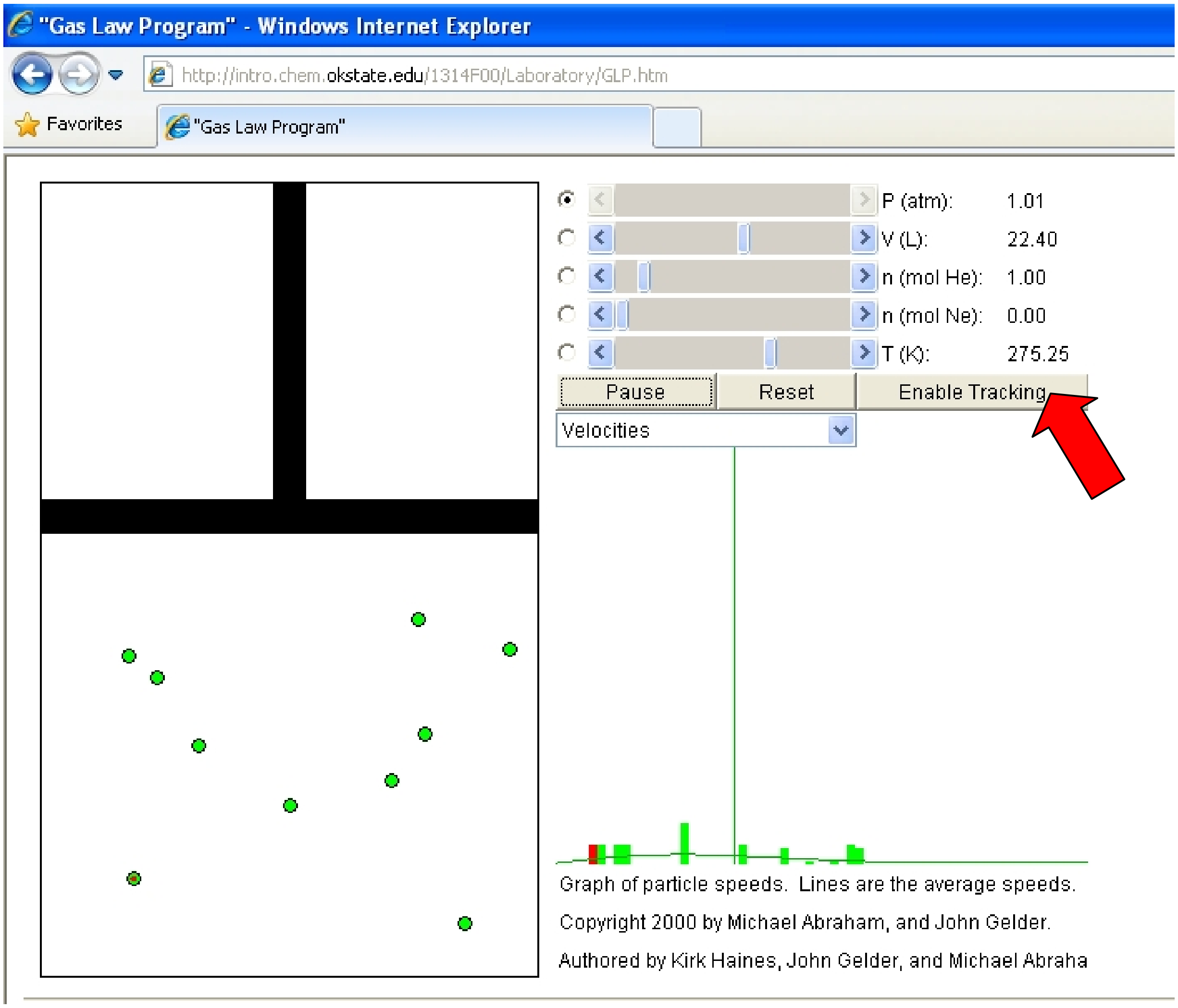
1. Log on to the computer.

2. Go to the "Gas Law Program" created by Michael Abraham and John Gelder from the University of Oklahoma: http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm

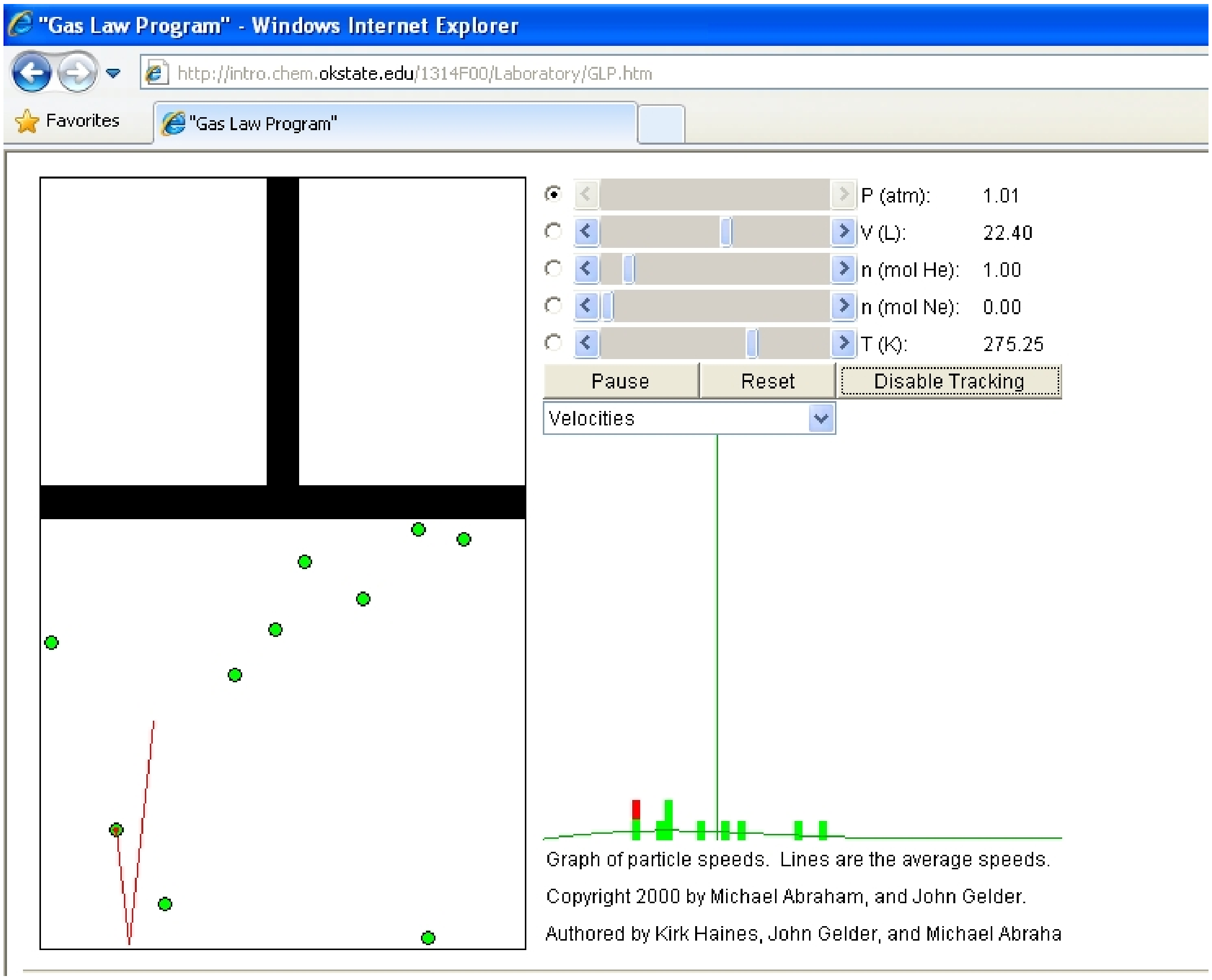
You should see the following:



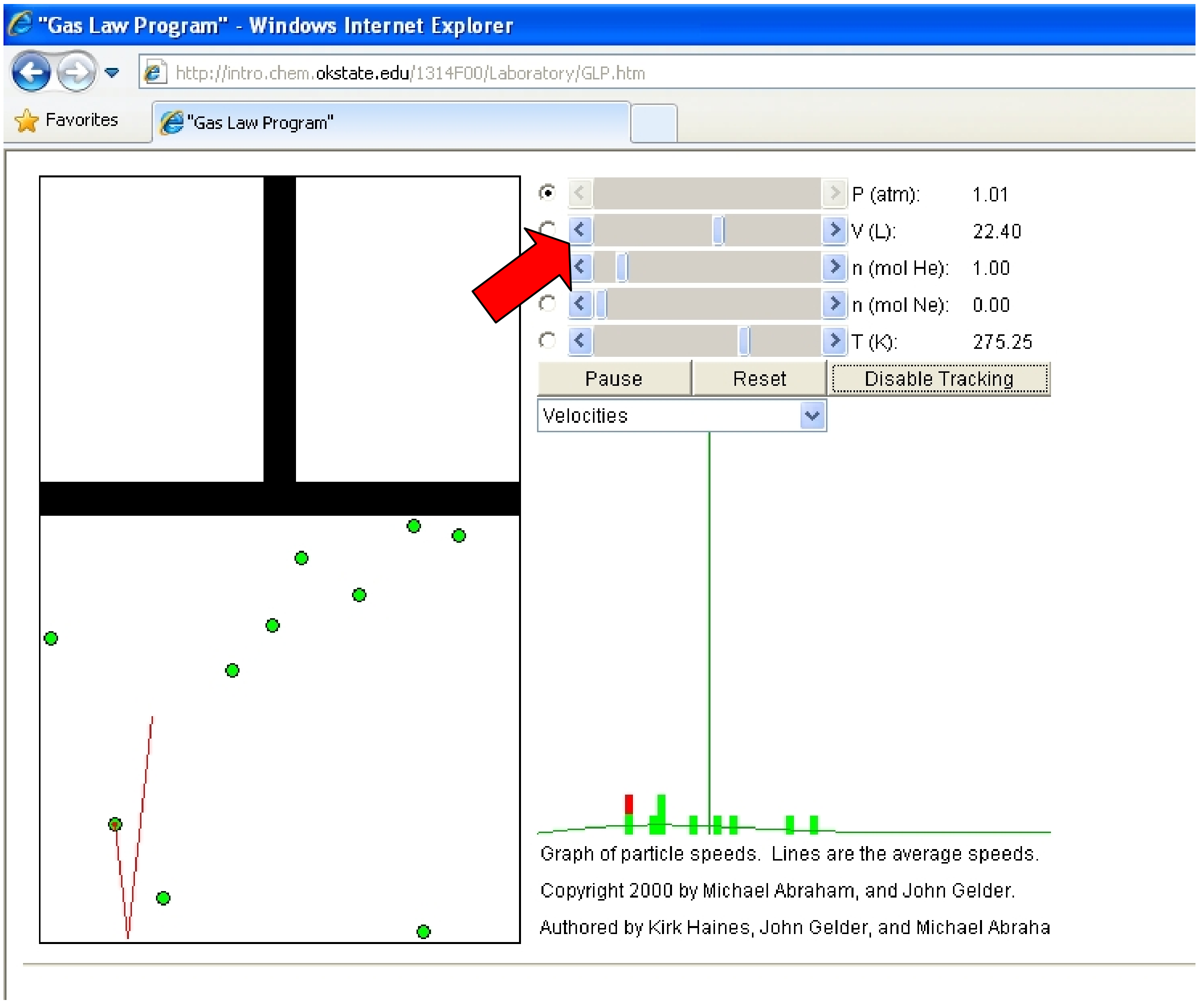
3. Click on the "Enable Tracking" (in this picture shown with a red cursor).



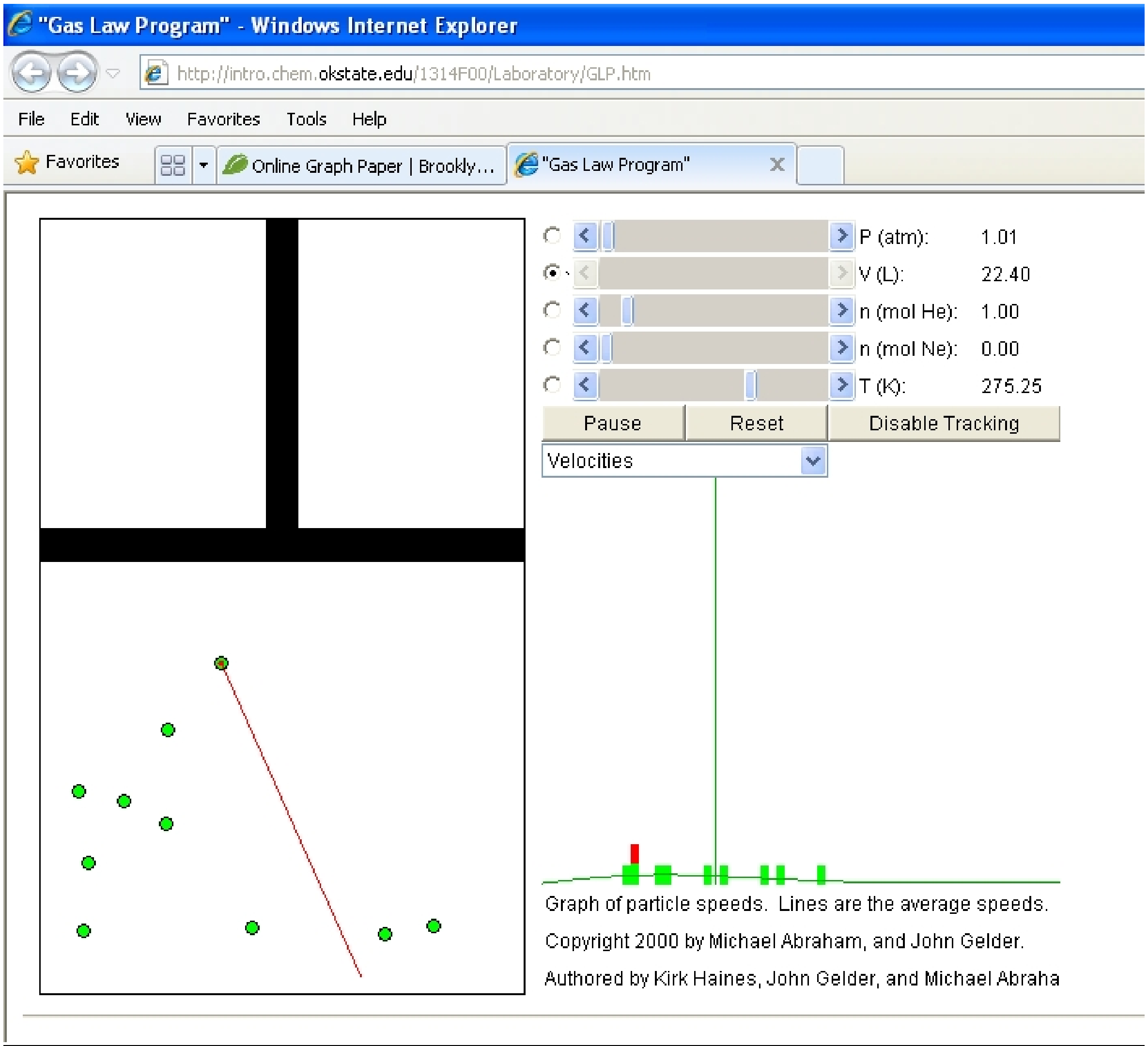
Your screen should now look like this. The red line helps you track the motion and velocity of a gas particle.



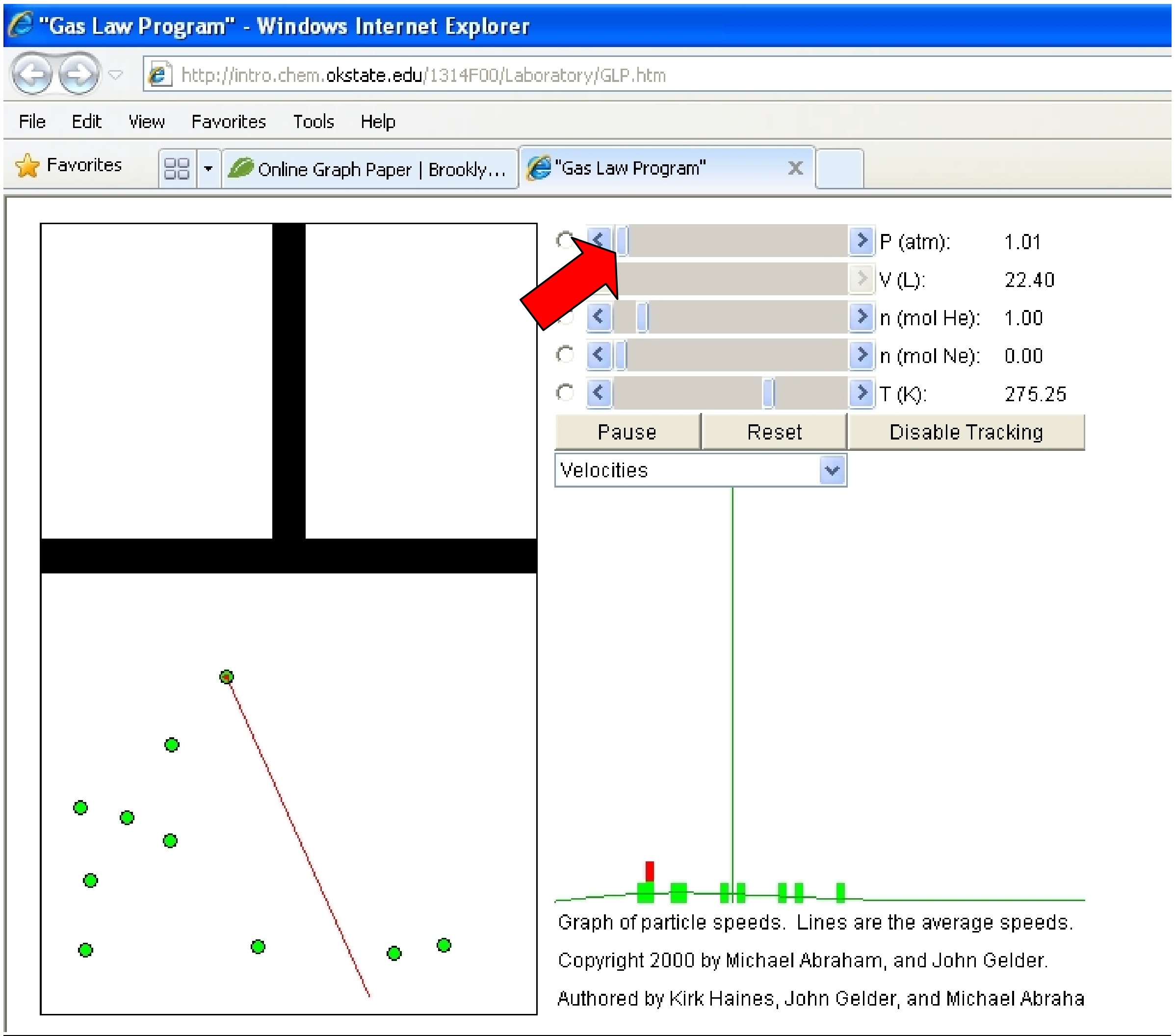
Click on the volume button. This sets volume as the dependent variable so that you can change the pressure, which is the ______________ variable.



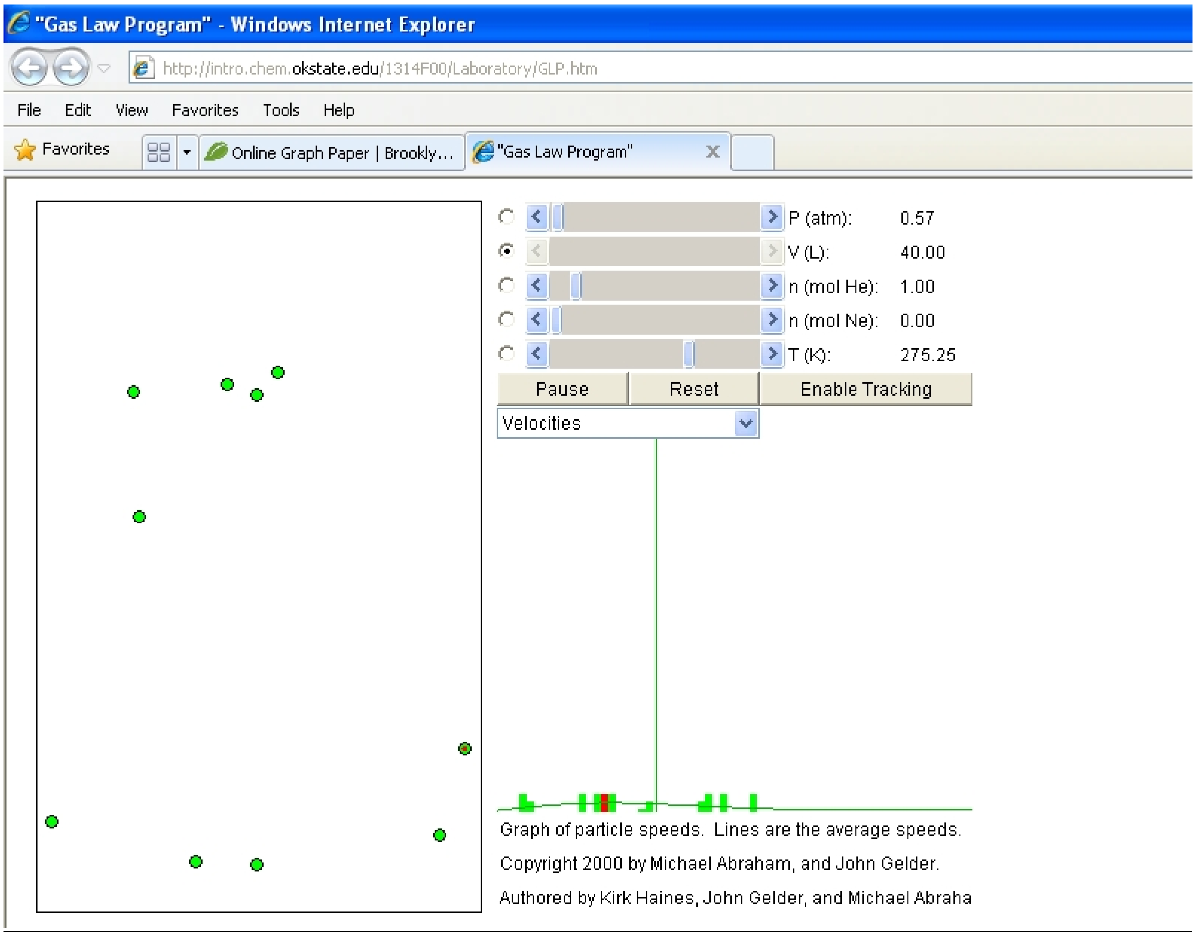
Your screen should now look like this:



Use the pressure scroll bar to decrease the pressure to 0.57 atm.



Your screen should look like this:



Activity

1. Start at a pressure of 0.57 atm. Record the volume.
2. Double the pressure. Record the volume.
3. Increase the pressure by four times the original pressure. Record the volume.
4. Increase the pressure by eight times the original pressure. Record the volume.
5. Increase the pressure by ten times the original pressure. Record the volume.

Questions

Table 1: Observations and results of the Boyle's Law activity.

Trial #	Pressure (atm)	Volume (L)	Statement	Multiply PV to find k
1	0.57			
2			When the pressure increases by _____ times the original pressure, the volume ____________ by _____ (times).	
3			When the pressure increases by _____ times the original pressure, the volume ____________ by _____ (times).	
4			When the pressure increases by _____ times the original pressure, the volume ____________ by _____ (times).	
5			When the pressure increases by _____ times the original pressure, the volume ____________ by _____ (times).	
6			When the pressure increases by _____ times the original pressure, the volume ____________ by _____ (times).	

1. In Table 1 above, fill in the blanks for each statement for trials #2-6.

2. Fill in the blanks to describe the general relationship between ambient pressure and volume.

   As ambient pressure increases, volume ____________.
   This is an _____________ relationship.

3. In the table above, multiply the pressure and volume for each trial (#1-6). Record the results in the final column.

4. What do you notice about the multiplication products for each trial? Are they similar or considerably different? ______________________

5. Given that:
   - Pressure and volume are have an ___________ relationship, and that
   - Multiplication products are ____________, (signified as "k")
   - Mathematically, the relationship between pressure and volume can be shown as...

6. Sketch your results on the graph paper below.

Appendix O

Boyle's Law Assignment 1

ROOM TEMPERATURE AND PRESSURE – R.T.P. Name______________________

Room Temperature can be assumed to be 20 °C =____________K°

Room Pressure = Atmospheric Pressure (1ATM)

1 ATM = 76cm = 101.3KPa = 1.013 bars = 1013 mbar

PRESSURE CHANGES ONLY

Start each situation with a 100 liter bubble at R.T.P. and calculate the new volume, V_2
*for each, clearly shown the pressure change ratio

1. Take the bubble to a mountain top at P_2 = 45cm

   P_1= T_1= $V_2 = V_1 \times \frac{P_1}{P_2}$ ΔP ratio = $\frac{P_1}{P_2} = \left(\frac{\ }{\ }\right) =$

   P_2= T_2=

   v_1=100L V_2 =?

2. Take the bubble way up almost to outer space where P_2= 0.5 KPa.

3. Pull it underwater to a depth of 150 meters.

   *pressure underwater increases 1ATM / every 10 meters down

4. Put it right to the bottom of the deepest part of the Pacific Ocean, The Mariana Trench.

   __________meters.

   (find it)

5. A different Bubble 1cm^3 rises from lake bottom from a depth of 2.0m. How big is it just at the surface?

Appendix P

Boyle's Law assignment 2

Boyle's Law Questions

Instructions

Answer each of the following questions in the spaces given below. For each of your answers include:

a) Your givens
b) A predication statement; and use a diagram showing the macroscopic (what you see) and microscopic (show particle crowding and pressure arrows) to explain your prediction
c) Calculations and final answer with units
d) A statement of whether the final number you calculated confirms your predictions

1. A balloon is 2.6 L in an open-window airplane at high altitude, where the air pressure sis 85 kPa. What was the original size of the balloon before the plane took off from the runway at sea level?

2. A balloon is 3.4 L at a pressure of 3 atm. What must the pressure be in order for the balloon to expand to 5.2 L?

3. At 40m deep a balloon is 8.0 L. To make the balloon expand to 24 L, what depth does the balloon have to move to?

4. You observe a balloon shrinking in a high pressure barochamber from 6.4 L down to 4.2 L, where the final pressure is 100 cmHg. What was the original pressure inside of the barochamber?

5. A person blows up a balloon at sea level, and then runs up Mt. Everest, where the air pressure is 72 kPa. On Everest, the balloon is 100 L. What was the original size of the balloon at sea level?

6. A balloon used to recover deep-sea wreckage is 1000 L at a depth of 60 m. What is the size of the balloon when it reaches the surface?

7. In an airplane movie, a child is seen holding a 4.3 L balloon after an accident where a window blew out at high altitude, where the pressure is 75 kPa. Moments before the accident, the balloon was 3.7 L. What was the original cabin pressure of the airplane?

8. A passenger is holding a helium balloon that is 2.5 L in volume in an airplane. The airplane cannot pressurize, and after take-off, the passenger notices the balloon expanding to 4 L. What is the pressure in the cabin at this point? Will the passenger stay conscious enough to continue observing the balloon? Why or why not?

Appendix Q

Laboratory activity 1: Boyle's Law syringe experiment

Boyle's Law Experiment – Land

Objective

To determine the relationship between pressure and volume.

Procedure

Set up the Boyle's Law Apparatus as directed by your teacher.

The final set-up should look as follows.

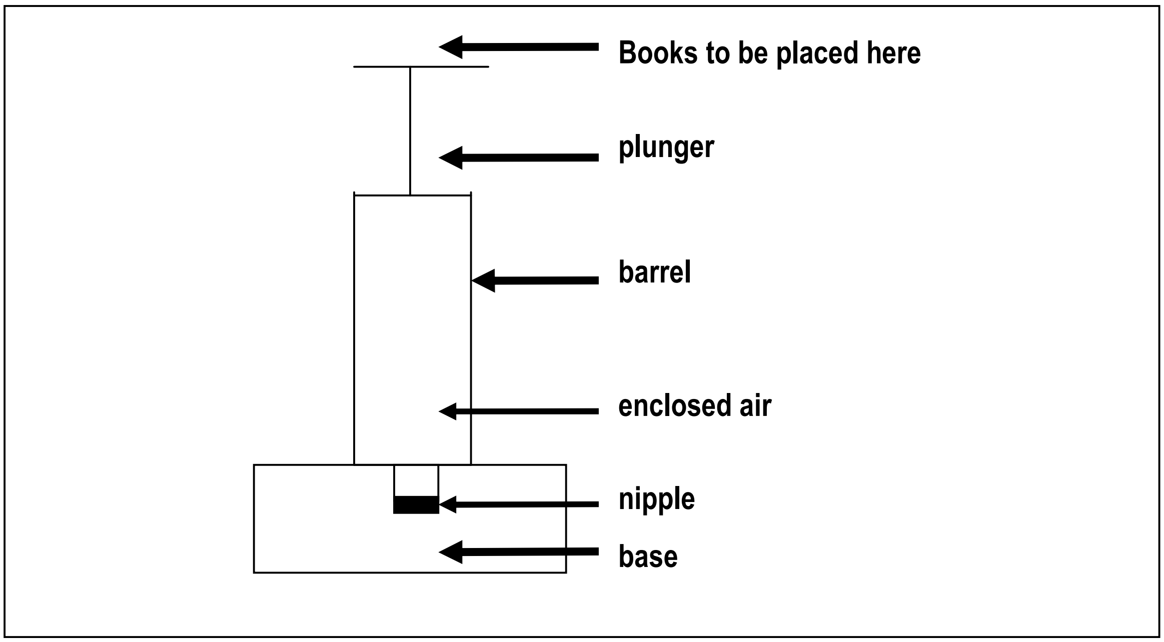


Figure 1: Boyle's Law Syringe Set-Up

1. Place the plunger at the top of the syringe. This mark will give the initial volume of air at a pressure of 1 atm.

2. Once the initial volume has been recorded, place one book on top of the plunger. Record the volume.

3. Place another book on the plunger. Record the volume.

4. Repeat this procedure until 5 books have been balanced on the plunger.

5. Take the books off of the plunger. Repeat steps 1-5 until three trials have been completed.

Results

1. Record the results on the following chart.

Pressure (Books)	Trial 1 Volume (ml)	Trial 2 Volume (ml)	Trial 3 Volume (ml)	Average Volume
0				
1				
2				
3				
4				
5				

2. Also record the results by making two graphs:
   a) Volume (ml) vs. Pressure (books)
   b) 1/Volume (1/ml) vs. Pressure (books).
      The x-axis should be extended as shown below:

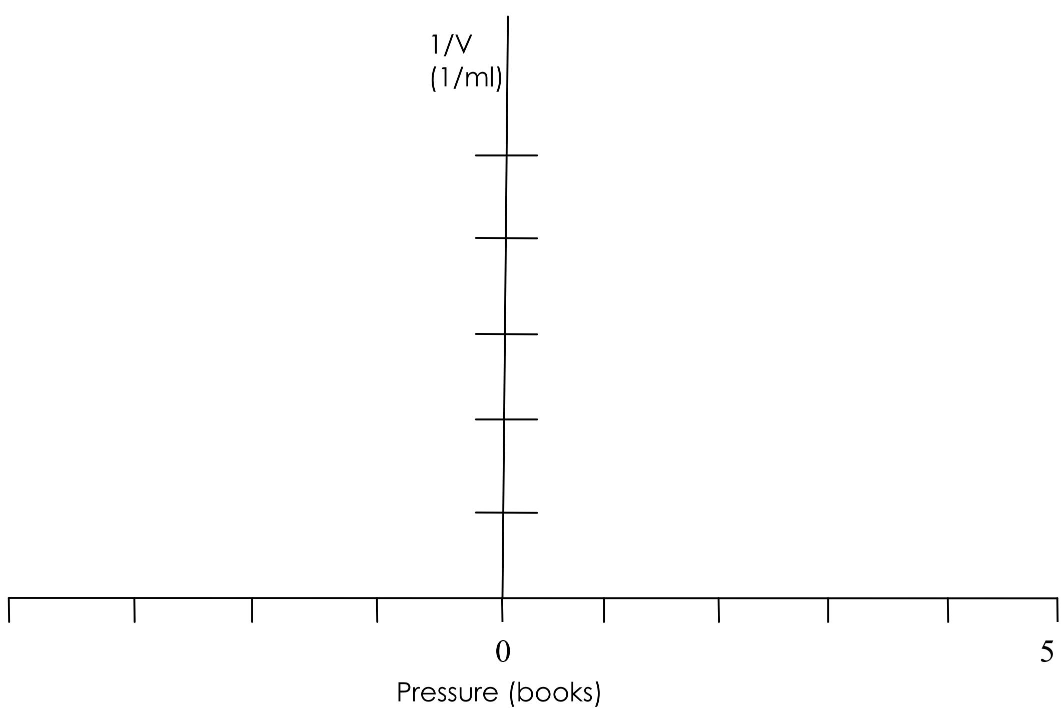


Figure 2: Axes for graph "b".

Conclusions

1. Describe the relationship between the dependent and independent variables for each of the graphs. That is, are the relationships direct or inverse?

2. Draw a diagram of the air bubble the macroscopic (what you see), microscopic (molecules and motion) and symbolic (pressure values in book units) at 0 books, 2 books and 4 books pressure. Describe the relative spacing and movement of the molecules.

3. Determine the following volumes:

   a. Use graph "a" to determine the volume of air in the syringe **if** the pressure was at 0.5 books and at 2.5 books. Show these points on the graph.

   b. Now use Boyle's Law to calculate the volume at 0.5 books and 2.5 books pressure. Are the values similar to the ones on your graph? Why or why not?

   c. Use a diagram to show what the syringe apparatus would look like at 0.5 books and 2.5 books pressure. In your diagram, include the microscopic, macroscopic and symbolic. Describe the movement and spacing of the enclosed air molecules.

4. Determine the following pressures:

   a. Use graph "a" to determine the pressure if the volume of enclosed air is at 18 ml and 9ml. Show these points on the graph.

   b. Now use Boyle's Law to calculate the pressures at these volumes. Are they similar to what you determined in question 4a? Why or why not?

   c. Diagram what the syringe apparatus would look like at 18 ml and 9 ml. In your diagram, include the microscopic, macroscopic and symbolic.

5. Extrapolate the points in graph b to hit the x-axis (pressure). What does this negative pressure represent? Hint: Does zero books on the syringe mean zero starting pressure?

6. Give at least two sources of error, and explain how each source of error would affect the results.

7. Research question: Identify a career or activity which is affected by Boyle's Law, and explain why. Note: DO NOT use one of our lab experiments.

Activity Evaluation:

1. Did you find this activity useful? Why or why not?

2. Can you suggest improvements to the activity?

3. Can you think another activity that could be used to learn this concept?

Appendix R

Diagnostic tool 11: Conceptions of scuba ear squeeze and equalization

Pre-Instruction Diagnostic Tool Series 15:

Scuba Diving and Ear Equalization Instructions

When scuba divers are learning how to dive beneath the surface of the water they are also taught how to pop their ears. A diver descends (downward) 10 m below the surface of the water. At 5 m, the diver pops her ears.

Draw an ear diagram to explain the following:
(a) what is happening when a diver is at the surface
(b) what causes the pressure while descending, and
(c) what occurs when the diver's ears pop.

You may use the diagram provided by the teacher to help you with your written explanation.

(a) Ear at the Surface	(b) Ear during descent	(c) Ear when it pops
Drawing:	Drawing:	Drawing:
Explanation:	Explanation:	Explanation:

What experiences and facts are you using to build your model? Explain.

Diagnostic Tool 15a:
Scuba Diving and Ear Equalization - Your Model

Ear at the Surface	Ear during descent	Ear when it pops
Drawing:	Drawing:	Drawing:
Explain your drawing.	Explain your drawing.	Explain your drawing.
What facts and experiences have you used to build your ear model at the surface model?		

Diagnostic Tool 15b:
Scuba Diving and Ear Equalization – Small Group Model

Ear at the Surface	Ear during descent	Ear when it pops
Drawing:	Drawing:	Drawing:
Explain your drawing.	Explain your drawing.	Explain your drawing.
What facts and experiences have you used to build your ear model at the surface model?		

Diagnostic Tool 15c:
Scuba Diving and Ear Equalization – Class Model

Ear at the Surface	Ear during descent	Ear when it pops
Drawing:	Drawing:	Drawing:
Explain your drawing.	Explain your drawing.	Explain your drawing.
What facts and experiences have you used to build your ear model at the surface model?		

Post-Instructional Diagnostic Tool 15d:
Scuba Diving and Ear Equalization – Scientific Model

Ear at the Surface	Ear during descent	Ear when it pops
Drawing:	Drawing:	Drawing:
Explain your drawing.	Explain your drawing.	Explain your drawing.
What facts and experiences have you used to build your ear model at the surface model?		

Post-Instruction Diagnostic Tool 15e:
Scuba Diving and Ear Equalization - Reflection

Compare your original model with the scientific model.

What parts of the scientific model were similar to your model?

Which parts were different?

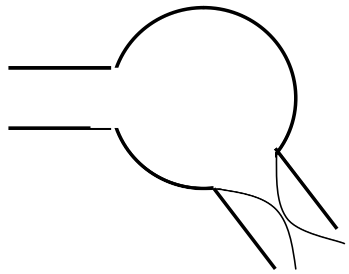
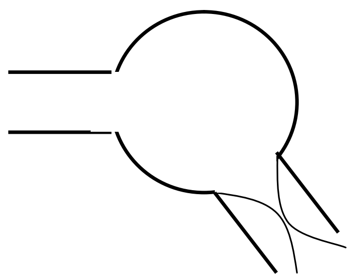
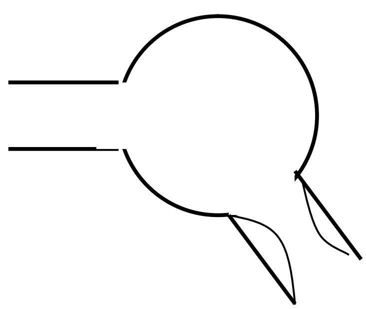
Are there parts of the scientific model you do not understand? If so, is it the macroscopic, microscopic or symbolic part(s) that is/are confusing?

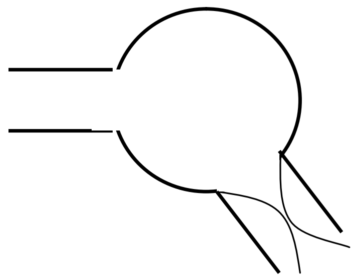
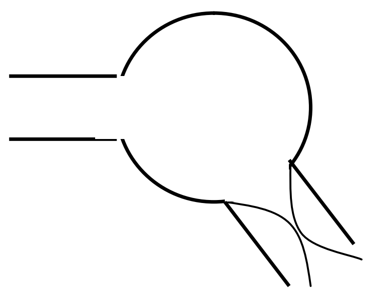
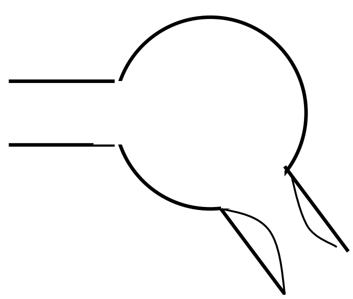
What experiences do you have that will help you remember the scientific model?

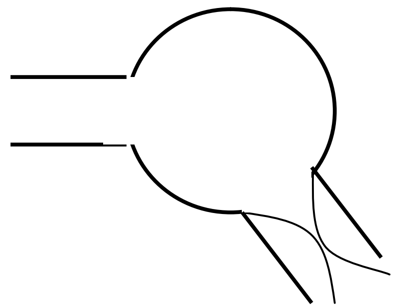
Appendix S

Note organizer 3: Ear squeeze and equalization while scuba diving

SCUBA: Ear Equalization Teaching Sequence

Situation	Diagrams	Explanation
Surface		
Descent **10 m depth** • Ear Squeeze • No Equalization		
Descent **10m depth** • During Equalization **In real dives, equalize BEFORE you feel pain, even every half-meter!**	 **Force ears to "pop"**	

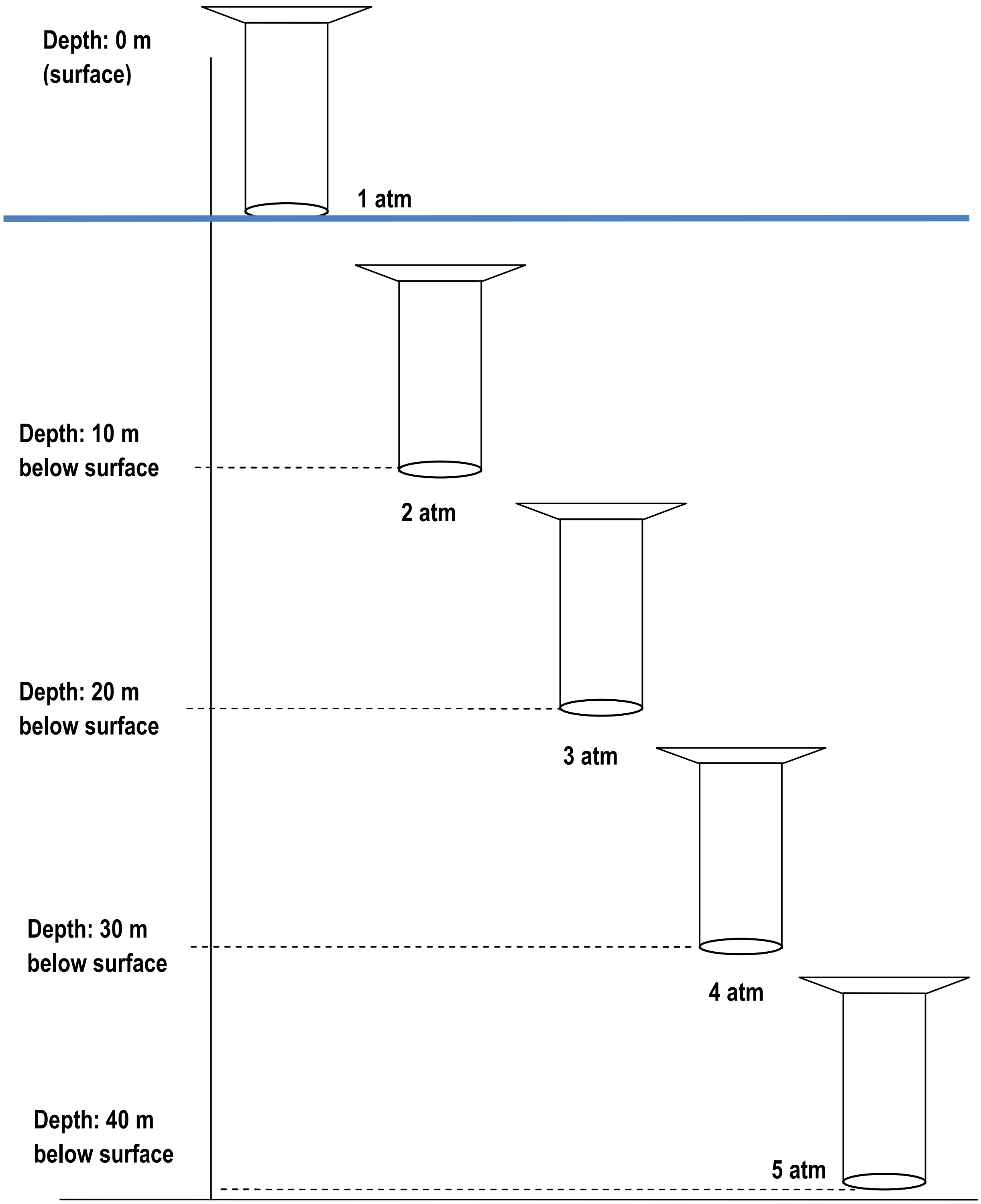
Situation	**Diagrams**	**Explanation**
10m depth • After Equalization		
Ascent **5 m depth** • Ear Squeeze • No Equalization		
5m depth • During Equalization **"Normally", the Eustachian tube automatically opens during ascent (going up)**		

Situation	Diagrams	Explanation
Ascent from 10 m to surface • Reverse Block • No automatic equalization		

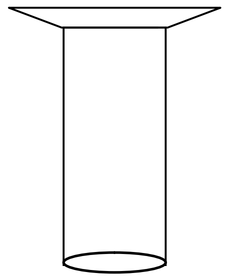
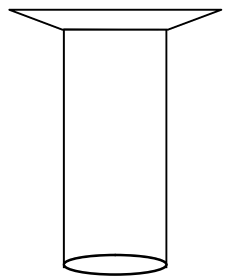
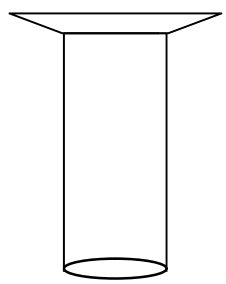
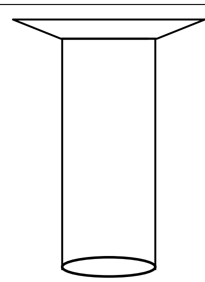
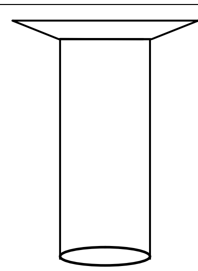
Appendix T

Activity: Student predictions of the cylinder experiment

A professional diver conducts an experiment using an inverted cylinder, similar to the experiment you will be conducting at the scuba diving field trip. Assuming the cylinder does not crush under pressure, predict what happens to the air bubble in the cylinder during descent. The volume of the cylinder is 1L.



Explain what will happen to the air bubble at each depth. Draw what the diver would have observed (macroscopic), the relative distances between the air and water molecules (microscopic) and the volume of the air bubble (symbolic).

Depth, Pressure	Macroscopic and Microscopic Representation	Symbolic (Calculations)	Explanation
Surface (0m) 1 atm			
Surface (10m) 2 atm			
Surface (20m) 3 atm			
Surface (30m) 4 atm			
Surface (40m) 5 atm			

Questions:

1. Compare your predictions to the computer simulation. Did your predictions match those of the simulation? If not, why?

2. Draw a volume vs. pressure graph of the results from the experiment above.
   a) What is the relationship (proportional, inverse, etc.) between volume vs. pressure?
   b) Compare this graph to the syringe experiment. What similarities do you notice?

3. In your scuba diving cylinder experiment, you will be diving down to 3.5m. What do you expect your graph to look like? That is, will it look the same as the results from question 2? Why or why not? Hint: draw a box around the portion of your graph from 0m to 3.5m.

Appendix U

Lab activity 2: Boyle's Law scuba experiments

ID NUMBER: ______________________________

Pool Procedure for Boyle's Law Demonstrations and Experiment

Objective

To determine the relationship between the pressure and the volume of a gas, and how it influences certain physiological effects while SCUBA diving.

Setup

You will be working in groups of 5, three student divers, one SCUBA instructor and one non-diver. There will be three groups in total. Your SCUBA instructor is your designated team leader. Always stay with your designated SCUBA instructor.

Note: You must listen to the leader at all times and pay attention. Always stay together in your team. You will descend together and surface together as a team. NO ONE is to wander away from their team leader. Always stay as a unit.

Part I: Suit Up and Initial Dive

You and your group will learn the basics of SCUBA by listening to the instructor, answering questions, then diving in the shallow end of the pool. This will take approximately 45 minutes.

Once everyone is comfortable, you and your group will dive down to the bottom of the deep end of the pool with your instructor. Make sure to equalize frequently, **before** you start to feel any discomfort. Depending on the time, you will be able to swim for a few minutes to get used to adjusting your buoyancy underwater.

When everyone is comfortable adjusting their buoyancy, the teachers will signal all groups to surface simultaneously. At this point, all students will line up against the edge of the pool.

Part II: The Physiological Effects of Boyle's Law – Skin Diving Demonstration

Your SCUBA team leader will have each person feel a sealed, 2L pop bottle filled with air at the surface of the pool. Note how "hard" the pop bottle feels. Is it easy to squeeze?

Draw a picture of the pop bottle at the surface showing why it maintains its shape. In your picture, include the microscopic, macroscopic and symbolic. Note: assume air pressure is 1 atm.

Then students will dive to the bottom of the pool with their leader and observe what happens to the pop bottle. What happens to the bottle?

Explain why the pop bottle has been crushed. Use a diagram to clarify your explanation. The diagram should include the macroscopic, microscopic and symbolic. Note: assume water pressure is 1.35 atm.

The instructor and students will then surface. Feel the bottle again. How does it feel compared to the first time at the surface?

Explain why the bottle regained its shape. In your diagram, use the macroscopic, microscopic and symbolic.

In this demonstration, the bottle simulates a person's lungs when they are skin diving. PADI (2006) states that:

> …your lungs experience no harmful effects from changes in pressure when you're holding your breath while skin diving. You take a breath and descend and the increasing water pressure compresses the air in your lungs. During ascent, this air re-expands so when you reach the surface, your lungs return to approximately their original volume. (PADI, 2006, p. 23)

Do your observations of the pop bottle support the statement made by PADI at the opening of this section? Explain your observations in terms of Boyle's law. Include pressure, volume and particle (water and air) collisions in your explanation.

Part III: Physiological Effects of Boyle's Law – Pulmonary Barotrauma

Again, you and your SCUBA leader will dive down to the bottom of the pool with the 2L pop bottle filled with air.

At the bottom of the pool, the leader will open the bottle and fill it with air from his or her tank. This simulates the air delivered from your SCUBA tank to your lungs. The instructor will then seal the bottle with the cap.

What happens to the shape of the bottle once filled with air?

Explain why the bottle has that shape once filled. Draw a diagram to clarify your explanation. Include the macroscopic, microscopic and symbolic in your diagram. Note: assume water pressure is 1.35 atm at this depth.

The team will then slowly ascend. This simulates what happens to a SCUBA diver's lungs if the diver holds their breath while ascending. Observe what happens to the bottle as you ascend.

How does the bottle feel in comparison to the first time at the surface?

Explain why the bottle feels this way at the end of the demonstration. Use a diagram to clarify your explanation. Your diagram should include the microscopic, macroscopic and symbolic. Your explanation should also be explained in terms of Boyle's Law, and pressure systems.

This demonstration simulates what happens to the lungs if a diver holds their breath and/or ascends too quickly. What happens to the lungs if a diver holds her breath while ascending? Use a diagram that includes the macroscopic, microscopic and symbolic to clarify your explanation. Your explanation should also be explained in terms of Boyle's Law, and pressure systems. Name two medical conditions that can occur.

Divers **must always** breath out while ascending. A rule of thumb is that they should never "beat their bubbles" to the surface. Using Boyle's Law, explain why divers must always breath out, and why they must ascend slowly?

Once the team has surfaced, line up against the pool wall for the next set of instructions.

Part IV: Demonstration: Why is Equalization Not a Problem When Ascending?

"Your other air spaces generally pose no problems during ascent. Normally, expanding air releases from these without any conscious effort." (PADI, 2006, p. 24)

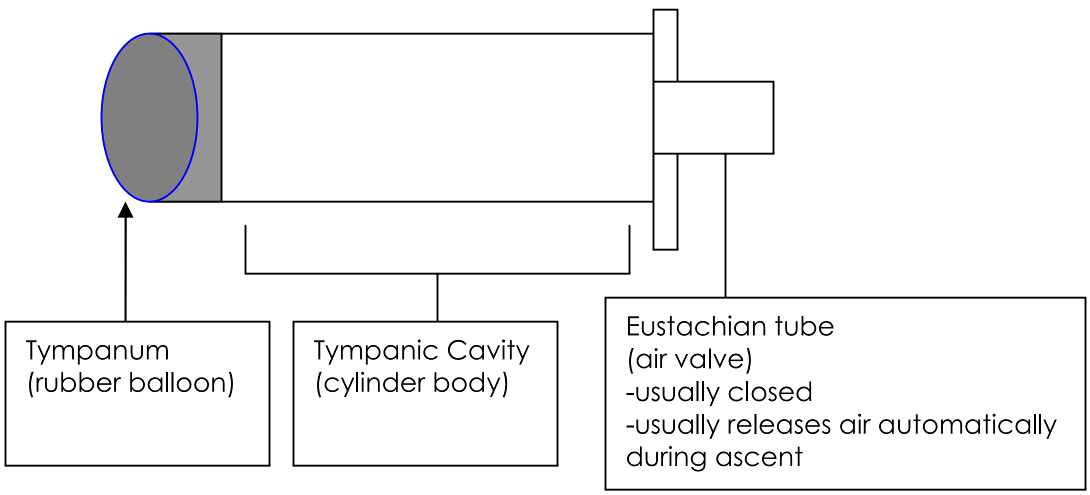
Your team leader will bring an inverted cylinder to the bottom of the pool. He or she will fill the cylinder with air at the bottom of the pool, then slowly ascend.

What happens to the air in the cylinder as you ascend? Why? Explain in terms of Boyle's Law, pressure (positive and negative), volume, and density.

Using your explanation above, explain why equalizing air spaces while **ascending** is normally not a concern.

Part V: Demonstration: The Squeeze, Equalization and Reverse Block

The team leader will show you a stylized model of the ear made from a cylinder, balloon, and air valve.



You and your SCUBA leader will dive down to the bottom of the pool with the ear model.

Look at your ear model at the surface of the pool. Explain why the tympanum is in this position. To clarify your explanation, draw a diagram of the ear model, showing the macroscopic, microscopic and symbolic. Note: assume 1 atm air pressure at the surface.

Look at what happens to the tympanum as you descend. Does it become concave, convex, or stay in the "normal" position?

What causes the change if any? Use a diagram to clarify your explanation. Your diagram should include the microscopic, macroscopic and symbolic. Assume water pressure is 1.35 atm.

At the bottom of the pool, the leader will fill the cylinder with air using the air from the SCUBA tank. This simulates the air delivered from your lungs to the middle ear via the Eustachian tube. "Equalization" has occurred. What happens to the position of the tympanum now?

What causes the change in the position of the tympanum after equalization? Use a diagram to clarify your explanation. Your diagram should include the microscopic, macroscopic and symbolic. Assume water pressure is 1.35 atm.

The team will then slowly ascend. The air valve will be blocked to prevent any air from escaping. This simulates what happens when a diver has reverse block. The Eustachian tubes are swollen and cannot open. Observe what happens to tympanum as you ascend. Does it become concave, convex, or stay in the "normal" position?

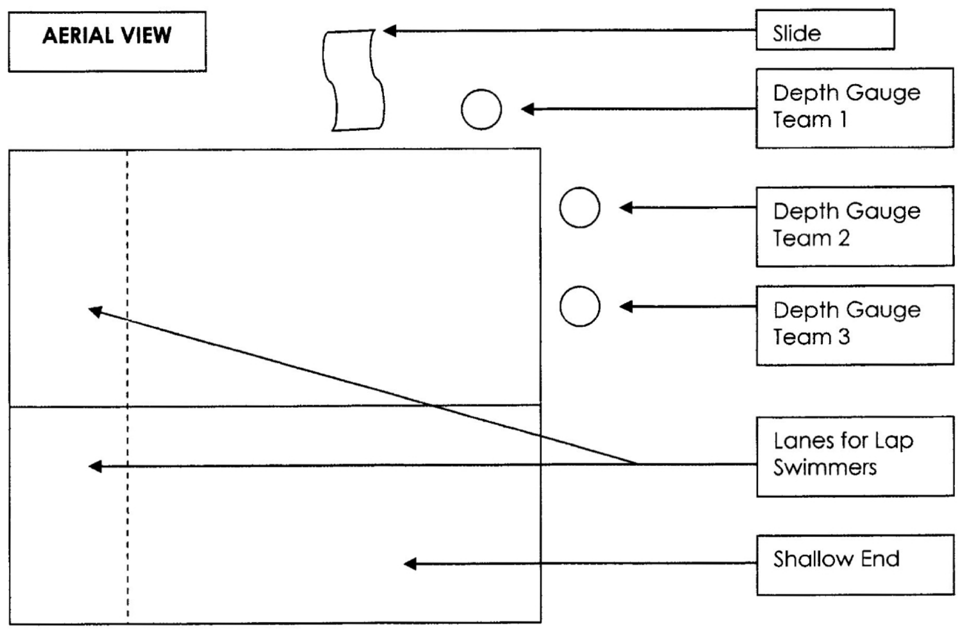
Explain why the tympanum assumes this position if no equalization occurs while ascending? Use a diagram to clarify your explanation. The diagram should include the macroscopic, microscopic and symbolic. Note: surface atmospheric pressure is 1 atm.

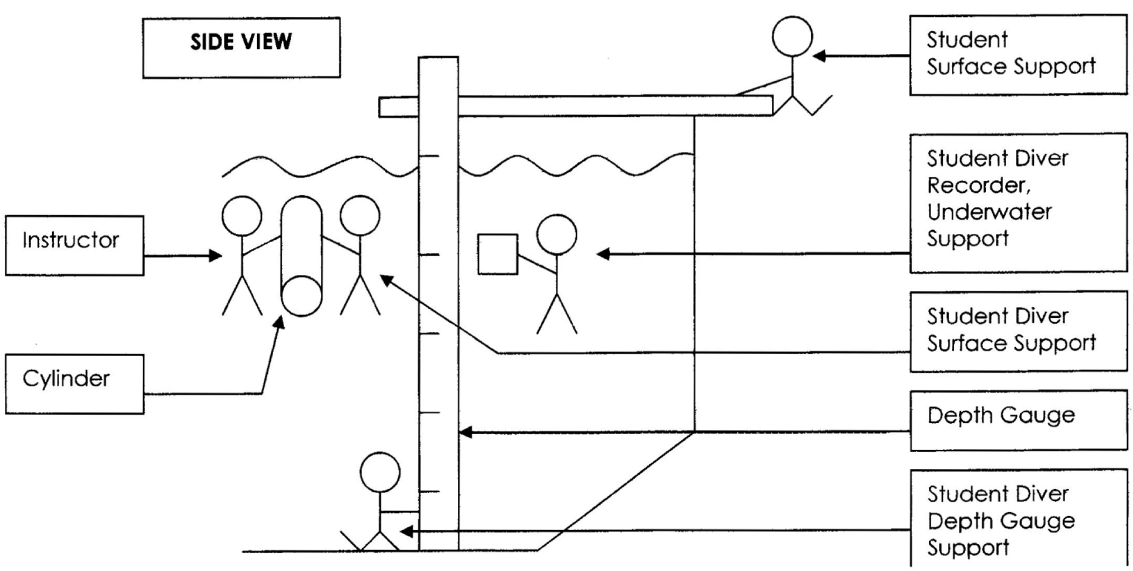
Part VI: Boyle's Law Experiment

Objective: To determine the relationship between pressure and volume.

Procedure

Each group will be assigned to a depth gauge and a position along the pool edge as indicated below.





One student will dive to the bottom of the pool to support the depth gauge, and keep it steady.

One student and one instructor will conduct the actual experiment. One student will hold the inverted cylinder at the designated depth while maintaining neutral buoyancy. Note: The inverted cylinder will add noticeable buoyancy so take time to practice attaining neutral buoyancy while holding the cylinder.

The instructor will help the student hold the cylinder close to the depth gauge and mark the water level of the cylinder. Make sure the levels are well marked before proceeding to the next depth. All measurement must be taken with the inverted cylinder in the vertical position. The third diving student will record data on the underwater slates provided.

The fourth student will be the member of the group who is not diving. This student will hold the depth gauge away from the edge of the pool with the horizontal extension. It is important to keep the gauge vertical throughout the procedure.

If a fourth student does dive, they will record the data using the underwater slate. They may also help by holding the supporting the depth gauge just below the surface, or whatever procedure works for your group. A fifth student will then be required to hold the depth gauge on the surface away from the edge of the pool with an extension. The availability of a fifth student is not guaranteed.

1. The initial level can be marked while at the surface by adjusting the depth of the inverted cylinder so that the water level inside the cylinder matches the surface of the pool. This mark will give the initial volume of air at a pressure of 1 atm.

2. Once the initial volume has been recorded all three divers descend to the bottom of the pool with the inverted cylinder. Note: It is very important to equalize pressure on the way down so that you are comfortable at the bottom of the pool. ie. Your ears are not hurting!!

3. Start taking readings at 0.500M depth and slowly descend taking readings at each mark on the depth gauge. Remember to equalize as you descend. Also record the readings using the underwater slate provided.

4. Once back at the surface hand the cylinder to the non-diver who will then record the levels on a lab sheet. Once the levels have been recorded this person will erase the marks and hand the cylinder back to the divers.

5. The divers can now switch jobs and repeat the procedure.

Results

1. Record the results on the following chart.

Depth (m)	Pressure (atm)	Trial 1 Volume (ml)	Trial 2 Volume (ml)	Trial 3 Volume (ml)	Average Volume
0.0	1.00				
0.5	1.05				
1.0	1.10				
1.5	1.15				
2.0	1.20				
2.5	1.25				
3.0	1.30				
3.5	1.35				

2. Also record the results by making three graphs:
    a) Depth (m) vs. Pressure (atm)
    b) Volume (ml) vs. Depth (m)
    c) Volume (ml) vs. Pressure (atm)
    d) 1/Volume (1/ml) vs. Pressure (atm).

Conclusions

1. Describe the relationship between the dependent and independent variables for each of the graphs. That is, are the relationships direct or inverse?

2. Compare your graphs from this lab to your graphs from the Boyle's Law syringe experiment. Is this a curved or straight graph? Does the shape of this graph differ from the land experiment? If there is a difference, how can this be explained?

3. For graph c, draw a diagram of the air bubble and water in the cylinder showing the macroscopic, microscopic and symbolic at 1.00 atm (surface), 1.10 atm (1 m depth) and 1.20 atm (2 m depth).

4. Determine the following volumes:

   a. Use graph "c" to volume of air in the cylinder if the pressure was at 1.175 atm and at 1.4 atm. Show these points on the graph.

   b. Now use Boyle's Law to calculate the volume at 1.175 atm and at 1.4 atm pressure. Are the values similar to the ones on your graph? Why or why not?

   c. Use a diagram to show what the cylinder would look like at these pressures. In your diagram, include the microscopic, macroscopic and symbolic. Describe the movement and spacing of the enclosed air and water molecules.

5. Determine the following pressures:

   a. Use your graph to determine the pressure if the volume of enclosed air is at 950 ml and 700 ml. Show these points on the graph.

   b. Now use Boyle's Law to calculate the pressures at these volumes. Are they similar to what you determined in question 4a? Why or why not?

   c. Diagram what the cylinder would look like at 950 and 700 ml. In your diagram, include the microscopic, macroscopic and symbolic. Describe the movement and spacing of the enclosed air and water molecules.

6. Extrapolate the points in graph d to hit the x-axis (pressure). What does this point represent?

7. Give at least two sources of error, and explain how each source of error would affect the results.

8. Explain why a person should always breath out while ascending. Make sure your explanation includes the microscopic, macroscopic, and symbolic.

9. A person has a cold and uses medication so he can equalize during descent. During ascent, the medication wears off, and the Eustachian tubes are swollen shut, and the diver is unable to equalize. This is called ______________ ______________. Explain what happens to the tympanum at this time. Make sure your explanation includes the microscopic, macroscopic, and symbolic. Name a medical condition that can result.

Activity Evaluation:

1. Are any activities you found useful? If so, which one(s)? Why do you think the activity(ies) was/were useful?

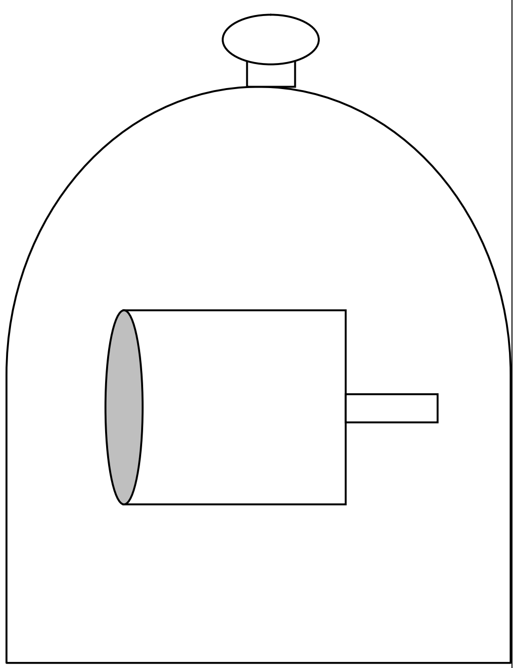
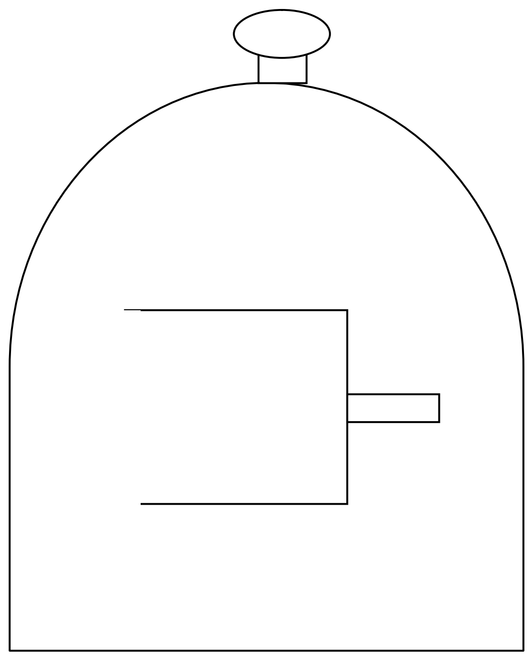
2. Are there activities that were not useful? ? If so, which one(s)? Why do you think the activity(ies) was/were not useful? Can you suggest improvements or alternatives to the activity?

3. Can you think another activity that could be used to learn these concepts?

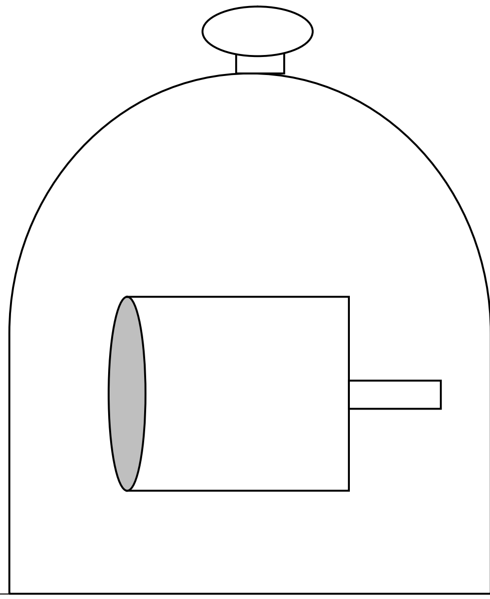
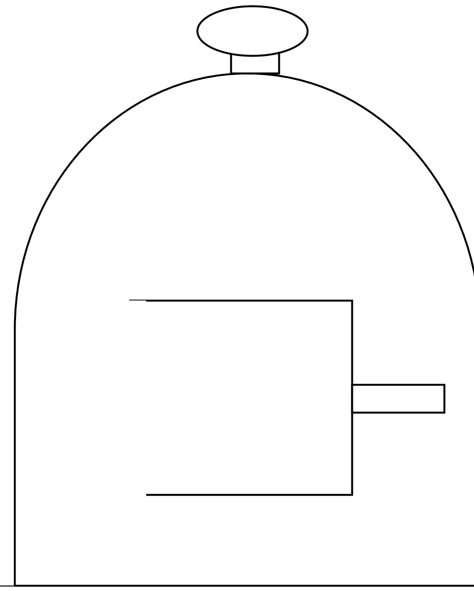
Appendix V

Diagnostic tool 12: Conceptions of ear squeeze during flight

Demonstration Instructions: Boyle's Law Ear Squeeze During Flight

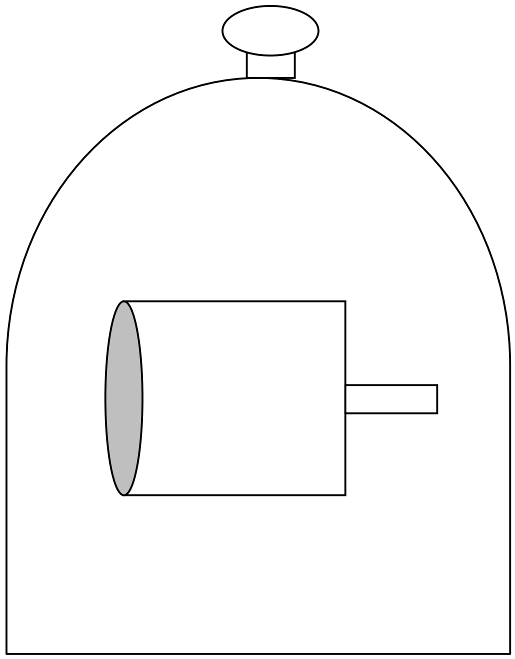
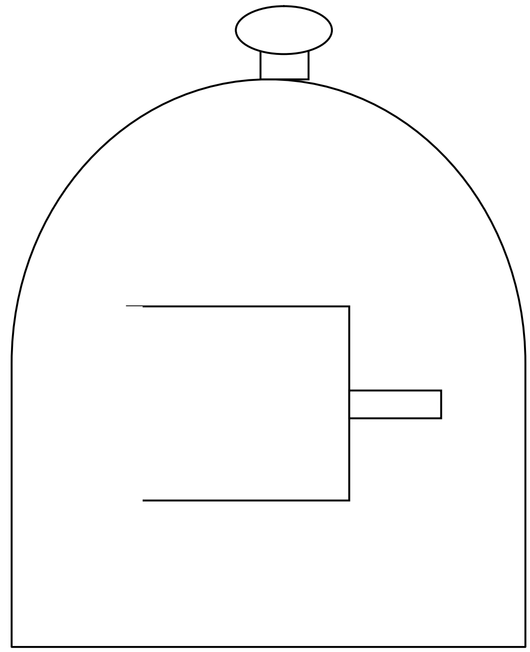
Part 1	Part 2
• Look at the simulated ear in the bell jar. • Consider the bell jar. The air pressure inside the jar is 1.0 atm. • Pretend that you can see the invisible air particles. Draw what is happening. Use this drawing to explain why the rubber diaphragm stays in a relatively vertical position.	• The teacher is pumping out half of the air inside the bell jar. The air pressure inside the bell jar is now 0.5 atm. • Predict what happens to the ear drum. Does it bulge outward, inward or stay in the same position? Draw in the ear drum. • Pretend that you can see the invisible air particles. Draw what is happening. Use this drawing to explain the position of the rubber diaphragm in this situation. Ensure your diagram takes into account what you drew in Part 1.
	

Demonstration: Boyle's Law Ear Simulation - Your Model

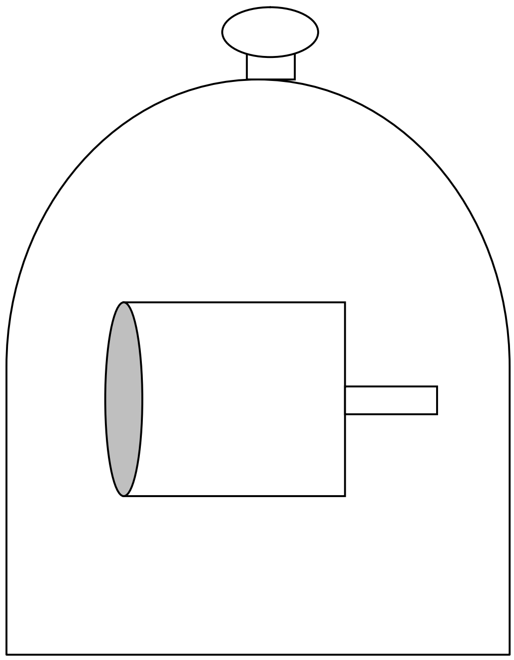
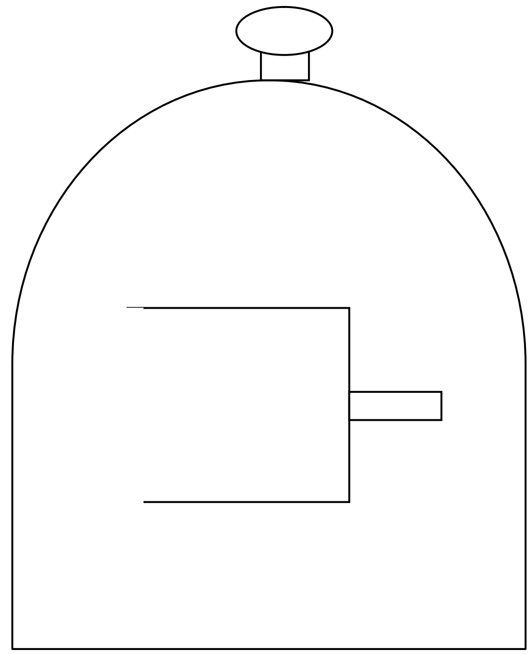
Part 1	Part 2
	
Show the movement of the air particles.	Show the movement of the air particles.
Use your drawing and explanation to explain the position of the diaphragm.	Use your drawing and explanation to explain the position of the diaphragm.
Recall that the air pressure inside the jar is 1.0 atm. What is the pressure of the enclosed air particles in the can?	Assume atmospheric pressure in the bell jar is 0.5 atm. What is the pressure of the enclosed air particles in the can?

Reflection: What experiences did you use to make this model?

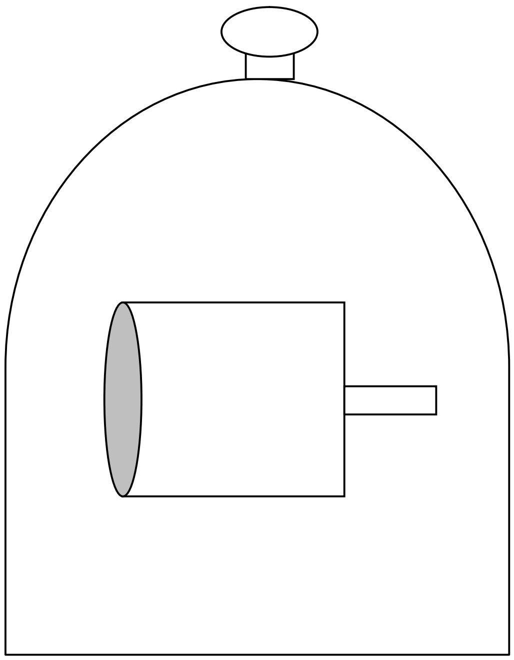
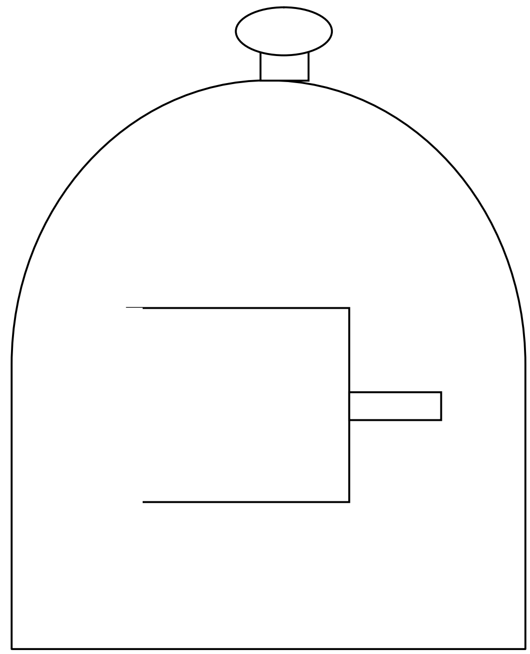
Demonstration: Boyle's Law Ear Simulation - Small Group Model

Part 1	Part 2
	
Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Recall that the air pressure inside the jar is 1.0 atm. What is the pressure of the enclosed air particles in the can?	Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Assume atmospheric pressure in the bell jar is 0.5 atm. What is the pressure of the enclosed air particles in the can?

Demonstration: Boyle's Law Ear Simulation - Large Group Model

Part 1	Part 2
	
Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Recall that the air pressure inside the jar is 1.0 atm. What is the pressure of the enclosed air particles in the can?	Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Assume atmospheric pressure in the bell jar is 0.5 atm. What is the pressure of the enclosed air particles in the can?

Demonstration: Boyle's Law Ear Simulation - Scientific Model

Part 1	Part 2
	
Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Recall that the air pressure inside the jar is 1.0 atm. What is the pressure of the enclosed air particles in the can?	Show the movement of the air particles. Use your drawing and explanation to explain the position of the diaphragm. Assume atmospheric pressure in the bell jar is 0.5 atm. What is the pressure of the enclosed air particles in the can?

Reflection:

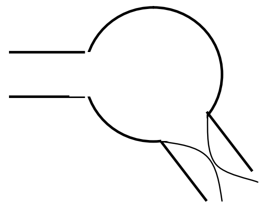
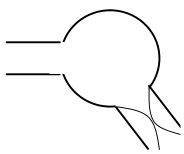
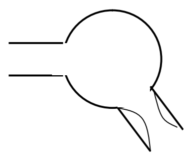
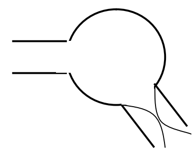
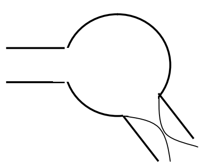
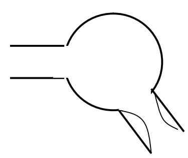
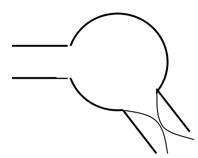
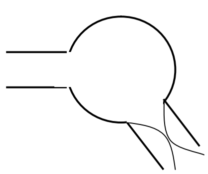
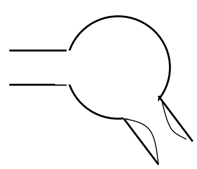
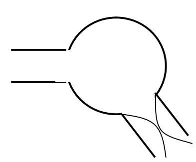
Compare your original model with your model after the demonstration.

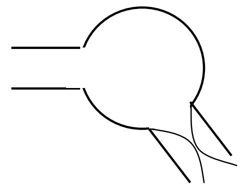
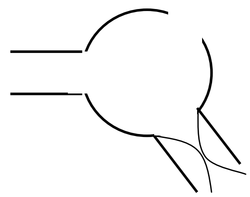
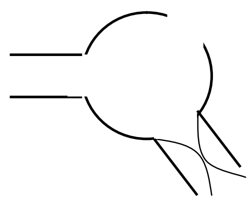
Did your model change? Why or why not? What arguments will help you remember the scientific model?

Appendix W

Note organizer 4: Ear squeeze and equalization during a flight

FLIGHT: Ear Equalization Teaching Sequence

Situation	**Diagrams** * **Macroscopic (Observe) – Draw the eardrum.** * **Microscopic (Air particles) – Draw the air particles.** * **Symbolic (Quantity) – Show the pressure in atm.**			**Explanation**
Surface/ Airport Runway (1 atm)				
Ascent • On the way up • No cabin pressurization	**Before Equalization (Cabin pressure 0.8 atm)** 	**During Equalization (Cabin pressure 0.8 atm)** 	**After Equalization (Cabin pressure 0.8 atm)** 	
Situation	**Diagrams**			**Explanation**
Cruising Altitude 9 000 m • Cabin fully pressurized	**Before Cruising Altitude Equalization (Cabin pressure 0.95 atm)** 	**During Cruising Altitude Equalization (Cabin pressure 0.95 atm)** 	**After Cruising Altitude Equalization (Cabin pressure 0.95 atm)** 	
Equalization at Surface • During Equalization	**Before Final Equalization (Cabin pressure 1 atm)** 	**During Final Equalization (Cabin pressure 1 atm)** 	**After Final Equalization (Cabin pressure 1 atm)** 	

Situation	Diagrams	Explanation
Reverse Block at Surface • During ascent • Before cabin fully pressurized (0.8 atm) • Reverse Block • No Equalization		
Forceful Equalization Ascent • NEVER DO!!! • Round Window Implosion		
Forceful Equalization Descent • NEVER DO!!! • Round Window Explosion •		

Appendix X

Student pre- and post-test analysis 1 questions

Pressure and Boyle's Law Pre- and Post Test 1 Analysis

1. Pick one question that you answered both times correctly. What experiences helped you remember the concepts to answer the question correctly?

2. Pick one question that you answered correctly the first time, and incorrectly the second time.

3. Pick one question that you answered the first time incorrectly, and the second time correctly. What experiences did you used to answer the question the first time? What experiences helped you remember the concepts to answer the question the second time?

4. Pick one question that you answered incorrectly both times. Were the answers you chose the same both times? If so, explain what experiences you used to answer this question. If not, explain the experiences you used to answer the question the first time, and the experiences you used to answer the question the second time.

Appendix Y

Student pre- and post-test 2 analysis questions

Pressure and Boyle's Law Pre- and Post Test Analysis 2

1. Pick one question that you answered both times correctly. What experiences helped you remember the concepts to answer the question correctly?

2. Pick one question that you answered correctly the first time, and incorrectly the second time.

3. Pick one question that you answered the first time incorrectly, and the second time correctly. What experiences did you used to answer the question the first time? What experiences helped you remember the concepts to answer the question the second time?

4. Pick one question that you answered incorrectly both times. Were the answers you chose the same both times? If so, explain what experiences you used to answer this question. If not, explain the experiences you used to answer the question the first time, and the experiences you used to answer the question the second time.

Appendix Z

Student evaluation of the scuba activity questions

ID NUMBER: ____________________

Student evaluation of the scuba activity

1. Did you go scuba diving? If so, please explain why you participated in the dive. If not, could you please explain why the decision was made not to dive?

If you went diving. please answer questions 2-5 below.

If you did not, skip questions 2-5 and proceed to question 6. Please answer questions 6-8.

2. If you went diving, were there any activities or demonstrations you thought were particularly useful in your learning and/or understanding of Boyle's Law? Please explain.

3. During your dive, was there an activity that you found less useful? Please explain.

4. If you were to dive again, can you suggest any activities you may want to try? What about non-scuba activities?

5. Would you recommend the scuba diving activity for future chemistry courses? Why or why not?

6. IF given the opportunity, would you try scuba diving now? Why or why not?

7. Can you suggest any activities (scuba or non-scuba you may want to try?

8. Would you recommend the scuba diving activity for future chemistry courses? Why or why not?

Thank you for taking the time to fill this out!

Appendix AA

Student evaluation of the Boyle's Law Unit

ID Number: ____________________

Appendix 26: Student evaluation of the Boyle's Law Unit

1. Are there any activities, demonstrations or lessons you found particularly useful? If so, which ones? Why do you think they were useful?

2. For the in-class activities, do you think the process of discussing the topics in small and large groups were helpful with learning the subject? Please explain.

3. Did you find that explaining concepts according to the four orientations of science (the microscopic, macroscopic, symbolic and humanity aspects) useful? Why or why not?

4. Are there any other comments you would like to make about the program, or your participation in the program?

Appendix BB

Teacher interview questions

Each interview will differ, based on teacher responses from day to day. The questions below may not be asked in exactly this way, as the teacher may not respond to the first question in the same way.

1. How did it go today? What are your first impressions of the delivering the activity, and how students responded to the activity?
2. Can you describe for me how you delivered the lesson?
3. Can you describe for me how feel about the way the lesson was delivered today?
   - Did it go well? If so, why do you think?
   - Did it not go well? If so, why?
4. Do you think the students found the activity useful? How do you know?
5. Would you use this activity in the lesson again? Why or why not?

Appendix CC

Interview questions for the scuba masters

Each interview will differ, depending on the . The questions below may not be asked in exactly this way, as each dive master may not respond to the first question in the same way. Some dive masters may prefer to have open, ,detailed questions to respond to; others may like to have prompts given to them throughout, and this will be at my discretion.

1. How did it go today? What are your first impressions of the delivering the activity, and how students responded to the activity?
2. Can you describe for me how you delivered the lesson?
3. Can you describe for me how feel about the way the lesson was delivered today?
   - Did it go well? If so, why do you think?
   - Did it not go well? If so, why?
4. Do you think the students found the activities useful? How do you know?
5. Think about the types of skills and information that is important for beginning divers to learn. Can you please describe these skills and base information that you think are essential for beginning divers?
6. From the perspective of diving education, what impact (positive, negative, or none) does each of the activities have on student learning?
7. Are there any activities that you think were particularly useful for diving education? Why do you think this/these activity(ies) were useful?
8. Can you make suggestions for improvement, or add activities that you think would be useful?
9. Has this had any impact on how you would teach scuba classes for other divers?